

FINAL REPORT

SPRING VALLEY FORMERLY USED DEFENSE SITE WASHINGTON, D.C.

GROUNDWATER REMEDIAL INVESTIGATION REPORT

Prepared for:

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°F	degrees Fahrenheit
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
ALS	ALS Laboratory Group
ATSDR	Agency for Toxic Substances and Disease Registry
ATV	Acoustic Televiewer
AU	American University
AUES	American University Experiment Station
BW	body weight
Cal EPA	California Environmental Protection Agency
CDI	chronic daily intake
CENAB	Baltimore District (USACE)
cm ² /s	square centimeters per second
CNS	central nervous system
COPC	chemical of potential concern
CR	contact rate
CSF	cancer slope factor
CT	central tendency
CWM	chemical warfare materiel
DCRBCA	District of Columbia Risk-Based Corrective Action
DOEE	District Department of Energy and Environment
DWHA	Drinking Water Health Advisory
ECBC	Edgewood Chemical Biological Center
EPC	exposure point concentration
EU	exposure unit
ft ² /day	square feet per day
ft bgs	feet below ground surface
ft msl	feet mean sea level
FUDS	Formerly Used Defense Site
HAS	hollow-stem auger
HEAST	Health Effects Assessment Summary Tables

Acronyms and Abbreviations

HHRA	human health risk assessment
HI	hazard index
HPFM	Heat Pulse Flow Meter
HQ	hazard quotient
IRIS	Integrated Risk Information System
kg	kilogram
L	liter
MCL	maximum contaminant level
MDL	method detection limit
mg	milligram
Mg	Manor Glenelg
mph	miles per hour
MRL	Minimal Risk Level
NAD 83/91	North American Datum of 1983 with 1991 adjustment
NAVD 88	North American Vertical Datum of 1988
Odm	biotite monzogranite and lesser granodiorite
Odt	muscovite trondhjemite
Ogh	biotite-hornblende tonalite
OSWER	Office of Solid Waste and Emergency Response
OTV	Optical Televiewer
ppb	part per billion
PPRTV	Provisional Peer Reviewed Toxicity Values
QAPP	Quality Assurance Project Plan
RAGS	Risk Assessment Guidance for Superfund
RAO	Remedial Action Objective
RfC	reference concentration
RfD	reference dose
RI	Remedial Investigation
RL	reporting limit
RME	reasonable maximum exposure
RSL	Regional Screening Level

Acronyms and Abbreviations

SMH	Sibley Memorial Hospital
SMOC	Standard Mean Ocean Chloride
SV	Spring Valley
SVOC	semi-volatile organic compound
TCR	target cancer risk
THQ	target non-cancer hazard quotient
TIC	tentatively identified compound
UCL	upper confidence limits
ULB	Urban Land Brandywine
ULMg	Urban Land-Manor Glenelg
ULSC	Urban Land-Sassafras Chillum
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
VISL	Vapor Intrusion Screening Level
VOC	volatile organic compound
VSMOW	Vienna Standard Mean Ocean Water
WMATA	Washington Metropolitan Area Transit Authority

PROJECT AUTHORIZATION

This report presents the findings of the Groundwater Remedial Investigation (RI) for the Spring Valley (SV) Formerly Used Defense Site (FUDS) conducted under the following contracts with the U.S. Army Corps of Engineers, Baltimore District (CENAB): DACA31-00-D-0011, W912WJ-05-D-0005, and W912DR-09-D-0017. In addition to CENAB, other organizations that provided technical input to this project include the U.S. Environmental Protection Agency and the District of Columbia Department of the Environment. Collectively, these organizations represent the SVFUDS Partners, created to facilitate coordinated SVFUDS investigation activities.

BACKGROUND

The SVFUDS consists of approximately 661 acres in the northwest section of Washington, DC, and encompasses approximately 1,600 private properties, including several embassies and foreign properties, as well as the American University (AU) and Wesley Seminary.

During World War I, the U.S. Government established the American University Experiment Station (AUES) to investigate the testing, production, and effects of noxious gases, antidotes, and protective masks. The AUES, located on the current grounds of AU, used additional property in the vicinity to conduct this research and develop chemical warfare materiel (CWM), including mustard (HD) and lewisite (L) agents, as well as adamsite, irritants, and smokes. After the war, these activities were transferred to other locations and the AUES property was returned to the owners. Chemical releases to the environment and waste disposal associated with the historical AUES activities caused the former AUES and surrounding area to be designated a FUDS, eligible for conduct of environmental investigation and remediation.

SCOPE

The SVFUDS groundwater study primarily focused on assessment of:

- Groundwater occurrence, flow and chemistry
- Surface water chemistry and relationship to groundwater flow
- Subsurface soil and groundwater chemistry near AU's Kreeger Hall where perchlorate-impacted groundwater was confirmed
- Impact of potential groundwater seepage into the Dalecarlia Reservoir
- Assessment of potential human health risks posed by chemicals detected in groundwater and surface water

Groundwater

The study assessed groundwater chemistry, elevations, and movement through the installation of a groundwater monitoring network. The network was used to measure groundwater elevations and collect groundwater samples for chemical analysis, including limited perchlorate stable

oxygen and chlorine isotope analysis. Groundwater samples were collected from 56 different groundwater monitoring locations. At some locations, multiple vertical intervals were monitored, representing a total of 84 monitored locations/intervals and including a pre-existing sump and vault. Chemical analysis was conducted for chemicals representing various chemical classes: volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), metals, explosives, and other chemicals, including perchlorate. As groundwater monitoring results became available, the SVFUDS Partners narrowed the focus of the groundwater analytical program.

Surface Water

Surface water chemistry was assessed by collecting and analyzing surface water samples from 27 surface water monitoring locations. The surface water analytical scope was the same as described for groundwater except no surface water samples were analyzed for perchlorate stable oxygen and chlorine isotopes. The relationship between surface water and groundwater flow was evaluated based on an assessment of chemical and water elevation data. As surface water monitoring results became available, the SVFUDS Partners narrowed the focus of the surface water analytical program.

Subsurface Soil

In an effort to investigate the possibility of an undefined perchlorate source near AU's Kreeger Hall, which could account for elevated perchlorate concentrations measured in groundwater at this location, 16 temporary shallow soil borings were installed. Soil samples and groundwater samples from the borings were analyzed for perchlorate.

Potential Groundwater Seepage into Dalecarlia Reservoir

Early in the SVFUDS groundwater study, much of the SVFUDS groundwater was noted to flow westward toward the natural valley currently occupied by the Dalecarlia Reservoir. The reservoir water elevation (typically about 150 feet mean sea level [ft msl]) was also noted to be similar to the water table elevation along the eastern reservoir shoreline, indicating the potential for groundwater seepage into the reservoir along the eastern reservoir boundary. The significance of this potential seepage was evaluated.

Human Health Risk Assessment

A human health risk assessment (HHRA) was performed in accordance with USEPA's *Risk Assessment Guidance for Superfund* (RAGS) (USEPA, 1989 and subsequent RAGS guidance, including USEPA, 1991; USEPA, 1992a; USEPA, 2001; USEPA, 2004; and USEPA, 2009a). The purpose of the HHRA was to identify any health threats posed by the chemicals detected in groundwater and surface water.

FINDINGS

Geology

The two general types of geologic materials that occur within the SVFUDS are bedrock associated with the Piedmont Physiographic Province and limited areas of sedimentary deposits associated with the Coastal Plain Physiographic Province. Where natural weathering of the bedrock has occurred, it has been converted to a material called saprolite.

Bedrock mapped within the SVFUDS comprises metamorphic and intrusive igneous rock types (Fleming et al., 1994). The metamorphic bedrock formations are the Cambrian-aged Sykesville Formation and the Actinolite Schist. The Ordovician-aged intrusive igneous bedrock formations are the Georgetown Intrusive Suite, Dalecarlia Intrusive Suite, and isolated quartz bodies.

The vast majority of the study area is underlain by Piedmont bedrock, with only a small isolated remnant of Coastal Plain sedimentary deposits underlying Nebraska Avenue and portions of Loughboro Road, along the southeastern SVFUDS boundary. These coastal plain sedimentary deposits are composed of the Miocene-aged Coastal Plain Terrace Formation (Fleming et al., 1994). This formation is fluvial in origin and consists of highly weathered, crudely bedded gravel, sand, silt, and clay (Fleming et al., 1994).

Hydrology

Groundwater in the SVFUDS occurs within the residual soils and underlying bedrock, generally under unconfined conditions. Deep bedrock borehole testing confirmed the occurrence of discrete confined or semi-confined fracture zones. Generally, the highest zone of permeability is at the interface between clay-rich weathered bedrock (saprolite) and underlying unweathered bedrock. Permeability within the bedrock is derived almost entirely through secondary porosity, and decreases with depth as a result of increasing spacing of fractures and decreasing fracture openings and fracture connectivity with depth. Fleming et al. (1994) observed and mapped the following secondary fractures within the SVFUDS area: joints, faults, and dissolution and widening along foliation. Such fractures can have localized influences on groundwater flow directions.

Groundwater table elevations were calculated based on groundwater elevations measured during sampling. The topography of the water table within the SVFUDS roughly follows ground surface topography and groundwater generally flows from relatively high topographic elevations in the eastern portion of the SVFUDS toward lower elevations in the western portion of the SVFUDS proximate to the former valley now occupied by the Dalecarlia Reservoir and toward the Potomac River, which is located further west-southwestward of the reservoir. The water table elevation in the eastern SVFUDS near AU is on the order of 350 ft msl, contrasted with approximately 150 ft msl near Dalecarlia Reservoir and the western portion of Sibley Memorial Hospital (SMH), and approximately 30 ft msl at the Potomac River. The curvature of the water table contour lines toward East Creek implies groundwater seepage into East Creek.

Dalecarlia Reservoir / Groundwater Flux Model

The flux modeling assessment between groundwater and the Dalecarlia Reservoir revealed a dilution factor of 2.56E-04. Thus, 1 part per billion (ppb) of any chemical in all groundwater seeping into the reservoir would result in a concentration of that chemical in the reservoir of 2.56E-04 ppb. Similarly, to affect a 1 ppb concentration increase in the reservoir, the concentration of the chemical in the groundwater seeping into the reservoir would need to be 3,906 ppb. The maximum arsenic and perchlorate concentrations ever measured in groundwater proximate to the eastern reservoir shoreline are orders of magnitude less than this threshold concentration (3,906 ppb) that would increase the reservoir concentration by 1 ppb. Thus, the reservoir water quality is not threatened by possible groundwater seepage into the reservoir.

Groundwater Chemistry

The following chemicals, by class, were detected at least once:

- 9 VOCs
- 6 SVOCs
- 1 explosive compound
- 23 inorganics
- 7 other chemicals, including perchlorate

In preparation for the HHRA, the SVFUDS groundwater monitoring locations were grouped into different groundwater exposure units (EUs). The purpose was to assure that HHRA exposure point concentrations were not biased low by mixing the data for locations with high groundwater chemical concentrations with the data for locations with low groundwater chemical concentrations (i.e., avoid numerical dilution).

Groundwater EU1 is represented by these groundwater monitoring locations proximate to SMH where groundwater is confirmed to be impacted by perchlorate: Sibley Sump and MW-21, MW-22, MW-46S, and MW-46D. Groundwater EU2 is represented by these groundwater monitoring locations proximate to Kreeger Hall on AU and the adjacent Glenbrook Road Disposal Areas where groundwater is confirmed to be impacted by perchlorate and/or arsenic: MP-2 (eight intervals), MW-24, MW-25, MW-44, MW-45S, MW-45D, PZ-4S, and PZ-4D. Groundwater EU3 is represented by all other groundwater monitoring locations where much lower arsenic and perchlorate concentrations occur and which are not grouped into groundwater EUs 1 or 2.

The maximum detected chemical concentrations were compared to drinking water regulatory criteria represented by maximum contaminant levels (MCLs), the action levels for copper and lead, and the Drinking Water Health Advisory (DWHA) for perchlorate. The following exceedances were noted:

- Groundwater EU1:
 - MCLs: none

- Action levels: none
- DWHA: perchlorate at three locations
- Groundwater EU2
 - MCLs:
 - Arsenic at two locations
 - Bis(2-ethylhexyl)phthalate at one location
 - Action levels: none
 - DWHA: perchlorate at six locations
- Groundwater EU3
 - MCLs: bis(2-ethylhexyl)phthalate at one location
 - Action levels: none
 - DWHA: none

Identification of chemicals of potential concern (COPCs) during the HHRA involved evaluation of health-based criteria supplemental to MCLs, the action levels for copper and lead, and the perchlorate DWHA. Resulting COPCs evaluated in the HHRA were as follows:

- Groundwater EU1: arsenic, cobalt, and perchlorate
- Groundwater EU2: arsenic, cobalt, manganese, and perchlorate
- Groundwater EU3: arsenic, cobalt, manganese, strontium, and perchlorate

Groundwater Concentration Trends

Two statistical methods, Ordinary Least Squares Linear Regression and Mann-Kendall, were used to evaluate arsenic and perchlorate concentration trends over time. The results for perchlorate and arsenic are individually summarized. Downward concentration trends were observed for several locations, potentially indicating a diminishing chemical source, possibly related to ongoing and completed SVFUDS remedial activities.

Perchlorate

No groundwater EU3 locations were assessed because the perchlorate concentrations are historically very low. The results for groundwater EUs 1 and 2 are summarized below.

Downward concentrations trends are indicated for these locations:

- Groundwater EU1: Sibley Sump and MW-21
- Groundwater EU2: MW-24, PZ-4S, and MP-2 (intervals 1, 2, 6, 7, and 8)

No trends are indicated for these locations:

- Groundwater EU1: none

- Groundwater EU2: MW-25, MW-45S, MW-45D, PZ-4D, and MP-2 (intervals 3, 4, and 5)

Upward trends are indicated for these locations:

- Groundwater EU1: MW-22
- Groundwater EU2: MW-44

Arsenic

No groundwater EU1 or EU3 locations were assessed for arsenic concentration trends because of historically very low arsenic concentrations at all groundwater EU1 locations. The trend results for groundwater EU2 are summarized below.

Downward trends are indicated for these locations:

- Groundwater EU2: MP-2 (intervals 4 and 7) and MP2 (all intervals)

No trends for arsenic are indicated for the following locations:

- Groundwater EU2: MW-24, MW-25, MW-44, PZ4-S, and MP-2 (intervals 1, 2, 3, 5, 6, and 8)

Upward trends for arsenic are indicated for the following locations:

- Groundwater EU2: PZ-4D

Surface Water Chemistry

The following chemicals, by class, were detected at least once:

- 1 VOC
- 4 SVOCs
- 18 inorganics
- 5 other chemicals, including perchlorate

In preparation for the HHRA, the SVFUDS surface water monitoring locations were grouped into different surface water EUs. The purpose was to avoid numerical dilution as previously discussed for groundwater.

Surface water EU1 is represented by these surface water locations proximate to the Lot 18 Debris Area and Glenbrook Road Disposal Areas where surface water is most likely impacted by groundwater seepage into East Creek: Lot 18 Drain, SW-1, SW-11, and SW-21. Surface water EU2 is represented by all other SVFUDS surface water locations where lower chemical concentrations occur, with the exception of SW-24 and SW-25 which concern an unknown perchlorate source unrelated to the SVFUDS and are not included in any surface water EU.

The maximum detected chemical concentrations were compared to drinking water regulatory criteria represented by MCLs, the action levels for copper and lead, and the DWHA for

perchlorate. There were no exceedances of MCLs, action levels, or the perchlorate DWHA for any surface water EU1 or surface water EU2 sample.

Identification of COPCs during the HHRA involved evaluation of health-based criteria supplemental to MCLs, the action levels for copper and lead, and the perchlorate DWHA. Resulting surface water COPCs evaluated in the HHRA were as follows:

- Surface water EU1: manganese
- Surface water EU2: none

Perchlorate Stable Oxygen and Chlorine Isotope Analysis

Monitoring confirmed two areas within the SVFUDS where groundwater is contaminated with perchlorate:

- Area 1: Vicinity of AU's Kreeger Hall and Glenbrook Road Disposal Areas
- Area 2: Vicinity of SMH

The nature of the perchlorate at these two locations was investigated by conducting stable oxygen and chlorine isotopic analysis. The isotopic signature of the perchlorate in groundwater at Areas 1 and 2 indicates that the perchlorate at both areas originated in Chile and was imported into the United States.

AUES activities likely involved using nitrates (which contained perchlorate) imported from Chile. Civil War and historical farming activities known to have occurred near SMH may also have involved using nitrates (which contained perchlorate) imported from Chile, as fertilizer during farming and as a component of the Civil War-era gunpowder. Thus, although the isotopic analysis confirms that perchlorate in groundwater at Areas 1 and 2 originated in Chile, the perchlorate in groundwater at Area 1 may be unrelated to historical activities at Area 2, and vice versa.

At the time the stable oxygen and chlorine isotope findings became available, MP-5, located between Areas 1 and 2, had not yet been installed. Also at this time it was hypothesized that perchlorate-contaminated groundwater from Area 1 could have migrated to Area 2 along a pathway undetected between monitoring wells MP-3 and MP-4 (both located between Areas 1 and 2), where essentially no groundwater perchlorate has been detected. To test this hypothesis, another deep bedrock multiport well (MP-5) was installed roughly midway between MP-3 and MP-4 and also between Areas 1 and 2.

No perchlorate has been detected in any water sample from any of the five MP-5 sampling intervals. This finding reduces the possibility that a groundwater perchlorate plume has migrated from Area 1 to Area 2, and reduces the possibility that historical AUES activities at Area 1 are the cause of the groundwater perchlorate at Area 2.

Soil Boring Program

A soil boring program was conducted to search for a potential perchlorate source on AU near Kreeger Hall that could account for the perchlorate-impacted groundwater originally detected in PZ-4S, PZ-4D, and PZ-5. Sixteen soil borings were installed over an area of approximately 2 acres roughly centered on these piezometers to further assess perchlorate concentrations in soil and groundwater.

Soil perchlorate concentrations were almost entirely non-detect, with the exception of three soil samples that showed trace perchlorate concentrations below the analytical reporting limit and that are J-flagged to indicate that the trace concentrations are estimated.

The spatial variability of the groundwater perchlorate concentrations measured during this investigation indicate that the groundwater perchlorate contamination is generally focused at the vicinity of the Kreeger Hall and diminishes outward from this location, indicating bounding of the impacted area. Although the source of the groundwater perchlorate contamination on AU near Kreeger Hall is not known precisely, it could relate to various soil and debris removal activities conducted at AU during the 2003 to 2010 timeframe.

Human Health Baseline Risk Assessment

An HHRA was conducted for groundwater and surface water for the current and future land use scenarios. The HHRA for groundwater and surface water indicate the current SVFUDS chemical concentrations do not pose cancer risks or non-cancer hazard indices (HIs) above $1E-06$ or 1, respectively, to any current human receptors, based on no receptor drinking the groundwater. Cancer risks and non-cancer hazards associated with these media are well below the threshold levels protective of the health of AU students and Spring Valley residents. However, future use of groundwater as a drinking source is possible, and thus a risk to human receptors for both cancer and non-cancer risks is possible. Also, impacted groundwater within the SVFUDS will have no influence on the Dalecarlia Reservoir water quality, based on the groundwater flux modeling results.

Screening Level Ecological Risk Assessment

A screening level ecological risk assessment (SLERA) was previously conducted that considered SVFUDS surface water chemistry (ERT, 2010). The SLERA concluded that ecological risks were negligible and that there was no need for additional ecological risk assessment or remediation on the basis of ecological risks.

CONCLUSIONS AND RECOMMENDATIONS

The SVFUDS Groundwater RI conclusions and recommendations are summarized below.

Conclusions

Chemical releases from historical AUES activities have impacted groundwater and surface water proximate to the Lot 18 Debris Area and Glenbrook Road Disposal Areas. The impacts are due

to arsenic and perchlorate in groundwater and, during the early phases of the remedial investigation, perchlorate in surface water. Recent perchlorate concentrations in surface water are lower and are approaching a concentration of about 1 µg/L, similar to the concentration typically measured at location SW-3 (indicative of background) where Potomac River water enters the Dalecarlia Reservoir. The perchlorate detected in groundwater along Glenbrook Road and in East Creek could partially, or in total, originate from the nearby upgradient area proximate to AU's Kreeger Hall where perchlorate-impacted shallow and deep groundwater has been confirmed.

The source of the groundwater perchlorate contamination on AU near Kreeger Hall, originally evidenced by groundwater perchlorate monitoring data for several locations (PZ-4S, PZ-4D, and PZ-5) is not known precisely, but is bounded based on soil borings and groundwater monitoring. Perchlorate was only detected in two soil samples at low estimated concentrations. Groundwater perchlorate concentrations measured during the soil boring program were observed to diminish radially outward from the center of the investigation area, indicating the source is residual and diffuse in nature. The source could relate to various soil and debris removal activities conducted at AU during the 2003 to 2010 timeframe. Perchlorate waste was identified and removed from Lot 18, as reported in the *Site-Specific Anomaly Investigation Report – American University* dated August 2008.

The perchlorate stable oxygen and chlorine isotope analyses confirmed that the perchlorate in groundwater proximate to SMH and in the vicinity of AU's Kreeger Hall was imported from Chile. However, the historic activities proximate to SMH that may have used the imported material are unrelated to the historical activities responsible for perchlorate in groundwater in the vicinity of AU's Kreeger Hall and the Glenbrook Road Disposal Areas. Groundwater perchlorate at SMH may be from nitrates imported from Chile and used as fertilizer associated with historic farming activities at the current SMH location, or used to manufacture gunpowder associated with historic Civil War activities conducted at the current SMH location. Additional evidence that the perchlorate in groundwater at SMH derives from activities unrelated to historic AUES activities is the observation that the groundwater monitoring well network situated between SMH and the vicinity of AU's Kreeger Hall and Glenbrook Road Disposal Areas confirms absence of a continuous groundwater perchlorate plume.

Recommendation

A Feasibility Study is recommended to determine the best alternative to remediate the groundwater risk to future residential users.

SECTION ONE: INTRODUCTION

1.1 PROJECT AUTHORIZATION

This report presents the findings of the Groundwater Remedial Investigation (RI) for the Spring Valley (SV) Formerly Used Defense Site (FUDS) conducted under the following contracts with the U.S. Army Corps of Engineers (USACE), Baltimore District (CENAB): DACA31-00-D-0011, W912WJ-05-D-0005, and W912DR-09-D-0017. In addition to CENAB, other organizations that provided technical input to this project include the U.S. Environmental Protection Agency (USEPA) and the District of Columbia Department of Energy and Environment (DOEE). Collectively these organizations represent the SVFUDS Partners, created to facilitate coordinated SVFUDS investigation activities. URS Group, Inc. contracted with numerous subcontractors for various technical services (**Table 1-1**).

1.2 OBJECTIVE AND SCOPE

This section discusses the objectives of the RI and the scope of the study.

1.2.1 Objectives

Table 1-2 summarizes the SVFUDS groundwater study objectives, as previously discussed in the various groundwater study planning documents written over the course of the groundwater study (USACE, 2005; USACE, 2006; USACE, 2007a; USACE, 2008; USACE, 2011; and USACE, 2013). The objectives were addressed following a phased approach whereby information from early phases guided scoping of subsequent phases.

1.2.2 Scope

The SVFUDS groundwater study scope primarily focused on:

- Groundwater flow and chemistry monitoring
- Surface water chemistry monitoring and assessment of the relationship between surface water and groundwater flow
- Subsurface soil chemistry monitoring near an area of groundwater contamination
- Assessment of potential groundwater seepage into the Dalecarlia Reservoir
- Assessment of potential human health risks posed by current or future contact with groundwater and surface water

1.2.2.1 Groundwater

The study assessed groundwater chemistry, elevations, and movement through the installation of a groundwater monitoring network. The network was used to measure groundwater elevations and collect groundwater samples for chemical and limited isotopic analysis. Groundwater samples were collected from 56 different groundwater monitoring locations. At some locations multiple vertical intervals were monitored, representing a total of 84 unique sampling points.

Groundwater samples for chemical analysis were also collected from a pre-existing sump and vault. The groundwater monitoring network is described in greater detail in Section 3.2.

The SV parameter list was developed by the Army following extensive multi-year historic records review to assess possible historic chemicals usage at the AUES and feedback from SVFUDS Partners. The groundwater analytical scope initially focused on the SV parameters identified in the Quality Assurance Project Plan (QAPP) (USACE 2005):

- 55 volatile organic compounds (VOCs)
- 79 semi-volatile organic compounds (SVOCs)
- 72 VOC and SVOC target tentatively identified compounds (TICs)
- 24 inorganics consisting of various metals, including arsenic
- 16 explosives compounds
- 11 other compounds, including perchlorate
- 4 chemical agents (ricin, mustard, and the lewisite breakdown products:
 - 2-chlorovinylarsonous acid (CVAA) and
 - chlorovinylarsenic oxide (CVAO)

Perchlorate stable oxygen and chlorine isotope analysis was also conducted on samples from two locations to determine whether the perchlorate detected in groundwater at the two locations was from the same original source. As groundwater monitoring results became available, the SVFUDS Partners narrowed the focus of the groundwater analytical program to a subset of the above parameters.

1.2.2.2 Surface Water

Surface water chemistry was assessed by collecting and analyzing surface water samples from 27 surface water monitoring locations. The surface water analytical scope was the same as described for groundwater (Section 1.2.2.1), except no surface water samples were analyzed for perchlorate stable oxygen and chlorine isotopes. The relationship between surface water and groundwater flow was evaluated based on an assessment of chemical and water elevation data. As surface water monitoring results became available, the SVFUDS Partners narrowed the focus of the surface water analytical program on a subset of the Section 1.2.2.1 parameters.

1.2.2.3 Soil

In an effort to investigate the possibility of an undefined perchlorate source near American University's (AU's) Kreeger Hall, which could account for elevated perchlorate concentrations measured in groundwater at this location, 16 temporary shallow soil borings were advanced. Soil samples and groundwater samples from the borings were analyzed for perchlorate.

1.2.2.4 Dalecarlia Reservoir Assessment

An assessment of Dalecarlia Reservoir was conducted to compare potential groundwater seepage into the reservoir to the water volume that enters the reservoir from the Potomac River. This comparison was used to estimate how high chemical concentrations would need to be in nearby groundwater to cause chemical concentrations in the reservoir to exceed acceptable concentrations.

1.2.2.5 Human Health Risk Assessment

A base line human health risk assessment was conducted to assess whether the measured chemical concentrations in groundwater and surface water pose potential current or future chemical risks or hazards above acceptable threshold levels.

1.3 SITE BACKGROUND

This section discusses the site location, history, and previous investigations.

1.3.1 Site Location

Figure 1-1 illustrates the location of the SVFUDS within the District of Columbia. SVFUDS consists of approximately 661 acres in the northwest section of Washington, D.C., and encompasses approximately 1,600 private properties, including several embassies and foreign properties, as well as the American University and Wesley Seminary.

1.3.2 History

During World War I, the U.S. Government established the American University Experiment Station (AUES) to investigate the testing, production, and effects of noxious gases, antidotes, and protective masks. The AUES, located on the current grounds of AU, used additional property in the vicinity to conduct this research and develop CWM, including mustard (HD) and lewisite (L) agents, as well as adamsite, irritants, and smokes. After the war, these activities were transferred to other locations and the AUES property was returned to the owners. Chemical releases to the environment and waste disposal associated with the historic AUES activities caused the former AUES and surrounding area to be designated a FUDS, eligible for conduct of environmental investigation and remediation.

More information on the Spring Valley project and history can be found at:
<http://www.nab.usace.army.mil/Home/SpringValley.aspx>.

1.3.3 Previous Investigation Activities

There have been no previous investigations of SVFUDS groundwater.

1.4 REPORT ORGANIZATION

This report is organized as follows:

- Section 1: Introduction

- Section 2: SVFUDS Physical Setting
- Section 3: Investigation Activities and Monitoring Network
- Section 4: Investigation Findings
- Section 5: Baseline Human Health Risk Assessment
- Section 6: Summary, Conclusions, and Recommendation

Tables are presented in the report section titled “Tables,” which follows the text. Figures are presented in the report section titled “Figures,” which follows the tables. The appendices follow the figures section.

SECTION TWO: SVFUDS PHYSICAL SETTING

This section provides background for the SVFUDS physical characteristics.

2.1 GEOLOGY

The SVFUDS is located proximate to the Fall Line, which is the boundary between the Piedmont and Coastal Plain physiographic provinces. Accordingly, two general geologic materials occur and are mapped (Fleming et al., 1994) within the SVFUDS (**Figure 2-1**):

- Bedrock (Piedmont)
- Sedimentary deposits (Coastal Plain)

2.1.1 Bedrock

Bedrock mapped within the SVFUDS comprises metamorphic and intrusive igneous rock types (Fleming et al., 1994). Where natural weathering of near-surface bedrock has occurred, it has been converted to a material called saprolite.

2.1.1.1 *Metamorphic Bedrock*

The metamorphic bedrock formations are:

- Sykesville Formation (Cs)
- Actinolite Schist (CZu)

The Sykesville Formation predominates. The Sykesville Formation is dated Early Cambrian and is described as a sedimentary melange consisting of a quartzofeldspathic matrix containing metagraywacke, migmatite, amphibolite, and actinolite schist. In some instances, the occurrence of actinolite schist is extensive enough that it becomes mappable. Mapped actinolite schist is rare within the SVFUDS. The Actinolite Schist unit consists of actinolite schist, actinofels, actinolite-chlorite schist, and lesser talc bearing rocks.

2.1.1.2 *Intrusive Igneous Bedrock*

The Ordovician-aged intrusive igneous bedrock formations are:

- Georgetown Intrusive Suite
- Dalecarlia Intrusive Suite
- Quartz bodies

The Georgetown Intrusive Suite is not common within the SVFUDS. Where present, it is described as a biotite-hornblende tonalite (Ogh). Ogh is described as (Cloos and Cooke, 1953; Drake and Froelich, 1997):

Medium- to coarse-grained, massive to foliated rock that has a strong relict igneous flow structure at many places. Unit contains many ultramafic and mafic xenoliths and(or)

autoliths, and xenoliths of metasedimentary rocks. Typically contains 40-50 percent dark minerals and contains small layers of biotite tonalite (Ogb) at many places.

The Dalecarlia Intrusive Suite is common within the SVFUDS. Where present, it is described as a muscovite trondhjemite (Odt) and biotite monzogranite and lesser granodiorite (Odm). Odt is described as (Drake and Fleming, 1994):

Fine- to medium grained, sugary textured, massive to weakly foliated. Forms dikes, sheets, and irregular bodies in monzogranite and adjacent country rocks.

Odm is described as (Drake and Fleming, 1994):

Medium- to coarse-grained, massive to well-foliated. Locally contains plagioclase phenocrysts. Mapped bodies contain widespread lenses, zones and irregular bodies of leucocratic biotite-muscovite monzogranite (Odl).

Quartz bodies are not common with the SVFUDS. Where present, they are described as (Fleming et al., 1994):

Veins, lenses and irregular bodies of massive to foliated, white to bluish-gray vein quartz. Frequently well-jointed. Probably of several generations.

2.1.2 Sedimentary Deposits

The vast majority of the study area is underlain by Piedmont bedrock, with only a small isolated remnant of Coastal Plain sedimentary deposits underlying Nebraska Avenue, and portions of Loughboro Road, along the southeastern SVFUDS boundary. These Coastal Plain sedimentary deposits are composed of the Miocene-aged Coastal Plain Terrace Formation (Fleming et al., 1994). This formation is fluvial in origin and consists of highly weathered, crudely bedded gravel, sand, silt, and clay (Fleming et al., 1994). More specifically, McCartan (1989) and McCartan et al. (1990) describe the Miocene deposits as follows:

Bleached white in upper part of deposit to pale orange below; crudely bedded. Gravel and sand are coarse; silt and clay are mainly interstitial, presumably emplaced post-depositionally or derived in place by alteration of minerals in detrital clasts. Clay is mostly soil vermiculite. Gravel clasts are mainly vein quartz, quartzite, and some red sandstone and mudstone. Other clasts may have disintegrated and now look like interstitial sand and clay. Sand is mainly quartz. Weathering and leaching have effectively removed much of the iron from this deposit; this accounts for the pale colors throughout, which along the stratigraphic position, serve to distinguish T4 from T1-T3. Thickness is typically less than 33 ft. The age is late Miocene, on the basis of stratigraphic position and possible correlation with St. Marys Formation in southern Maryland.

2.1.3 Saprolite

Saprolite (rotten rock) occurs in the SVFUDS where bedrock has undergone significant chemical weathering to form a clay-rich material. Saprolite typically occurs in the zone between

underlying unaltered bedrock and overlying soil. Green et al. (2004) describe saprolite at the nearby Medical Center Metro Station as:

Soft, red/brown to gray, earthy, weathered porous material formed from decomposed crystalline rock in which constituent minerals, other than quartz, have been altered to clays.

Where erosion is active in the SVFUDS (e.g., along stream valleys), neither saprolite nor soil is present, and unaltered bedrock is present at the surface. At most other SVFUDS locations, both soil and saprolite are present, with thicknesses generally (but not always) less than 50 feet, depending on the localized erosion rates.

2.2 SOIL

Four soil associations are present within SVFUDS:

- Urban Land-Sassafras Chillum (ULSC)
- Urban Land-Manor Glenelg (ULMg)
- Manor Glenelg (Mg)
- Urban Land Brandywine (ULB)

The ULSC soil type occurs in urban areas and results from the weathering of Coastal Plain deposits. However, typically these soils have been greatly disturbed by construction and landscaping activities. This soil type is deep, nearly level to steep, well-drained, and underlain by sandy and gravelly sediment on uplands.

The ULMg soil type occurs in urban areas and is deep, steep to gently sloping, somewhat excessively drained and well drained, and underlain by acid crystalline rocks on uplands.

The Mg soil type is a deep, steep to nearly level, well drained, and somewhat excessively drained soil that is underlain by acid crystalline rocks, and occurs on uplands that have broad ridge tops.

The ULB soil type occurs in urban areas and is deep, steep to gently sloping, somewhat excessively drained and excessively drained, and underlain by acid crystalline rocks on uplands.

In addition to these natural soil types, there are areas within the SVFUDS where fill has been placed.

2.3 HYDROGEOLOGIC SETTING

This discussion is based on a review of the literature during the planning stages of the SVFUDS Groundwater RI. This information was influential in scoping the groundwater monitoring network discussed in Section 4.1.

Groundwater in the Piedmont typically occurs within the residual soils and underlying bedrock under unconfined conditions (Nutter and Otton, 1969). Generally, the highest zone of permeability is at the interface between clay-rich weathered bedrock (saprolite) and underlying unweathered bedrock. Permeability within the bedrock is derived almost entirely through

secondary porosity, and decreases with depth due to increasing spacing of fractures and decreasing fracture openings and fracture connectivity with depth. Fleming et al. (1994) observed and mapped the following secondary fractures within the SVFUDS area: joints, faults, and dissolution and widening along foliation (**Figure 2-1**). Such fractures can have localized influences on groundwater flow directions.

Groundwater flow is expected to be influenced by topography, flowing from higher to lower topographic elevations. Accordingly, groundwater is expected to ultimately discharge into creeks and springs at relatively low topographic elevations (Johnston, 1964). This suggests that groundwater movement at the SVFUDS would ultimately be into the Potomac River. The combined influences of topography, residual soils, and saprolite on groundwater flow in a generalized setting are conceptually illustrated in **Figure 2-2**.

Leakage of water from public drinking water supply lines could locally influence groundwater occurrence and flow. Similarly, seepage of groundwater into manmade structures could locally influence groundwater occurrence and flow. Examples of such structures within or close to the SVFUDS include sanitary sewers, storm drains, sumps, and the groundwater drainage system underlying the settling basins at the Washington Aqueduct located west of the SVFUDS.

On behalf of the Washington Metropolitan Area Transit Authority (WMATA), Greene et al. (2004) assessed hydrogeologic factors controlling groundwater flow into the Red Line subway tunnel near the Medical Center Station and Crossover in Montgomery County, MD. The geology at this location is similar to that of the SVFUDS. The relevant Greene et al. (2004) findings are as follows:

- Fractures in the Sykesville Formation appeared to be poorly connected and, in contrast, the fractures in the Georgetown Intrusive Suite (Ogh member) appeared to be more numerous and have a greater degree of connectivity.
- The excessive water intrusion at the Medical Center Station and Crossover could be the result of its location within the Georgetown Intrusive Suite.
- The abrupt changes in the mapped directions of groundwater flow based on the hydraulic heads at the contact between the Sykesville Formation and Ogh member of the Georgetown Intrusive Suite could partly be the result of the change in fracturing between these two lithologies.
- Saprolite overlies the bedrock and varied in thickness from about 20 to 55 feet. On the basis of a slug test conducted in the lower part of the saprolite, transmissivity and storativity of the saprolite were estimated to be 10 square feet per day (ft^2/day) and 10^{-6} (unitless), respectively.
- The transmissivity of fractures intersecting bedrock boreholes drilled in the Ogh member of the Georgetown Intrusive Suite varied by over five orders of magnitude, from a maximum of approximately $10 \text{ ft}^2/\text{day}$ to the detection limit of the in situ testing apparatus, which is approximately $10^{-4} \text{ ft}^2/\text{day}$.

- The transmissivity of bedrock fractures in close proximity to the saprolite was low and this was hypothesized to be caused by the fractures being filled with byproducts of rock weathering (e.g., clay), resulting in reduced permeability. The transmissivity of bedrock fractures below and not in close proximity to the clay-rich saprolite was higher.
- The bulk transmissivity of the bedrock aquifer was approximately 3.7 ft²/day, as determined from an aquifer test conducted by pumping a 240-foot-deep borehole and monitoring the drawdown over 3 days in the pumped borehole and several observation boreholes.
- In general, the hydraulic head decreased with depth in bedrock boreholes, indicating the potential for downward groundwater flow and the possibility that saprolite recharges the bedrock aquifer.

2.4 TOPOGRAPHY

Figure 2-3 illustrates the topography of the SVFUDS. The highest elevations are on the order of 400 feet mean sea level (ft msl) along Nebraska Avenue proximate to Ward Circle. From here, elevations decrease generally toward the west and northwest to about 150 ft msl proximate to the Dalecarlia Reservoir and MacArthur Boulevard, located just west of the western SVFUDS boundary. Beyond Dalecarlia Reservoir and MacArthur Boulevard, the land elevation decreases rapidly toward the southwest to an elevation of about 30 ft msl along the Potomac River.

The natural topography has been altered in some areas by soil grading activities associated with land development. Several streams and unnamed tributaries generally trend westward across the SVFUDS, along small valleys that influence SVFUDS topography.

2.5 SURFACE WATER

Figure 2-3 depicts the few small streams and tributaries that cross the SVFUDS. In general, they flow toward the vicinity of the Dalecarlia Reservoir, which was a natural valley before construction of the reservoir. Today, all surface water that flows toward the reservoir is routed around the reservoir along manmade drainage controls.

With the exception of East Creek, the small streams and tributaries are unnamed. East Creek originates at the former Lot 18 Debris area, several hundred feet west of the intersection of Rockwood Parkway and Nebraska Avenue. It generally flows northwestward along Rockwood Parkway and Glenbrook Road toward the vicinity of the Dalecarlia Reservoir, where it is routed around the reservoir. At several locations along the way, East Creek is routed through culverts below streets, such as: 1) the intersection area for Glenbrook Rd, Rockwood Parkway, Indian Lane, and Overlook Road; and 2) Dalecarlia Parkway.

A short unnamed intermittent tributary flows westward through Spring Valley Park for a distance of about 500 feet between 49th Street, where it originates, and Fordham Road, where it is routed into a subsurface storm drain system.

Near the northern SVFUDS boundary, between Warren Place, and Yuma Street, an unnamed tributary flows westward for a distance of about 1,200 feet from its point of origin (near the intersection of 50th Place, and 50th Street) to a conduit under Dalecarlia Parkway. Immediately west of the parkway the tributary surfaces from the conduit and then flows around the north end of Dalecarlia Reservoir.

In addition to these streams and tributaries, there are numerous unnamed groundwater seeps that produce minor surface water, generally during wet weather conditions.

2.6 CLIMATE

SVFUDS is located in the humid subtropical climate zone (Köppen climate classification: *Cfa*), exhibiting four distinct seasons (Kottek et al., 2006). A humid subtropical climate is characterized by hot, usually humid summers and mild to cool winters. SV is also located in the U.S. Department of Agriculture plant hardiness zone 7b, indicating a temperate climate and average annual extreme minimum temperatures of zero to 5 degrees Fahrenheit (°F) between 1976 and 2005 (USDA, 2012).

According to the National Oceanic and Atmospheric Administration (2015a), for Washington, DC, for 1981 through 2010, the normal annual temperature was 58.2 °F. The normal temperatures for winter, spring, summer, and fall during this time period were 38.2 °F, 56.6 °F, 77.7 °F, and 60.0 °F, respectively.

Normal annual precipitation between 1981 and 2010 was 39.7 inches (NOAA, 2015b). The normal precipitation for winter, spring, summer, and fall was 8.5 inches, 10.5 inches, 10.4 inches, and 10.3 inches, respectively (NOAA, 2015b).

Normal annual snowfall between 1981 and 2010 was 15.4 inches (NOAA, 2015c). The normal snowfall for the months when more than a trace of snow occurred (November, December, January, February, and March) was 0.5 inch, 2.3 inches, 5.6 inches, 5.7 inches, and 1.3 inches, respectively (NOAA, 2015c).

The prevailing wind direction is from the northwest. The average wind speed in the Washington, DC, area is approximately 9 miles per hour (mph). Wind gusts can be expected to peak at approximately 40 mph, but may occasionally reach approximately 60 mph. Tornadoes and tropical storms occur infrequently, but can and have caused damage in the District (Parsons, 2003).

SECTION THREE: INVESTIGATION ACTIVITIES AND MONITORING NETWORK

This section describes the groundwater, surface water, and soil investigation activities and monitoring networks. The SVFUDS Partners scoped the activities using a phased approach whereby monitoring results and interpretations from completed phases or rounds of monitoring were shared and used to inform the scope of subsequent phases. Collective interpretation of the data produced scope recommendations for subsequent investigation phases/monitoring rounds.

3.1 SITE INVESTIGATION ACTIVITIES

Table 3-1 details the primary site investigation activities conducted during the course of the SVFUDS groundwater RI. The site investigation activities focused on groundwater and surface water monitoring throughout the SVFUDS and implementation of a soil boring program to attempt to identify the source of groundwater perchlorate contamination near AU's Kreeger Hall. The scope of the groundwater and surface water monitoring networks and soil boring program are discussed in the following sections.

3.2 GROUNDWATER MONITORING NETWORK

Figure 3-1 shows the groundwater monitoring network. Network construction began in 2005 and was completed in 2014. The network generally evolved chronologically as follows:

- Piezometers were installed to gather preliminary information, such as the depths to bedrock and the water table.
- Numerous wells were installed immediately east of Dalecarlia Reservoir to assess groundwater quality proximate to the reservoir.
- Potential groundwater seepage into the Dalecarlia Reservoir was assessed to confirm that none of the detected chemicals in groundwater threatened the reservoir water quality.
- Wells were installed in the general vicinity of Sibley Sump and the hydroelectric vault because USEPA had previously confirmed that perchlorate was present in groundwater at these two locations.
- Background monitoring wells were installed north of the SVFUDS.
- Monitoring wells were installed in the Glenbrook Road area near AU because AUES wastes were known to have been buried in this area.
- A well was installed at 52nd Court, downgradient of the munitions burial pit that was discovered here in 1993.
- Wells, including deep bedrock multiport wells, were installed in the area between AU and Sibley Memorial Hospital (SMH) to assess whether groundwater perchlorate contamination confirmed along Glenbrook Road (near AU) and at AU (near Kreeger Hall) is related to the groundwater perchlorate contamination confirmed in the vicinity of SMH.

Groundwater was monitored at 56 locations. At some of the locations, multiple vertical intervals were monitored, for a total of 84 discrete intervals. Over the course of the project, four shallow monitoring wells (MW-16, MW-19, MW-18, and MW-20) located near SMH were abandoned to facilitate construction projects unrelated to the SVFUDS groundwater study.

3.2.1 Groundwater Monitoring Network Design Considerations

The groundwater monitoring network design was influenced by various horizontal and vertical spatial monitoring considerations described in the following sections.

3.2.1.1 *Horizontal*

The principal consideration that influenced the horizontal groundwater monitoring network design was the goal of monitoring:

- Background locations upgradient and outside the SVFUDS.
- Vicinity of confirmed groundwater contamination areas indicated by groundwater monitoring data for the Sibley Sump and hydroelectric vault that pre-dates the SVFUDS Groundwater RI.
- Vicinity of confirmed groundwater contamination areas indicated by groundwater monitoring data acquired during execution of the SVFUDS Groundwater RI.
- Vicinity of Dalecarlia Reservoir to confirm that there is no risk posed to the reservoir by the SVFUDS.
- Vicinity of known SVFUDS features, such as:
 - 52nd Court Recovery Pit
 - Lot 18 Debris Area
 - Glenbrook Road Disposal Areas
 - Select Areas of Interest indicated by geophysical surveys and soil chemistry
- Locations between confirmed areas of groundwater contamination to assess whether the contamination occurs as a single large groundwater contamination plume or separate smaller plumes.

3.2.1.2 *Vertical*

The principal considerations that influenced the vertical groundwater monitoring network design were the desires to:

- Install piezometers at selected locations to acquire initial basic preliminary data to determine drilling logistics for subsequent monitoring wells. Such data included the depth to groundwater, the nature of the subsurface interval in which the water occurred (overburden, saprolite, upper competent bedrock, etc.), and the direction of the hydraulic head gradient.

- Focus on monitoring the top of the unconfined water table because that is where contamination from potential near-surface sources would most readily be detected.
- Conduct deep bedrock monitoring at locations of confirmed shallow groundwater contamination to assess the vertical extent of the contamination.

3.2.2 Constructed Groundwater Monitoring Network

Figure 3-1 depicts the groundwater monitoring network, which consists of the following monitoring devices:

- A pre-existing sump and hydroelectric vault
- Three piezometers (with a single, shallow-screened interval)
- Two piezometers (with two screened intervals)
- Thirty monitoring wells (with a single, shallow-screened interval)
- Two monitoring wells (with two screened intervals)
- Thirteen monitoring wells (completed as shallow open bedrock boreholes)
- Four multiport monitoring wells (deep bedrock borehole fitted with a liner containing multiple sampling ports at different depths)

Table 3-2 presents the location coordinates (northing and easting coordinates [North American Datum of 1983 with 1991 adjustment [NAD 83/91]] and elevation data (North American Vertical Datum of 1988 [NAVD 88]) for each of the groundwater monitoring network devices.

Table 3-3 lists all of the monitoring devices for the SVFUDS groundwater monitoring network and summarizes each ID number, construction timeframe, rationale, type of monitoring device, monitored zone, finish type (flush or stickup), hole bottom (feet below ground surface [ft bgs]), casing bottom (ft bgs), open borehole length (feet), top and bottom of the screen (ft bgs), screen length (feet), and top and bottom of the sampling ports (ft bgs) for lined deep bedrock boreholes. Each of the **Table 3-3** monitoring devices is briefly discussed below.

3.2.2.1 Pre-Existing Sump and Hydroelectric Vault

Prior to the SVFUDS Groundwater RI, USEPA in late 2003 analyzed groundwater collected from the Sibley Sump at SMH and the hydroelectric vault near the Washington Aqueduct. These efforts confirmed that groundwater at these location was contaminated with perchlorate. Accordingly, both locations were selected as SVFUDS Groundwater RI groundwater monitoring locations.

3.2.2.2 Piezometers

To gather preliminary hydrogeologic data, such as the depths to bedrock and the water table, five piezometers were installed at four general locations:

- PZ-1 and PZ-2 were located near SMH. PZ-2 has two screened intervals in the same borehole, referred to as PZ-2S and PZ-2D. The letter “S” signifies the shallow (upper-most) screened interval and the letter “D” signifies the deep (lower-most) screened interval. These letters (S and D) have the same meaning throughout this report whenever they are incorporated into piezometer or monitoring well ID numbers.
- PZ-3 was located near the former Lot 18 Debris Area along Rockwood Parkway.
- PZ-4S and PZ-4D were located near Kreeger Hall on AU.
- PZ-5 was located near the Child Day Care Center on AU. This piezometer is no longer accessible.

After the piezometers were installed, they became useful for collecting groundwater samples for chemical analysis, even though they were not initially intended for this purpose.

3.2.2.3 Monitoring Wells with a Single Shallow Screened Interval

Monitoring wells with a single, shallow-screened interval were installed at locations where the groundwater table was encountered within the overburden/saprolite zone above competent bedrock. The following 27 SVFUDS monitoring wells were of this type: MWs 1 through 5, 7, 8, 10, 13 through 15, 19, 21 through 27, 29, 33, 35 through 37, and 39 through 41.

3.2.2.4 Monitoring Wells Completed as Shallow Open Bedrock Boreholes

At some locations, the water table occurred within or very close to the top of competent bedrock. At such locations, the casing was set into the top of bedrock and the monitoring well was completed as a shallow open bedrock borehole. The following 13 SVFUDS monitoring wells were of this type: MWs 6, 9, 11, 12, 16 through 18, 20, 28, 30 through 32, and 38.

3.2.2.5 Monitoring Wells with Two Screened Intervals

Monitoring well boreholes MW-45 and MW-46 each contain two screened intervals discussed below.

MW-45S and MW-45D: PZ-4S and PZ-4D, located in front of Kreeger Hall at AU, confirmed groundwater contamination by perchlorate. Accordingly, the SVFUDS Partners found it necessary to further assess the vertical extent of the perchlorate contamination. Deep multiport bedrock monitoring well MP-1 was planned for this purpose. However, unusually deep overburden and soft weathered bedrock caused problems during the drilling of the borehole for MP-1. Thus, instead of completing the boring as a multiport well (MP-1), the objective of assessing the vertical extent of the perchlorate contamination was accomplished by supplementing vertical information available from PZ-4S and PZ-4D with additional vertical information from MW-45S and MW-45D. The MP-1 objectives were fulfilled by the following monitoring wells located in very close proximity to each other:

- PZ-4S (screened interval: 27 to 47 ft bgs)
- PZ-4D (screened interval 52 to 62 ft bgs)

- MW-44 (screened interval 80 to 90 ft bgs)
- MW-45S (screened interval 119 to 124 ft bgs)
- MW-45D (screened interval 147 to 152 ft bgs)

MW-46S and MW-46D: Shallow groundwater was confirmed to be contaminated with perchlorate based on the chemical results for groundwater samples collected from the Sibley Sump. Accordingly, the SVFUDS Partners found it necessary to further assess the vertical extent of the perchlorate contamination. This was accomplished by installing MW-46S and MW-46D as close to the Sibley Sump as practical. The screened intervals are:

- MW-46S (screened interval: 72 to 92 ft bgs)
- MW-46D (screened interval 107.5 to 117.5 ft bgs)

3.2.2.6 *Multiport Monitoring Wells*

Four multiport wells were installed to assess groundwater quality at different depths: MP-2 through MP-5. MP-1 was not installed, as discussed in section 3.2.2.5. MP-2 was installed near the Glenbrook Road Disposal Areas, where shallow groundwater contamination was confirmed during conduct of the SVFUDS Groundwater RI. MP-3 and MP-5 were installed downgradient and west of this area to assess the extent of the contamination in the direction of SMH. MP-4 was installed cross-gradient and southwest of this area to assess the extent of the contamination in the direction of the south-central SVFUDS boundary.

3.3 SURFACE WATER MONITORING NETWORK

Figure 3-2 shows the surface water monitoring network established early in the investigation. **Table 3-4** presents the location coordinates (northing and easting coordinates [NAD 83/91]) for each surface water monitoring location.

The surface water monitoring network was designed to address these surface water areas of interest:

- Surface water near areas of known or reasonably anticipated impacted groundwater near SMH (SW-4, SW-6, and SW-17) and near the Lot 18 Debris Area and Glenbrook Road Disposal Areas (Lot 18 Drain, SW-1, SW-11, and SW-21).
- East Creek locations downstream from the Lot 18 Debris Area and Glenbrook Road Disposal Areas: SW-2, SW-16, SW-15, and SW-14.
- Known or suspected springs in or near the SVFUDS: SW-12, SW-18, SW-22, SW-23, SW-24, and SW-25 located downgradient of SW-24.
- Streams in valleys south and east of the SVFUDS: SW-5 and SW-13.
- Unnamed tributaries near 52nd Court: SW-7, SW-8, and SW-19.
- Unnamed tributaries near Spring Valley Park: SW-9, SW-10, and SW-20.

- Potomac River water entering Dalecarlia Reservoir: SW-3.
- Dalecarlia Reservoir: RESERVOIR.

3.4 SOIL BORING PROGRAM

Figure 3-3 shows the locations of the soil borings installed in a 2-acre area near AU's Kreeger Hall to investigate the possibility of an undefined perchlorate source implied by the groundwater chemistry data. **Table 3-5** presents the location coordinates and ground elevations for these borings. The 16 soil boring locations were selected considering:

- Assessment of the approximately 2-acre area around PZ-4S and PZ-4D where elevated perchlorate concentrations were measured in groundwater.
- Installation of the soil borings coincident with known geophysical anomalies.
- Need to avoid AU infrastructure.

SECTION FOUR: INVESTIGATION FINDINGS

The following investigation findings discussion is organized as follows:

- Hydrogeology
- Groundwater chemistry
- Surface water chemistry
- Groundwater concentrations trends
- Groundwater and surface water relationship
- Soil boring program chemistry
- Stable oxygen and chlorine isotope analysis
- Environmental fate and transport

4.1 HYDROGEOLOGY

This section discusses the site-specific geology, groundwater occurrence during drilling and well construction, bedrock borehole geophysical logging results, slug test results, groundwater elevations and inferred groundwater flow directions, and the flux modeling assessment between groundwater and the Dalecarlia Reservoir.

4.1.1 Geology

Site-specific geologic information is available from the groundwater monitoring network boring logs (**Appendix A**) and the boring logs from the soil boring program (**Appendix B**).

4.1.1.1 Groundwater Monitoring Network Boring Logs

The boring logs (**Appendix A**) reveal site geology consistent with the description in Section 2.1. Material encountered during drilling consisted of top soil, fill, variably decomposed bedrock (saprolite), and variably competent bedrock. The material (overburden) overlying competent bedrock is generally a silty-clay, silt, and sandy silt material, with occasional residual bedrock fragments. The significant clay content of the overburden implies relatively low permeability and low capacity to facilitate groundwater movement. With increasing depth the relatively fine-grained overburden transitions into more competent coarser-grained material with relic bedrock structure where permeability increases. This zone transitions into fractured upper bedrock with reduced weathering and reduced occurrence of fine-grained material. Deeper into bedrock, permeability becomes highly variable and dependent on the presence of fractures. Groundwater movement within the deeper bedrock is primarily along fractures and is highly variable, depending on fracture characteristics such as size, frequency of occurrence, interconnectivity, hydraulic head differences along the fractures, and degree of fracture ‘healing’ by mechanisms such as in-filling with quartz precipitated from solutions.

The depth to the fractured upper bedrock with reduced occurrence of fine-grained material at the SVFUDS is inferred based on the boring logs. For the locations where the boreholes were drilled using hollow-stem augers (HSAs), the depth of auger refusal is a good proxy for the boundary between overburden (presumed lower permeability) and the underlying variably competent upper bedrock (presumed higher permeability).

Per **Table 4-1**, auger refusal occurred at these 18 locations: MWs 6, 9, 11, 12, 16 through 18, 20, 28, 30 through 32, 38, PZ-1, PZ-2, PZ-4, PZ-5, and MP-3. Auger refusal depths varied from 13 ft bgs at PZ-1 to 49 ft bgs at MW-6. The average depth to HSA refusal was about 28 ft bgs. For all of the above “MW” locations, the monitoring wells were completed as open bedrock boreholes.

At locations where HSA refusal did not occur, the overburden/bedrock boundary is below the bottom of the borehole. Per **Table 4-1**, this was the circumstance for the following 30 locations: MWs 1 through 5, 7, 8, 10, 13 through 15, 19, 21 through 27, 29, 33, 35 through 37, 39 through 43, and PZ-3. The total depths of these boreholes varied from about 20 to 65 ft bgs. The average depth was 33 feet. For all of these borings, groundwater was encountered within the overburden and screened wells were constructed in all of the borings.

Rotary drilling (not HSA) was conducted at boring locations MWs 44 through 46 and multiport borings MPs 2, 4, and 5. At these locations, casings were set into the top of competent bedrock. **Table 4-1** indicates that the estimated overburden/bedrock boundary for these locations varied from 30.5 to 38 feet for the multiport borings and 47 to 99 feet for MWs 44 through 46. The vicinities of MWs 44 through 46 are unique regarding the great depth to the estimated overburden/bedrock boundary.

4.1.1.2 Soil Boring Program Boring Logs

Sixteen temporary soil borings (**Figure 3-3**) were advanced in close proximity to Kreeger Hall on AU during the soil boring program to seek the source of groundwater perchlorate contamination confirmed in this area. The boring logs (**Appendix B**) reveal deeply weathered bedrock throughout the soil boring program project area (vicinity of Kreeger Hall on AU), which is consistent with the boring logs for the groundwater monitoring wells installed in this area.

Soil borings were drilled using HSA. The logs for borings SA-1 through SA-16 show that auger refusal did not occur at any boring. The **Table 4-2** boring data shows that the boring depths ranged from 37 to 56 ft bgs, and the elevation of the borehole bottoms ranged from about 315 to 331 ft msl. The material encountered during drilling is described in the boring logs as primarily consisting of decomposed rock.

4.1.2 Groundwater Occurrence During Drilling and Well Construction

Groundwater was monitored during borehole drilling to determine the appropriate well and piezometer designs. For the four deep bedrock boreholes converted to multiport monitoring wells (MPs 2 through 5), profiling and borehole geophysics were also conducted to determine the appropriate design. Borehole geophysics without profiling assisted with design decisions at MW-45 and MW-46.

4.1.2.1 Monitoring Wells and Piezometers

During drilling of the borings for the groundwater monitoring wells and piezometers, if groundwater was encountered within overburden (i.e., above bedrock), then a screened well was constructed so that the screened interval would straddle the water table. If the groundwater occurred in the bedrock underlying overburden, then the monitoring well was completed as an open bedrock borehole. **Table 3-3** summarizes which borings and piezometers were completed as screened wells and which were completed as open bedrock borehole wells. **Appendix C** presents the monitoring well and piezometer construction diagrams. **Appendix D** presents the well permits. Permits were issued by Montgomery County, MD, for MWs 1 through 3, which are located in Montgomery County just north of the northwest District of Columbia boundary line. The District of Columbia issued permits for the remaining monitoring wells.

Water levels monitored during the drilling process and prior to well construction are listed in **Table 4-3**. **Table 4-3** also lists the top and bottom of the screened intervals and the bottom of casing for wells completed as open bedrock boreholes. All screen bottoms were designed to be below the most recent measured water levels in **Table 4-3**, except for MW-46S. At MW-46S, the desired screened interval was determined based on borehole geophysics identifying the borehole zone that yielded water. The hydraulic head in MW-46S rose to an elevation above the screened interval after well construction was completed.

All screen tops are above the most recent water levels (facilitating water table straddling) in **Table 4-3**, except as follows:

- The screened intervals were intended to be, and are, entirely below the water table for wells/piezometers intended to measure vertical conditions (MW-44, MW-45S, MW-45D, MW-46S, MW-46D, PZ-1D, and PZ-4D)
- MW-7: The water level and top of the screened interval were the same
- MW-14: The water level was 2 feet above the top of the screen
- MW-26: The water level was 7 feet above the top of the screen

4.1.2.2 Deep Bedrock Boreholes

Deep bedrock boreholes were drilled at five locations to assess the vertical extent of groundwater contamination, as discussed in Section 3.2.2.6. The deep boreholes and their completed depths/elevations are:

- MW-44: 100 ft bgs / 275.8 ft msl (located on AU)
- MW-45: 174.5 ft bgs / 201.1 ft msl (located on AU)
- MW-46: 120.8 ft bgs / 68.5 ft msl (located near Sibley Sump)
- MP-1: Not drilled. See MW-44 and MW-45
- MP-2: 201.9 ft bgs / 121.3 ft msl (located near the Glenwood Road Disposal Areas)
- MP-3: 187 ft bgs / 67.4 ft msl (located downgradient from MP-2)

- MP-4: 192.5 ft bgs / 88.4 ft msl (located cross-gradient from MP-2)
- MP-5: 197.5 ft bgs / 46.4 ft msl (located downgradient from MP-2)

Table 4-4 summarizes the deep bedrock borehole activities. Borehole geophysical logging was conducted on all of the above boreholes except MW-44 because the open borehole was unstable. Profiling using a blank liner was conducted on all of the above boreholes except MW-44 and MW-45, which were unstable boreholes, and MW-46 where profiling was not planned and selection of the intervals to be screened was based solely on review of the borehole geophysics data. In boreholes MW-2 through MP-5, final multiport liners were installed to facilitate groundwater sample collection from different vertical intervals.

4.1.3 Deep Bedrock Borehole Geophysical Logging, Profiling, and Final Liners

This section discusses the deep bedrock borehole geophysical logging and profiling findings and final liner designs.

4.1.3.1 Geophysical Logging

Groundwater in the SVFUDS bedrock primarily occurs in fractures. Primary bedrock pores that could contain groundwater are essentially absent. The characteristics of the bedrock fracture system and the hydraulic head distribution within the bedrock are the primary influences on the bedrock hydrology. An extensive fracture system (e.g., many wide fractures) increases the opportunity for groundwater to occur within bedrock. However, assuming a hydraulic gradient is present in the bedrock, the orientation of the fractures and how interconnected they are determines their ability to facilitate bedrock groundwater movement, and movement of any contamination associated with the groundwater. Absent a hydraulic gradient, the groundwater will not move, regardless of how extensive or interconnected the fractures are. Contamination may be persistent in fractures that are poorly interconnected and not subject to flushing by groundwater movement.

After the deep bedrock boreholes were drilled, borehole geophysical logging was conducted for the boreholes as indicated in **Table 4-4**. This logging assisted with interpretation of fracture occurrence and orientation, groundwater occurrence, relationship between groundwater occurrence/flow and fracturing, and lithology. The geophysical logging involved the geophysical logging tests described in **Table 4-5**.

Optical Televiewer and Acoustic Televiewer

Appendix E presents the borehole geophysics logging results. The results reveal overall good correlation between the Optical Televiewer (OTV), Acoustic Televiewer (ATV) amplitude, and ATV acoustic caliber, which, collectively, reveal the occurrence of bedrock fractures. Fractures indicated by the OTV are generally also indicated by the ATV amplitude results; however, the reverse situation was not always true, indicating a greater sensitivity of ATV amplitude to identify fractures. The ATV acoustic caliber results correlate very well with the ATV amplitude results. Where the ATV acoustic caliber indicated the borehole diameter increases, the ATV

amplitude results support the interpretation that open fractures were the cause of the ATV acoustic caliber response.

Table 4-6 lists the overall fracture ranks, frequencies, and orientations for the six bedrock boreholes. Four different fracture ranks were observed:

- Fracture Rank 1 describes minor fractures that are not distinct and may not be continuous around the borehole.
- Fracture Rank 2 describes intermediate fractures that are distinct and continuous around the borehole with little or no apparent aperture.
- Fracture Rank 3 describes intermediate fractures that are distinct and continuous around the borehole with some apparent aperture.
- Fracture Rank 4 describes major fractures that are distinct with continuous apparent aperture around the borehole.

For each borehole and fracture rank, **Table 4-6** lists the number of fractures (count), the mean dip azimuth, the mean dip, and the percentage of fractures for each borehole.

Most of the borings are similar regarding the mean dips of the fracture azimuth, regardless of fracture rank. For example, the mean dips of the fracture azimuths are all within the range of 214° to 296° (e.g., roughly dipping in the directions between southwestward to northwestward) except for borings MP-2 and MW-45. For MP-2, the mean dips of the fracture azimuths are within the range of 169° to 193° (e.g., roughly dipping toward the south). For MW-45, the Rank 1 and Rank 2 fractures have mean dip azimuths similar to MP-2, with the exception of the six Rank 3 fractures, which dip generally westward. **Figure 4-1** presents graphic summaries of fracture occurrence and orientation for each of the logged bedrock boreholes.

The boreholes were similar regarding fracture rank percentages with a few exceptions. Rank 4 fractures were only observed in MP-3, and almost all of them occurred immediately below the bottom of the surface casing. Rank 3 fractures generally occurred infrequently, except in boring MP-2 where their occurrence was 44 percent. The percentage of fractures that were Rank 2 was similar for all of the boreholes. Also, the percentage of fractures that were Rank 1 was similar for all of the boreholes, except MP-2 where the Rank 1 fracture percentage was only 15 percent.

Table 4-7 lists the bedrock borehole fracture frequencies normalized by logged borehole length. The fracture frequencies are expressed as the number of fractures per 10-foot interval of logged borehole. The total fracture frequencies vary from a low of 9.2 fractures per 10 feet for MP-5 to a maximum of 20 fractures per 10 feet for MW-45. Per **Table 4-7**, logged borehole lengths (feet) vary from a minimum of 21 feet in MW-45 to a maximum of about 168 feet in MP-3. These lengths exclude the cased intervals for all borings and the lower 52 feet of borehole MW-46 because the OTV and ATV tools could not pass a depth of about 123 ft bgs where the borehole diameter narrowed to 3.5 inches as the result of a partial obstruction associated with a fracture zone.

Heat Pulse Flow Meter

Heat Pulse Flow Meter (HPFM) measures the direction and rate of vertical flow in the borehole under two conditions: under ambient conditions when no water is pumped from or added to the borehole, and under non-ambient conditions when a small volume of water is pumped from or added to the borehole. Water movement in the borehole under ambient conditions indicates a natural pressure gradient between fracture zones intersected by the borehole, and the fracture zones can be identified that are facilitating groundwater movement. In the absence of a natural pressure gradient at the time of testing, there will be no water movement in the borehole, and fractures that would otherwise be transmissive will not be identifiable. In this circumstance, an artificial gradient is induced by adding or removing water from the borehole to induce water movement within the borehole and facilitate identification of the transmissive fractures.

Table 4-8 summarizes the HPFM results based on the HPFM logs presented in **Appendix E**. Under ambient conditions, flow into the boreholes was detected for all borings except MW-45. For the borings where ambient flow was detected, it generally flowed into the lower portions of the borings, which induced upward borehole flow that exited the borehole at relatively shallow fracture zones. When water was pumped from the boreholes at a typical rate of less than 0.5 gallon per minute, flow into the borehole was induced, which then flowed upward toward the pump.

4.1.3.2 Profiling

The following bedrock boreholes were profiled: MP-2, MP-3, MP-4, and MP-5. **Appendix F** presents the profiling results. The purpose of profiling was to: 1) line the borehole to eliminate groundwater movement within the borehole during the multi-week time period when the final ported liner was being constructed, and 2) measure the hydraulic properties of the bedrock fractures and borehole during installation of the liner.

The top half of **Figure 4-2** illustrates the profile liner installation process, and the bottom half shows how the fracture transmissivity (capacity to transmit water) is calculated. During profiling, the liner descends into the borehole by pushing water below the liner out of the borehole. Pushed water exits the borehole via the bedrock fractures below the liner. In the absence of intersecting, transmissive fractures, water cannot leave the borehole and the liner cannot descend. The liner descent rate is faster in situations where the intersecting fracture system is well developed (e.g., numerous transmissive fractures) and slower in situations where the intersecting fracture system is poorly developed.

Per the bottom half of **Figure 4-2**, individual fracture transmissivities were calculated. The liner descent rate multiplied by the hole cross-section is the flow rate out of the hole. A change in the liner descent velocity and flow rate occurs as the descending liner seals fractures. This change in flow rate corresponds to the flow rate for the fracture that was sealed by the liner and caused the liner descent rate to decrease over the monitored interval.

Figure 4-3 presents the profile results for MP-2, MP-3, MP-4, and MP-5, expressed as transmissivities over defined 1-foot intervals. The net influence of multiple fractures within each

interval is responsible for the interval transmissivity. For each borehole, the transmissivities for defined intervals are plotted versus depth. Graph displacement to the right indicates higher interval transmissivities. **Figure 4-4** presents the profile results for MP-2, MP-3, MP-4, and MP-5 expressed as total borehole transmissivity below the indicated depth. The transmissivity plots begin at the bottom of the surface casing. At the start of the profiling test, none of the borehole fractures had been sealed by the profiling liner; therefore, borehole transmissivities are greatest. For example, for boring MP-2 in **Figure 4-4**, the borehole maximum transmissivity (about 0.5 square centimeter per second [cm^2/s]) was measured when the profile liner was only as deep as the bottom of the casing (34 ft bgs), which is when the entire borehole fracture system was exposed and available to transmit water out of the borehole as the liner began to descend. The MP-2 borehole transmissivity decreased to about 0.2 cm^2/s by the time the liner had reached a depth of 100 ft bgs. Where the **Figure 4-4** borehole transmissivity curves have a vertical orientation, the borehole zone has relatively few transmissive fractures. Where borehole transmissivity curves trend away from vertical, the borehole zone transmissive fractures occur and are being sealed by the descending liner.

Transmissive zones identified by the HPFM are also confirmed by the profiling data. Because of the greater vertically discrete nature of the profiling data, more discrete transmissive fracture zones are identified by the profiling data.

Total open borehole transmissivities were (cm^2/s): MP-2 (0.51), MP-3 (0.06), MP-4 (0.34), and MP-5 (1.73). The relative high MP-5 value is due to high transmissive fractures very close to the bottom of the casing. By 2 feet below the bottom of the casing, the MP-5 borehole transmissivity decreased to about 0.25 cm^2/s .

4.1.3.3 Final Liners or Screened Intervals

For the deep bedrock boreholes, this section discusses the installed depth intervals for the final liner sampling ports and the screened intervals for the boreholes where screens were installed.

Final Liners

The sampling ports for the borehole liners were specified for MP-2, MP-3, MP-4, and MP-5 based on the borehole geophysics and profiling data (**Table 3-3**). The sampling ports facilitate the collection of bedrock groundwater from discrete bedrock intervals. The sampling port intervals were coincident with bedrock fractures zones with varying transmissivities, including low transmissivity zones where flushing of groundwater contamination, if present, would be minimized (increasing the likelihood of being able to detect such potential contamination).

Screened Intervals

The screened intervals for MW-45S, MW-45D, MW-46S, and MW-46D were specified based on the borehole geophysics data (**Table 3-3**).

4.1.4 Slug Tests

On September 22, 2014 CENAB performed slug testing on the following piezometers and monitoring wells: PZ-4S, PZ-4D, MW-21, MW-22, MW-45S, MW-45D, MW-46S, MW-46D,

and MW-44. The objective of the tests was to estimate the hydraulic conductivity of the aquifer, which is useful for estimating groundwater movement. The slug test report is presented in **Appendix G**.

A slug test is conducted by either injecting or withdrawing a known volume of water (or inserting a solid slug) into or from a well and measuring the artificially induced groundwater level change. For the SVFUDS tests, a solid slug of known volume was inserted into the wells. This caused an instantaneous rise in the water level/head. The associated increased pressure caused water in the well to flow out of the well and into the surrounding aquifer, causing the water level in the well to decrease toward the level prior to inserting the slug. The rate at which the water level dropped in the well after the slug was inserted was monitored and the data were used to estimate hydraulic conductivity. After the water levels equilibrated, the mechanical slug was removed. This caused the water level to drop and water from the aquifer to flow into the well. The rate at which the water level rose in the well after the slug was removed was monitored, and the data were used to estimate hydraulic conductivity.

This approach was adjusted for wells with 1-inch diameter riser pipes that were too small for using mechanical slugs: PZ-4S, PZ-4D, MW-45S, and MW-45D. At these locations, water level increases were induced by adding 0.5 gallon of distilled water into the well and then monitoring the rate of subsequent water level decreases.

The AQTESOLV software was used to analyze the field data measured from both the rising and falling head tests. The estimated hydraulic conductivities (K) of the groundwater monitoring wells tested were determined using the Bouwer-Rice solution for an unconfined aquifer in the overburden-screened wells, as well as highly fractured weathered rock, e.g., PZ-4S; the Barker-Black solution was used for a fractured aquifer in the fractured rock-screened wells.

Table 4-9 presents the slug test results, which reveal estimated hydraulic conductivities (feet per day) as follows:

- Overburden near Kreeger Hall (PZ-4S): 8.4
- Bedrock near Kreeger Hall (MWs 44, 45S, 45D, & PZ-4D): 2.6E-03 to 5.4E-01
- Overburden near SMH: (MWs 21 & 22): 2.1E-01 to 1.3
- Bedrock near SMH (MWs: 46S & 46D): 1.3E-02 to 2.0E-02

These slug test results and Darcy's Law can be used to estimate groundwater flow rates. Darcy's Law states that the groundwater flow velocity (v ; feet per second) in a porous medium is calculated from the head gradient (dh/dl ; dimensionless), which is the change in head (feet) per unit length (feet) in the direction of flow, and the hydraulic conductivity (K; feet per second), and the porosity (n ; unitless):

$$\text{Eq 4-1} \quad v = -K * (dh/dl) / n$$

The porosity of the overburden at both SMH and AU is estimated to be in the range of 20 to 30 percent (Heath, 1984; cited in Greene et al., 2004). The porosity of the bedrock at both SMH and AU is estimated to be 2.5 percent, which is the midpoint of the range of 0 to 5 percent (Davis,

1969; cited in Freeze and Cherry, 1979). The head gradient (0.038) is estimated as the head difference across the site based on **Figure 4-7**, presented in Section 4.1.5, and the associated distance. The groundwater flow rates are estimated (**Table 4-10**), using these assumptions and **Eq. 4-1**, to be in the range of 3.19E-02 to 1.28 feet per day for the overburden and from 3.95E-03 to 8.21E-01 feet per day for the bedrock.

4.1.5 Groundwater Elevations and Inferred Flow Directions

Groundwater table elevations were calculated based on groundwater levels measured in monitoring wells during well sampling (**Appendix H** presents the well location and elevation survey reports). **Figure 4-5** shows a representative water table contour map for the area proximate to SMH and Dalecarlia Reservoir. **Figure 4-6** and **Figure 4-7** show the site-wide water table contour map during different stages of the build-out of the groundwater monitoring well network.

Arrows on **Figures 4-6** and **4-7** show the inferred groundwater flow directions, which are in the direction of decreasing groundwater elevation. The topography of the water table roughly follows ground surface topography. Therefore, groundwater generally flows from relatively high topographic elevations in the eastern portion of the SVFUDS toward lower elevations in the western portion of the SVFUDS proximate to the former valley now occupied by the Dalecarlia Reservoir and toward the Potomac River, which is located further west-southwestward of the reservoir. The water table elevation in the eastern SVFUDS near AU is on the order of 350 ft msl, approximately 150 ft msl near Dalecarlia Reservoir and the western portion of SMH, and approximately 30 ft msl at the Potomac River.

The curvature of the water table contour lines toward East Creek implies groundwater seepage into East Creek. This is particularly evident at and westward of MW-35, where East Creek becomes more incised (has a deeper valley). East Creek flows westward along Glenbrook Road, and Rockwood Parkway. **Figure 4-8** shows the location of cross sections A-A' and B-B', which have been drawn to illustrate the relationship between the elevation of topography, the water table, and features such as East Creek.

Figure 4-9 presents cross-section A-A', which runs southwestward from MW-43 at AU to MW-39 at Loughboro Road, on the southern SVFUDS boundary. Beginning at A' near MW-43, the water table is shown at an elevation of approximate 350 ft msl, or about 23 ft bgs. Moving southwestward along A-A', the elevation of the water table and East Creek are the same (approximately 300 ft msl), suggesting shallow groundwater seepage into East Creek. At a groundwater discharge zone, such as along East Creek, one expects a localized upward groundwater gradient (increasing hydraulic head with increasing depth into the aquifer, which in the present situation is bedrock). This was confirmed based on the HPFM conducted on the MP-2 borehole during the borehole geophysics logging. Under ambient HPFM test conditions, flow was into and up the borehole from the three deepest intervals (intervals 6, 7, and 8), encompassed by the 55-foot borehole interval from 105 to 160 ft bgs. At the same time, flow was outward from shallow intervals 1, 2, and 4, encompassed by the 41-foot borehole interval from 35 to 76 ft bgs. No flow was measured at intervals 3 and 5. A similar situation of inward and

upward groundwater flow within the borehole was observed at MP-4 and MP-3. MP-4 is located further westward along A-A', and MP-3 is located along cross-section B-B' illustrated in **Figure 4-10**.

Figure 4-10 presents cross-section B-B', which runs westward from MW-27, adjacent to the former Lot 18 debris area, to MW-32, located west of SMH. The topographic depression shown by the cross section near MW-27 corresponds to East Creek. Here, the similarity between the ground surface and water table elevations implies groundwater seepage into East Creek, as discussed for Section A-A'. Because the alignment of B-B' is generally not along East Creek where ground surface elevations are lowest, the water table illustrated in cross section B-B' is generally well below the ground surface. The decrease in the water table elevation from about 340 ft msl near MW-27 to 105 ft msl at MW-32 implies groundwater flow from right to left in **Figure 4-10**, which is westward across the SVFUDS.

4.1.6 Dalecarlia Reservoir / Groundwater Flux Model

Early in the SVFUDS groundwater study, much of the SVFUDS groundwater was noted to flow westward toward the natural valley currently occupied by the Dalecarlia Reservoir. The reservoir water elevation (typically about 150 ft msl) was also noted to be similar to the water table elevation along the eastern reservoir shoreline, indicating the potential for groundwater seepage into the reservoir along the eastern reservoir boundary. Westward from the eastern reservoir shoreline, the reservoir water elevation is above the inferred groundwater table elevation (**Figures 4-5 through 4-7**); therefore, water seepage here would be from the reservoir into the underlying groundwater. East Creek flows along the eastern shoreline of the Dalecarlia Reservoir but cannot flow into the reservoir because the creek flows within a man-made diversion channel.

Also observed early in the SVFUDS groundwater study were low concentrations of arsenic and perchlorate in groundwater immediately east of the reservoir. The perchlorate concentrations were generally less than about 1 part per billion (ppb), but ranged up to 1.5 ppb at MW-10. The arsenic concentrations were also generally less than about 1 ppb or not detected, but ranged up to 7J ppb at MW-8. The data qualifier "J" indicates an estimated concentration.

In response to the possibility of groundwater seepage into the reservoir near where arsenic and perchlorate were detected in groundwater, the following two questions were posed:

- What concentration of perchlorate or arsenic in groundwater east of the reservoir would be necessary to cause a 1 ppb increase in the concentration of perchlorate or arsenic in the reservoir?
- What maximum concentration of perchlorate or arsenic could occur in the reservoir as a result of such seepage?

Using Darcy's Law and site-specific groundwater monitoring data, the rate of potential groundwater seepage (flux) into the reservoir was estimated. This seepage volume was compared to the dilution that occurs within the reservoir by mixing of the seepage volume with Potomac

River water constantly flowing into the reservoir. **Appendix I** presents the flux and dilution assessment.

The flux modeling assessment between groundwater and the reservoir revealed a dilution factor of 2.56E-04. Thus, 1 ppb of any chemical in all groundwater seeping into the reservoir would result in a concentration of that chemical in the reservoir of 2.56E-04 ppb. Similarly, to affect a 1 ppb concentration increase in the reservoir, the concentration of the chemical in the groundwater seeping into the reservoir would need to be 3,906 ppb, derived as follows: $1 \text{ ppb} / 2.56\text{E-}04 = 3,906 \text{ ppb}$. The maximum arsenic and perchlorate concentrations ever measured in groundwater proximate to the eastern reservoir shoreline are orders of magnitude less than this threshold concentration (3,906 ppb) that would increase the reservoir concentration by 1 ppb. Thus, the reservoir water quality is not threatened by possible groundwater seepage into the reservoir.

4.2 GROUNDWATER CHEMISTRY

Groundwater samples from throughout the SVFUDS were analyzed for the chemicals comprising the parameter groups identified in Section 1.2.2.1. During the earlier phases of the monitoring program, samples were analyzed for all of these parameter groups. However, most chemicals were not detected. Therefore, the analytical scope during later phases of the monitoring program focused on the detected chemicals. Groundwater chemistry supporting documentation is presented in various appendices. **Appendices J and K** present the well purging records and chain of custody's for the collected samples, respectively. **Appendices L and M** present the laboratory analytical reports and the associated third-party data validation reports, respectively. **Appendix N** presents the tabulated analytical results for the detected chemicals, and **Appendix O** presents all the tabulated analytical results.

Table 4-11 summarizes the number of sampling events and the chemical classes analyzed at each groundwater sampling location, to date. A blank cell indicates that no samples were analyzed for the associated chemical class. An "X" in the cell indicates that at least one sample was analyzed. If a cell contains an "X" and chemical names in parentheses after the "X," not all of the chemicals in the chemical class were analyzed, only those shown in the parentheses. Green shading indicates that no chemical from the chemical class was ever detected.

Table 4-12 lists all of the SVFUDS parameters detected at any time for each groundwater sample location. An "X" in this table indicates the chemical was detected. The "chemical agents," VOC target TICs, and SVOC target TICs chemical classes are not presented in **Table 4-12** because no chemical from any of these classes was ever detected at any location. The following chemicals, by class, were detected at least once:

- 9 VOCs
- 6 SVOCs
- 1 explosive compound
- 23 inorganics

- 7 other chemicals, including perchlorate

The results for each of these chemical classes are further discussed in the following subsections. The maximum detected concentrations were compared to USEPA Regional Screening Levels (RSLs) for tap water and corresponding to a target non-cancer hazard quotient (THQ) of 0.1 and target cancer risk (TCR) of 1E-06. The results are discussed below in Sections 4.2.1 through 4.2.7.

As will be discussed in Section 5.2.1, the SVFUDS groundwater monitoring locations are organized into one of three different exposure units (EUs) to support the human health risk assessment (HHRA). Groundwater EU1 encompasses these monitoring locations proximate to SMH: Sibley Sump, MW-21, MW-22, MW-46S, and MW-46D. Groundwater EU2 encompasses these monitoring locations proximate to AU's Kreeger Hall and the adjacent Glenbrook Road/Rockwood Parkway area: MP-2 (eight intervals), MW-24, MW-25, MW-44, MW-45S, MW45D, PZ-4S, and PZ-4D. Groundwater EU3 encompasses all other monitoring locations not associated with groundwater EUs 1 and 2.

Any detected result that is "J"-flagged is an estimated value (i.e., is below the lowest calibration standards of the analytical program); it is unknown if the value is above or below the RSL. Any "J"-flagged results presented in this section are rounded to one significant figure.

4.2.1 Volatile Organic Compound Results

Table 4-13 lists the nine VOCs detected in at least one SVFUDS groundwater sample. The VOC results are discussed below for groundwater EUs 1, 2, and 3, with an emphasis on chemicals detected at concentrations exceeding RSLs.

4.2.1.1 Groundwater EU1

Tetrachloroethylene was the only VOC detected in any groundwater EU1 sample. The maximum detected concentration (1 J $\mu\text{g/L}$ in a sample from MW-22) was less than the tetrachloroethylene tap water RSL.

4.2.1.2 Groundwater EU2

Chloroform and methylene chloride were the only VOCs detected in any EU2 samples. Only chloroform was detected at a concentration exceeding its tap water RSL. The tap water RSL is 0.22 $\mu\text{g/L}$.

Chloroform was detected in 1 out of 5 groundwater EU2 samples, at a concentration of 15 $\mu\text{g/L}$ in a sample collected from MW-25 in August 2005. Chloroform was also detected in a background well sample at a maximum concentration of 11 $\mu\text{g/L}$.

4.2.1.3 Groundwater EU3

Nine VOCs were detected in one or more groundwater EU3 samples: chloroform, dibromochloromethane, diphenylether, ethylbenzene, methylene chloride, tetrachloroethylene, toluene, trichlorofluoromethane, and xylene. Of these, the following were detected at

concentrations exceeding their tap water RSLs: dibromochloromethane, ethylbenzene, and tetrachloroethylene.

Dibromochloromethane was detected in 1 of 32 groundwater EU3 samples; the maximum concentration of 11 $\mu\text{g/L}$ is in the sample from MW-33 collected in June 2007. The tap water RSL is 0.17 $\mu\text{g/L}$. In 2009 it was not detected in the sample from MW-33.

Ethylbenzene was detected in 1 out of 32 groundwater EU3 samples, at a maximum concentration of 2 JB $\mu\text{g/L}$ in the sample collected from MW-3 collected in July 2006. The tap water RSL is 1.5 $\mu\text{g/L}$. In 2007 it was not detected in the sample from MW-3.

Tetrachloroethylene was detected in 11 out of 32 groundwater EU3 samples, at a maximum concentration of 14 B $\mu\text{g/L}$ in PZ-1S. All of the detected concentrations were B-flagged because tetrachloroethylene was also detected in all of the associated blank samples, and all of the detected concentrations exceeded the tetrachloroethylene tap water RSL (4.1 $\mu\text{g/L}$). The RSL exceedances were for samples collected from the following locations: MWs 2, 5, 8, 10, 31, 32, 33, 36, 40, and PZ-1D.

4.2.2 Semivolatile Organic Compound Results

Table 4-14 lists the six SVOCs detected in at least one groundwater sample. The SVOC results are discussed below for groundwater EUs 1, 2, and 3, with an emphasis on chemicals detected at concentrations exceeding RSLs.

4.2.2.1 Groundwater EU1

Two SVOCs were detected in one or more groundwater EU1 samples: bis(2-ethylhexyl)phthalate and benzoic acid. The maximum detected concentrations for both did not exceed the corresponding tap water RSLs.

4.2.2.2 Groundwater EU2

Two SVOCs were detected in one or more groundwater EU2 samples: bis(2-ethylhexyl)phthalate and di-n-butylphthalate. Only bis(2-ethylhexyl)phthalate was detected at a concentration exceeding its tap water RSL.

Bis(2-ethylhexyl)phthalate was detected in 3 of 5 groundwater EU2 samples, at a maximum concentration of 6 J $\mu\text{g/L}$ in the sample from MW-25 collected in August 2005. The tap water RSL is 5.6 $\mu\text{g/L}$. This is the only location where the tap water RSL was exceeded. It was also detected in the sample from MW-25 collected in June 2007, at a concentration of 1 J $\mu\text{g/L}$. It was not detected in the sample from MW-25 collected in November 2009. It was also detected in a background well sample at a maximum concentration of 5 J $\mu\text{g/L}$.

4.2.2.3 Groundwater EU3

Five SVOCs were detected in one or more groundwater EU3 samples: Benzoic acid, bis(2-ethylhexyl)phthalate, di-n-butylphthalate, phenyl isocyanate, and 2-nitrophenol. Only bis(2-ethylhexyl)phthalate was detected at a concentration exceeding its tap water RSL. A tap water RSL is not available for phenyl isocyanate.

Bis(2-ethylhexyl)phthalate was detected in 14 out of 31 groundwater EU3 samples, at a maximum concentration of 8.3 J $\mu\text{g/L}$ in the sample from MW-3 collected in June 2007. The tap water RSL is 5.6 $\mu\text{g/L}$. This is the only location where the tap water RSL was exceeded. It was also detected in a background well at a maximum concentration of 5 J $\mu\text{g/L}$.

4.2.3 Explosives Results

Table 4-15 lists the one detected explosives chemical (HMX). HMX was detected in only one sample, from groundwater EU2. HMX was detected in 1 of 5 groundwater EU2 samples, at a maximum concentration of 0.2 J $\mu\text{g/L}$ in the sample from MW-24 collected in August 2005. The tap water RSL is 100 $\mu\text{g/L}$. In 2009, it was not detected in the sample from this well.

4.2.4 Metals Results

Table 4-16 lists the 23 metals detected in at least one groundwater sample. The metals results are discussed below for groundwater EUs 1, 2, and 3, with an emphasis on chemicals detected at concentrations exceeding tap water RSLs or the lead action level.

4.2.4.1 Groundwater EU1

Sixteen metals were detected in one or more groundwater EU1 samples: aluminum, arsenic, barium, cadmium, cobalt, copper, lead, manganese, nickel, selenium, strontium, tellurium, titanium, vanadium, zinc, and zirconium. Of these, three were detected at concentrations exceeding their tap water RSLs or lead action level (tap water RSLs are not available for tellurium and titanium). The results for these three are discussed below.

Arsenic was detected in 14 of 33 groundwater EU1 samples, at a maximum concentration of 5 $\mu\text{g/L}$ in the sample from Sibley Sump collected in February 2012. The tap water RSL is 0.052 $\mu\text{g/L}$. Maximum detected concentrations in the samples from these other groundwater EU1 locations also exceeded the tap water RSL: MWs 21, 22, 46S, and 46D. It was also detected in a background well sample at a maximum concentration of 1 J $\mu\text{g/L}$.

Cobalt was detected in 2 of 2 groundwater EU1 samples, at maximum concentrations of 2 J $\mu\text{g/L}$ (MW-22; August 2005) and 0.7 J $\mu\text{g/L}$ (MW-21; June 2007). The tap water RSL is 0.6 $\mu\text{g/L}$. It was also detected in a background well sample at a maximum concentration of 2 J $\mu\text{g/L}$.

Zirconium was detected in 1 of 2 groundwater EU1 samples, at a maximum concentration of 3 J $\mu\text{g/L}$ in the sample from MW-21 collected in June 2007. The tap water RSL is 0.16 $\mu\text{g/L}$.

4.2.4.2 Groundwater EU2

Eighteen metals were detected in one or more groundwater EU2 samples: antimony, arsenic, barium, beryllium, cadmium, cobalt, copper, lead, manganese, mercury, nickel, silver, strontium, tellurium, titanium, vanadium, zinc, and zirconium. Of these, four were detected at concentrations exceeding their tap water RSLs or lead action level (tap water RSLs are not available for tellurium and titanium). The results for these four are discussed below.

Arsenic was detected in 102 of 114 groundwater EU2 samples, at a maximum concentration of 18 $\mu\text{g/L}$ in the samples from MP-2-3 (third interval of multiport well MP-2) collected in May

and July 2012. The tap water RSL is 0.052 µg/L. Maximum detected concentrations in the samples from these other groundwater EU2 locations also exceeded the tap water RSL: MWs 24, 24, 44, 45D, and 45S and PZs 4S and 4D. It was also detected in a background well sample at a maximum concentration of 1 J µg/L.

Cobalt was detected in 4 of 5 groundwater EU2 samples, at a maximum concentration of 2 J µg/L in the sample from MW-25 collected in August 2005. The tap water RSL is 0.6 µg/L. The maximum concentrations detected in the samples from the other locations did not exceed the tap water RSL. It was also detected in a background well sample at a maximum concentration of 2 J µg/L.

Manganese was detected in 5 of 5 groundwater EU2 samples, at a maximum concentration of 946 µg/L in the sample from MW-25 collected in August 2005. The tap water RSL is 43 µg/L. The maximum concentration (66.7 µg/L) detected in the sample from one other location (MW-24 in August 2005) also exceeded the tap water RSL. It was also detected in a background well sample at a maximum concentration of 553 µg/L.

Zirconium was detected in 1 of 5 groundwater EU2 samples, at a maximum concentration of 3 J µg/L in MW-25. The tap water RSL is 0.16 µg/L.

4.2.4.3 Groundwater EU3

Twenty-three metals were detected in one or more groundwater EU3 samples: aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, silver, strontium, tellurium, thallium, tin, titanium, vanadium, zinc, and zirconium. Of these, 10 were detected at concentrations exceeding their tap water RSLs or lead action level (tap water RSLs are not available for tellurium and titanium). The results for these 10 are discussed below.

Arsenic was detected in 62 of 234 groundwater EU3 samples, at a maximum concentration of 7.3 µg/L in the sample from MW-8 collected in August 2011. The tap water RSL is 0.052 µg/L. Maximum detected concentrations in the samples from these other groundwater EU3 locations also exceeded the tap water RSL: MPs 3, 4, and 5; MWs 3, 10, 15, 19, 23, 27, 32, 33, 37, 39, and 43; and PZs 1S, 1D, 2, 3, and 5. It was also detected in a background well sample at a maximum concentration of 1 J µg/L.

Barium was detected in 41 of 41 groundwater EU3 samples, at a maximum concentration of 452 µg/L in the sample from MW-38 collected in June 2007. The tap water RSL is 380 µg/L. The maximum concentrations detected in the samples from the other locations did not exceed the tap water RSL. It was also detected in a background well sample at a maximum concentration of 204 µg/L.

Chromium was detected in 12 of 41 groundwater EU3 samples, at a maximum concentration of 8 J µg/L in the sample from MW-32 collected in June 2007. The tap water RSL is 0.035 µg/L. Maximum detected concentrations in the samples from these other groundwater EU3 locations also exceeded the tap water RSL: MPs 3 and 5; MWs 8, 10, 26, 27, 33, 36, 38, 39; and PZ-1D. It was also detected in a background well sample at a maximum concentration of 3 J µg/L.

Cobalt was detected in 35 of 41 groundwater EU3 samples, at a maximum concentration of 159 µg/L in the sample from MW-33 collected in June 2007. The tap water RSL is 0.6 µg/L. Maximum detected concentrations in the samples from these other groundwater EU3 locations also exceeded the tap water RSL: MWs 1, 3, 4, 7, 8, 14, 15, 19, 20, 23, 26, 27, 32, and 35 through 40 and PZs 1S and 1D. Excluding the MW-33 results, the maximum cobalt concentration was 16 J in the sample from PZ-1S. It was also detected in a background well sample at a maximum concentration of 2 J µg/L.

Manganese was detected in 41 of 41 groundwater EU3 samples, at a maximum concentration of 14,400 µg/L in the sample from MW-33 collected in June 2007. The tap water RSL is 43 µg/L. Maximum detected concentrations in the samples from these other groundwater EU3 locations also exceeded the tap water RSL: MWs 1, 3, 4, 5, 7, 8, 14, 15, 19, 20, 23, 26, 27, 32, and 35 through 40 and PZ-1S and 1D. It was also detected in a background well sample at a maximum concentration of 553 µg/L.

Mercury was detected in 8 of 41 groundwater EU3 samples, at a maximum concentration of 0.2 J µg/L in the duplicate sample from MW-14 collected in August 2005. The tap water RSL is 0.063 µg/L. It was not detected in the primary sample from MW-14 collected on this date. Maximum detected concentrations in the samples from these other groundwater EU3 locations also exceeded the tap water RSL: MWs 32 and 33, and PZ-1D.

Strontium was detected in 41 of 41 groundwater EU3 samples, at a maximum concentration of 2,240 µg/L in the sample from PZ-1D collected in June 2007. The strontium tap water RSL is 1,200 µg/L. Maximum detected concentrations in the samples from these other groundwater EU3 locations also exceeded the tap water RSL: MWs 19 and 38. It was also detected in a background well sample at a maximum concentration of 202 µg/L.

Thallium was detected in 5 of 41 groundwater EU3 samples, at a maximum concentration of 0.6 J µg/L in the sample from MW-19 collected in October 2009. The tap water RSL is 0.02 µg/L. Maximum detected concentrations in the samples from these other groundwater EU3 locations also exceeded the tap water RSL: MWs 3, 8, 32, and 40.

Vanadium was detected in 21 out of 41 groundwater EU3 samples, at a maximum concentration of 10 J µg/L in the sample from MW-32 collected in June 2007. The vanadium tap water RSL is 8.6 µg/L. None of the maximum detected concentrations in the samples from the other groundwater EU3 locations exceeded the vanadium tap water RSL.

Zirconium was detected in 16 of 41 groundwater EU3 samples, at a maximum concentration of 7 J µg/L in the sample from MW-32 collected in June 2007. The zirconium tap water RSL is 0.16 µg/L. Maximum detected concentrations in the samples from these other groundwater EU3 locations also exceeded the tap water RSL: MWs 3, 5, 8, 10, 31, 33, 35, 36, 38, and 39 and PZ1S and 1D.

4.2.5 Other Chemicals (Including Perchlorate) Results

Table 4-17 lists the seven other chemicals (including perchlorate) detected in at least one groundwater sample: oxathiane (1,4), acetic acid, bromide, chloride, iodate, iodide, and

perchlorate. The results for these chemicals are discussed below, except perchlorate which is individually discussed in sections 4.2.5.1 through 4.2.5.3 for each of EUs 1, 2, and 3.

Acetic acid was detected in 17 of 37 SVFUDS groundwater samples, at a maximum concentration of 4,400 µg/L in the sample from MW-24 collected in August 2005. It was also detected in a background well sample at a maximum concentration of 12,000 µg/L.

Bromide was detected in 79 of 103 SVFUDS groundwater samples, at a maximum concentration of 2,600 µg/L in the sample from MW-19 collected in June 2007. It was also detected in a background well sample at a maximum concentration of 440 µg/L.

Chloride was detected in 104 of 104 SVFUDS groundwater samples, at a maximum concentration of 1,100,000 µg/L in the sample from MW-33 collected in June 2007. It was also detected in a background well sample at a maximum concentration of 220,000 µg/L.

Iodate was detected in 29 of 39 SVFUDS groundwater samples, at a maximum concentration of 1,800 µg/L in the samples from MW-15 and MW-24 collected in October 2009. It was also detected in a background well sample at a maximum concentration of 500 µg/L.

Iodide was detected in 10 of 39 SVFUDS groundwater samples, at a maximum concentration of 3,100 µg/L in the sample from MW-7 collected in August 2005. It was also detected in a background well sample at a maximum concentration of 3,800 µg/L.

Oxathiane (1,4) was detected in 1 of 36 SVFUDS groundwater samples, at a maximum concentration of 0.52 µg/L in the sample from MW-25 collected in October 2009.

4.2.5.1 Groundwater EU1 Perchlorate Results

Perchlorate was detected in 38 of 39 groundwater EU1 samples, at a maximum concentration of 48 µg/L in the sample from MW-21 collected in August 2005. This concentration exceeds the perchlorate Drinking Water Health Advisory (DWHA) (15 µg/L) and RSL (1.4 µg/L).

Groundwater EU1 locations where maximum detected perchlorate concentrations exceeded the perchlorate RSL are: MWs 21, 22, 46S, and Sibley Sump.

Groundwater EU1 locations where maximum detected perchlorate concentrations exceeded the perchlorate DWHA are: MWs 21, 22, and Sibley Sump.

Perchlorate was also detected at a maximum concentration of 0.99 µg/L J in a sample from a background well.

4.2.5.2 Groundwater EU2 Perchlorate Results

Perchlorate was detected in 106 of 115 groundwater EU2 samples, at a maximum concentration of 146 µg/L in the sample from PZ-4S collected in June 2007.

Groundwater EU2 locations where maximum detected perchlorate concentrations exceeded the perchlorate RSL are: MP-2, MWs 24, 25, 44, 45S, and 45D and PZs 4S and 4D.

Groundwater EU2 locations where maximum detected perchlorate concentrations exceeded the perchlorate DWHA are: the same locations as described for the RSL exceedances.

Perchlorate was also detected at a maximum concentration of 1 J in a sample from a background well.

4.2.5.3 Groundwater EU3 Perchlorate Results

Perchlorate was detected in 139 of 251 groundwater EU3 samples, at a maximum concentration of 10.6 µg/L in the sample from MW-19 collected in August 2005.

Groundwater EU3 locations where maximum detected perchlorate concentrations exceeded the perchlorate RSL are: MWs 10, 19, 20, 26, 27, 36 through 39, and 41 through 43, PZs 1D, 1S, 2, 3, and 5, and the hydroelectric vault.

Groundwater EU3 locations where maximum detected perchlorate concentrations exceeded the perchlorate DWHA are: none.

Perchlorate was also detected at a maximum concentration of 1 J in a sample from a background well.

4.2.6 Chemical Agents and Agent Breakdown Products

No chemical agents or agent breakdown products were detected in any groundwater sample at any time, with the exception of one detection of oxathiane (1,4) (mustard breakdown product) at a concentration of 0.52 µg/L in the October 2009 sample from MW-25.

4.2.7 Tentatively Identified Compounds

Table 4-18 lists the 15 TICs detected in at least one groundwater sample. The results are discussed below for groundwater EUs 1, 2, and 3. RSLs are not available for any of the TICs.

4.2.7.1 Groundwater EU1

No TICs were detected in any samples from groundwater EU1.

4.2.7.2 Groundwater EU2

Two TICs were detected in one or more groundwater EU2 samples: 2-ethyl-hexanoic acid and n-hexadecanoic acid.

Hexanoic acid, 2-ethyl was detected in 1 of 5 groundwater EU2 samples, at a maximum concentration of 10 J µg/L in the sample from MW-25 collected in June 2007.

N-hexadecanoic acid was detected in 1 of 5 groundwater EU2 samples, at a maximum concentration of 5 J µg/L in the sample from in MW-24 collected in August 2005. It was detected in a background well sample at a maximum concentration of 6 J µg/L.

4.2.7.3 Groundwater EU3

Thirteen TICs were detected in one or more groundwater EU3 samples.

13-tetradecen-1-ol-acetate was detected in 2 of 31 groundwater EU3 samples, at a maximum concentration of 3 JN µg/L in the sample from MW-31 collected in June 2007. It was also detected in a sample from MW-39 at a concentration of 3 JN µg/L.

1-docosene was detected in 2 of 31 groundwater EU3 samples, at a maximum concentration of 7 JN $\mu\text{g/L}$ in the sample from MW-10 collected in June 2007. It was also detected in a sample from MW-5 at a concentration of 4 JN $\mu\text{g/L}$.

1-eicosanol was detected in 1 of 31 groundwater EU3 samples, at a maximum concentration of 6 JN $\mu\text{g/L}$ in the sample from MW-10 collected in June 2007.

1-hexacosanol was detected in 1 of 31 groundwater EU3 samples, at a maximum concentration of 4 JN $\mu\text{g/L}$ in the sample from MW-40 collected in June 2007.

2-chloro-2-butane was detected in 1 of 31 groundwater EU3 samples, at a maximum concentration of 4 JN $\mu\text{g/L}$ in the sample from MW-8 collected in July 2006.

3-methyl-3-buten-2-one was detected in 1 of 31 groundwater EU3 samples, at a maximum concentration of 5 JN $\mu\text{g/L}$ in the sample from MW-8 collected in July 2006.

3-penten-2-ol was detected in 1 of 31 groundwater EU3 samples, at a maximum concentration of 8 JN $\mu\text{g/L}$ in the sample from MW-8 collected in July 2006.

3-penten-2-one, 4-methyl was detected in 1 of 31 groundwater EU3 samples, at a maximum concentration of 4 JN $\mu\text{g/L}$ in the sample from MW-37 collected in June 2007.

Acetic acid, octadecyl ester was detected in 1 of 31 groundwater EU3 samples, at a maximum concentration of 6 JN $\mu\text{g/L}$ in the sample from MW-8 collected in June 2007.

Benzenesulfonamide, N-4-dimethyl was detected in 1 of 31 groundwater EU3 samples, at a maximum concentration of 20 JN $\mu\text{g/L}$ in the sample from MW-3 collected in June 2007.

Hexanoic acid, 2-ethyl was detected in 1 of 31 groundwater EU3 samples, at a maximum concentration of 200 JN $\mu\text{g/L}$ in the sample from MW-36 collected in June 2007.

Methane, dichloronitro was detected in 1 of 31 groundwater EU3 samples, at a maximum concentration of 4 JN $\mu\text{g/L}$ in the sample from MW-40 collected in June 2007.

N-hexadecanoic acid was detected in 3 of 31 groundwater EU3 samples, at a maximum concentration of 10 JN $\mu\text{g/L}$ in the sample from MW-8 collected in June 2007. It was also detected at groundwater EU3 locations MW-10 and MW-31, and in a background well sample at a maximum concentration of 6 J $\mu\text{g/L}$.

4.2.8 Comparison to Drinking Water Standards

The health implications of the groundwater chemical detections discussed in the preceding sections are thoroughly evaluated in the HHRA, presented in Section 5.0. Regardless, all exceedances of maximum contaminant levels (MCLs), action levels for copper and lead, or the DWHA for perchlorate are considered noteworthy and are summarized below for each EU. It should be noted that MCLs are not to be used as screening tools and are not necessarily risk-based values. In the HHRA process, MCLs are concentrations that are to be achieved by a remedial action in cases where a groundwater use exposure scenario exceeds EPA's risk threshold. The discussion below reveals that the exceedances are primarily due to arsenic and perchlorate. Accordingly, all arsenic and perchlorate results for all monitored locations are

plotted in **Figure 4-11**. Results shaded yellow in this figure represent the measured concentrations that either exceeded the arsenic MCL or the perchlorate DWHA.

4.2.8.1 Groundwater EU1

Exceedances of the following are discussed below for groundwater EU1: MCLs, action levels for lead and copper, and the perchlorate DWHA.

Maximum Contaminant Levels

No detected chemical concentrations in groundwater exceeded any MCLs.

Action Levels

No detected chemical concentrations in groundwater exceeded the copper or lead action levels.

Perchlorate Drinking Water Health Advisory

The perchlorate DWHA value of 15 µg/L was exceeded by one or more samples from MW-21, MW-22, and Sibley Sump. The maximum perchlorate concentrations were 48 µg/L, 25 µg/L, and 25.2 µg/L at MW-21, MW-22, and Sibley Sump, respectively.

4.2.8.2 Groundwater EU2

Exceedances of the following are discussed below for groundwater EU2: MCLs, action levels for lead and copper, and the perchlorate DWHA.

Maximum Contaminant Levels

Two chemicals were detected at concentrations in groundwater that exceeded their MCL values: arsenic and bis(2-ethylhexyl)phthalate.

The arsenic MCL (10 µg/L) was exceeded at MW-24 and MP-2. At MW-24, the exceedances were associated with the samples collected in December 2005 (10.4 µg/L), July 2006 (10.5 µg/L), and April 2013 (16.8 µg/L). More recent samples from MW-24 (December 2013 and June 2014) revealed arsenic concentrations (1.8 µg/L and 4.2 µg/L, respectively) below the arsenic MCL.

The arsenic MCL was also exceeded for samples from the seven deepest MP-2 intervals. Concentrations that have exceeded the MCL ranged from 10.2 to 18 µg/L for samples collected between May 2012 and December 2013.

The bis(2-ethylhexyl)phthalate MCL (6 µg/L) was exceeded at MW-25. The MW-25 exceedance is associated with the sample collected in August 2005 with a bis(2-ethylhexyl)phthalate concentration of 6.5 µg/L.

Action Levels

No detected chemical concentrations in groundwater exceeded the copper or lead action levels.

Perchlorate Drinking Water Health Advisory

The perchlorate DWHA value of 15 µg/L was exceeded by one or more samples from MW-24, MW-25, MW-44, MW-45S, MW-45D, MP-2, PZ-4S, and PZ-4D. The range of maximum concentrations and the dates when they were measured is as follows:

- MW-24: 70 µg/L; December 2005
- MW-25: 124 µg/L; July 2006
- MW-44: 49.8 µg/L; July 2014
- MW-45S: 31.1 µg/L; May 2013
- MW-45D: 54.3 µg/L; May 2013
- MP-2: 27 µg/L; March 2012
- PZ-4S: 146 µg/L; June 2007
- PZ-4D: 45 µg/L; November 2011

4.2.8.3 Groundwater EU3

Exceedances of the following are discussed below for groundwater EU3: MCLs, action levels for lead and copper, and the perchlorate DWHA.

Maximum Contaminant Levels

One chemical was detected at a concentration in groundwater that exceeded its MCL value: bis(2-ethylhexyl)phthalate. The bis(2-ethylhexyl)phthalate MCL (6 µg/L) was exceeded at MW-3. The MW-3 exceedance is associated with the sample collected in June 2007 with a bis(2-ethylhexyl)phthalate concentration of 8.3 µg/L.

Action Levels

No detected chemical concentrations in groundwater exceeded the copper or lead action levels.

Perchlorate Drinking Water Health Advisory

No detected chemical concentrations in groundwater exceeded the perchlorate DWHA.

4.3 SURFACE WATER CHEMISTRY

Surface water samples from throughout the SVFUDS were analyzed for the chemicals comprising the parameter groups identified in Section 1.2.2.1. During the earlier phases of the monitoring program, samples were analyzed for all of these parameter groups. However, most chemicals were not detected. Therefore, the analytical scope during later phases of the monitoring program focused on the detected chemicals. Surface water chemistry supporting documentation is presented in **Appendices K through O** and previously described in Section 4.2.

Table 4-19 summarizes the number of sampling events and the chemical classes analyzed at each surface water sampling location to date. A blank cell indicates that no samples were analyzed for the associated chemical class. An “X” in the cell indicates that at least one sample was analyzed. If a cell contains an “X” and chemical names in parentheses after the “X,” not all of the chemicals in the chemical class were analyzed, only those shown in the parentheses. Green shading indicates that no chemical from the chemical class was ever detected.

Table 4-20 lists all of the SVFUDS parameters detected at any time for each surface water sample location. An “X” in this table indicates the chemical was detected. The “chemical agents,” VOC target TICs, SVOC target TICs, and “explosives” chemical classes are not

presented because no chemical from any of these classes was detected at any location. The following chemicals, by class, were detected at least once:

- 1 VOC
- 4 SVOCs
- 18 inorganics
- 5 other chemicals, including perchlorate

The results for each of these chemical classes are further discussed in the following subsections. For information purposes, detected concentrations are compared to tap water RSLs based on a TCR of 1E-06 and THQ of 0.1, even though no SVFUDS surface water is used for drinking water.

As will be discussed in Section 5.2.2, the SVFUDS surface water monitoring locations are organized into one of two different surface water EUs (surface water EU1 and surface water EU2) to support the HHRA. Surface water EU1 encompasses the monitoring locations along East Creek where impacted groundwater seeps into the creek: Lot 18 Drain, SW-1, SW-11, and SW-21. Surface water EU2 encompasses all other surface water monitoring locations not associated with surface water EU1, excluding SW-3. SW-3 serves as a background surface water sampling location where the Potomac River water first enters the Dalecarlia Reservoir.

4.3.1 Volatile Organic Compound Results

Table 4-21 lists the one VOC detected in at least one surface water sample.

Acetone was detected in 1 of 4 samples, at a maximum concentration of 10 J µg/L in the sample collected from SW-1 in August 2005. The tap water RSL is 1,400 µg/L.

4.3.2 Semivolatile Organic Compound Results

Table 4-22 lists the four SVOCs detected in at least one surface water sample.

The SVOC 4-methylphenol was detected in 1 of 4 surface water samples, at a concentration of 3 J µg/L in the sample collected from SW-1 in August 2005. The tap water RSL is 190 µg/L.

Benzoic acid was detected in 3 of 4 surface water samples, at a maximum concentration of 11 B µg/L, in the sample collected from SW-1 in August 2005. The tap water RSL is 7,500 µg/L.

Bis(2-ethylhexyl)phthalate was detected in 2 of 4 surface water samples, at a maximum concentration of 4 J µg/L in a sample collected from SW-2 in August 2005. The tap water RSL is 5.6 µg/L and the MCL is 6 µg/L.

Di-n-butyl phthalate was detected in 1 of 4 surface water samples, at a maximum concentration of 3 J µg/L in a sample collected from SW-2 in August 2005. The tap water RSL is 90 µg/L.

4.3.3 Metals Results

Table 4-23 lists the following 18 metals detected in at least one surface water sample: aluminum, antimony, arsenic, barium, beryllium, cadmium, cobalt, copper, lead, manganese, nickel, silver, strontium, tellurium, titanium, vanadium, zinc, and zirconium.

Of these, six were detected at concentrations exceeding their tap water RSLs or lead action level (tap water RSLs are not available for tellurium and titanium). The results for these six are discussed below.

Antimony was detected in 8 of 12 surface water samples, at a maximum concentration of 2 J $\mu\text{g/L}$ in the sample collected from SW-2 in August 2005. The tap water RSL is 0.78 $\mu\text{g/L}$.

Arsenic was detected in 70 of 132 surface water samples, at a maximum concentration of 3 J $\mu\text{g/L}$ in the sample collected from SW-1 in July 2006. The tap water RSL is 0.52 $\mu\text{g/L}$ and the MCL is 10 $\mu\text{g/L}$. At all of the detection locations shown in **Table 4-20**, the RSL was exceeded. Arsenic was detected in a sample from SW-3, representing Potomac River water, at a concentration of 2 J $\mu\text{g/L}$.

Cobalt was detected in 6 of 12 surface water samples, at a maximum concentration of 4.9 $\mu\text{g/L}$ in the sample collected from SW-1 in August 2005. The tap water RSL is 0.6 $\mu\text{g/L}$. The RSL was also exceeded by the results for one or more samples from these additional locations: SW-2 and SW-5.

Manganese was detected in 12 of 12 surface water samples, at a maximum concentration of 949 $\mu\text{g/L}$ in the sample collected from SW-1 in August 2005. The tap water RSL is 43 $\mu\text{g/L}$. The RSL was also exceeded by the results for one or more samples from these additional locations: SWs 2, 5, 16, and 22, and Reservoir. Manganese was detected in a sample from SW-3, representing Potomac River water, at a concentration of 18.7 $\mu\text{g/L}$.

Nickel was detected in 12 of 12 surface water samples, at a maximum concentration of 180 $\mu\text{g/L}$ in the sample collected from SW-1 in November 2009. The tap water RSL is 39 $\mu\text{g/L}$. This is the only location where the results exceeded the tap water RSL. Nickel was detected in a sample from SW-3, representing Potomac River water, at a concentration of 1 J $\mu\text{g/L}$.

Zirconium was detected in 1 of 12 surface water samples, at a maximum concentration of 2 J $\mu\text{g/L}$ in the sample collected from SW-2 in August 2005. The tap water RSL is 0.16 $\mu\text{g/L}$.

4.3.4 Other Chemicals (Including Perchlorate) Results

Table 4-24 lists the following five other chemicals (including perchlorate) detected in at least one surface water sample: bromide, chloride, iodate, iodide, and perchlorate.

Bromide was detected in 41 of 53 surface water samples, at a maximum concentration of 1,600 $\mu\text{g/L}$ in the sample collected from SW-1 in July 2006. There is no tap water RSL. It was detected in a sample from SW-3, representing Potomac River water, at a concentration of 80 J $\mu\text{g/L}$.

Chloride was detected in 52 of 52 surface water samples, at a maximum concentration of 1.1E06 $\mu\text{g/L}$ in a sample collected from SW-9 in November 2009. There is no tap water RSL. It was

detected in a sample from SW-3, representing Potomac River water, at a concentration of 50,000 µg/L.

Iodate was detected in 4 of 4 surface water samples, at a maximum concentration of 1,100 µg/L in the sample collected from Reservoir in August 2005. There is no tap water RSL.

Iodide was detected in 2 of 4 surface water samples, at a maximum concentration of 27 µg/L in the sample collected from SW-1 in August 2005. There is no tap water RSL.

Perchlorate was detected in 129 of 139 surface water samples, at a maximum concentration of 9.94 µg/L in the sample collected from SW-11 in July 2006. The tap water RSL is 1.4 µg/L and the DWHA is 15 µg/L. It was detected in a sample from SW-3, representing Potomac River water, at a concentration of 0.742 µg/L. Of the 27 detection locations shown in **Table 4-20**, the RSL was exceeded at 16 locations. The perchlorate DWHA was not exceeded in any sample except some samples from SW-24 and SW-25. However, perchlorate occurrence at SW-24 and SW-25 is unrelated to the SVFUDS because these locations are in the opposite direction from which impacted SVFUDS groundwater and surface water flows.

4.3.5 Tentatively Identified Compounds

No TICs were detected in any surface water EU1, surface water EU2, or background surface water samples.

4.3.6 Screening Level Ecological Risk Assessment

A SLERA was previously conducted that considered SVFUDS surface water chemistry (ERT, 2010). The SLERA concluded that ecological risks were negligible and that there was no need for additional ecological risk assessment or remediation on the basis of ecological risks.

4.4 GROUNDWATER CONCENTRATIONS TRENDS

This section discusses the evaluations of potential concentration variations by season (winter, spring, summer, and fall) and through time. The evaluations focused on arsenic and perchlorate because these are the chemicals of concern based on exceedances of the arsenic MCL and perchlorate DWHA.

4.4.1 Seasonality Trend Evaluation

The purpose of this evaluation was to assess whether or not chemical concentrations in groundwater are seasonally influenced. On a limited basis, the groundwater monitoring program was adjusted beginning in 2011 to collect samples from select monitoring points on a quarterly basis (i.e., winter, spring, summer, and fall).

The data were assessed for seasonality using the non-parametric Kruskal-Wallis Test for seasonality (Gilbert, 1987 and Helsel and Hirsch, 1995; cited in State of Idaho Department of Environmental Quality, 2014). This test answers the question: “Do the measurements taken in one quarter of the year differ significantly from the measurements taken in any other quarter of the year?”

Groundwater data were evaluated for the time period between 2011 and 2014. Potential perchlorate seasonality was evaluated for the locations where perchlorate concentrations have historically been elevated: Sibley Sump, MW-21, MW-22, MW-24, MW-25, and PZ-4D. Potential arsenic seasonality was evaluated for these locations, where arsenic concentrations have historically been elevated: MW-24 MW-25, and PZ-4D.

As summarized in **Table 4-25**, none of the arsenic or perchlorate results exhibited seasonality at the 97.5 percent confidence interval. The seasonality test results are presented in **Appendix P**.

4.4.2 Time Trend Evaluation

USEPA's ProUCL 5.0 statistical software was used to assess whether select arsenic and perchlorate data exhibited any of these trends: upward, downward, no trend. An upward trend indicates concentrations are increasing with time. A downward trend indicates concentrations are decreasing with time. No trend indicates that the data are neither increasing nor decreasing with time. Two statistical methods, Ordinary Least Squares (OLS) Linear Regression and Mann-Kendall, were used to evaluate arsenic and perchlorate concentration trends over time. The OLS method is a parametric linear regression analysis that is used for the purpose of prediction. It determines a linear relationship between a dependent response variable (in this case, the arsenic and perchlorate groundwater concentrations) and a predictor (i.e., sampling events from 2005 through 2014). The Mann-Kendall trend analysis was used to determine whether the upward or downward trend is significant or if there is insufficient evidence of a trend at this time.

Separate trend results were generated for monitoring well MP-2, which is screened and sampled at 8 different intervals, for each screen depth to determine whether arsenic and/or perchlorate persistence varied vertically within the bedrock at the borehole location. However, trends for each interval do not represent separate aquifer results. An additional MP-2 trend analysis, "MP-2-All," was conducted using all MP-2 groundwater data (i.e., not averaged according to year or vertical interval).

Also, detected and non-detected results were incorporated into the trend analysis. The reporting limit was used to represent non-detect results. If the reporting limit was greater than the maximum detection, then the non-detect data point was removed from the trend analysis to prevent biasing the trend results (USEPA, 2009b). The data assumptions used in the trend analysis are documented in **Appendix Q**.

Table 4-26 summarizes the trend evaluation results, which are also discussed below for perchlorate and arsenic. **Appendix Q** presents the trend analysis results.

Perchlorate

Downward trends for perchlorate are indicated for the following locations:

- Groundwater EU1: Sibley Sump and MW-21
- Groundwater EU2: MW-24, PZ-4S, MP-2 (intervals 1, 2, 6, 7, and 8), and MP-2 (all intervals)

- Groundwater EU3: not assessed because of historically very low perchlorate concentrations

No trends for perchlorate are indicated for the following locations:

- Groundwater EU1: none
- Groundwater EU2: MW-25, MW-45S, MW-45D, PZ-4D, and MP-2 (intervals 3, 4, and 5)
- Groundwater EU3: not assessed because of historically very low perchlorate concentrations

Upward trends for perchlorate are indicated for the following locations:

- Groundwater EU1: MW-22
- Groundwater EU2: MW-44
- Groundwater EU3: not assessed because of historically very low perchlorate concentrations

Arsenic

Downward trends for arsenic are indicated for the following locations:

- Groundwater EU1: not assessed because of historically very low arsenic concentrations
- Groundwater EU2: MP-2 (intervals 4 and 7) and MP2 (all intervals)
- Groundwater EU3: not assessed because of historically very low arsenic concentrations

No trends for arsenic are indicated for the following locations:

- Groundwater EU1: not assessed because of historically very low arsenic concentrations
- Groundwater EU2: MW-24, MW-25, MW-44, PZ-4S, and MP-2 (intervals 1, 2, 3, 5, 6, and 8)
- Groundwater EU3: not assessed because of historically very low arsenic concentrations

Upward trends for arsenic are indicated for the following locations:

- Groundwater EU1: not assessed because of historically very low arsenic concentrations
- Groundwater EU2: PZ-4D
- Groundwater EU3: not assessed because of historically very low arsenic concentrations

4.5 GROUNDWATER AND SURFACE WATER RELATIONSHIP

The site hydrogeology discussed in Section 4.1 indicates that shallow groundwater likely seeps into East Creek because the water table elevation is similar to the elevation of the East Creek stream bed. This interpretation of groundwater seepage into East Creek is supported by the historical perchlorate chemistry data, which shows elevated perchlorate in East Creek in the area of perchlorate-impacted shallow groundwater.

Specifically, the groundwater EU2 groundwater monitoring network confirmed perchlorate contamination in groundwater proximate to the Glenbrook Road Disposal Areas (historically ranging up to 124 $\mu\text{g/L}$ at MW-25) and the vicinity of Kreeger Hall at AU (historically ranging up to 146 $\mu\text{g/L}$ at PZ-4S). Contemporaneously, the East Creek monitoring network in this area (e.g., surface water locations SW-1, SW-11, SW- 21) confirmed perchlorate in East Creek at historical concentrations ranging up to 9.94 $\mu\text{g/L}$ at SW-11.

Shallow groundwater proximate to the Glenbrook Road Disposal Areas has also been impacted historically by arsenic ranging up to a concentration of 16.8 $\mu\text{g/L}$ at MW-24, 9.5 $\mu\text{g/L}$ at MW-25, and 8.4 $\mu\text{g/L}$ in the upper-most interval of MP-2 (deeper groundwater at MP-2 has higher arsenic concentrations). However, potential arsenic impacts on East Creek are not obvious. This does not undermine the interpretation that shallow groundwater is discharging into East Creek. Rather, the lower arsenic concentrations (compared to perchlorate) in shallow groundwater may be too low to have an obvious impact on East Creek.

There are no other locations in the SVFUDS where impacted shallow groundwater has effected obvious changes in surface water chemistry. However, this does not change the fact that shallow groundwater likely seeps into surface water at many other locations throughout the SVFUDS.

4.6 SOIL BORING PROGRAM CHEMISTRY

Sixteen soil borings were installed over an area of approximately 2 acres near AU's Kreeger Hall to assess perchlorate concentrations in soil and groundwater and the possibility of an undefined perchlorate source.

The locations of the 16 soil borings (**Figure 4-12**) were selected:

- To assess the area around PZ-4S and PZ-4D for a distance approximately equal to the distance to MWs 41 and 42, where negligible perchlorate was measured
- To assess known geophysical anomalies
- To avoid AU infrastructure

4.6.1 Sampling Program

The soil boring program was conducted in July 2011. Prior to drilling, each boring location was cleared to a depth of 10 ft bgs using an air knife, and the air knife hole was screened for unexploded ordnance using a magnetometer. Once the hole was cleared, drilling commenced from a depth of 10 ft bgs.

The borings were advanced with a 5³/₄-inch outside diameter HSA. Continuous split spoon samples were collected from a depth of 10 ft bgs to a predetermined depth corresponding to 15 feet below the 1918 ground surface elevation, determined from the cut/fill map of the area. Below this predetermined depth, split spoon samples were collected every 5 feet.

All split spoon samples were screened with a photoionization detector for the presence of volatile compounds, inspected for moisture, and logged. The geologist on site developed a geologic boring log using visual descriptions of the soils in the split spoon in accordance with the Unified Soil Classification System, ASTM D-2488. The drilling logs were prepared using USACE boring log forms and are presented in **Appendix B. Table 4-27** summarizes the boring depths and the soil sample depths selected for chemical analysis.

Borings were advanced to the first encountered groundwater (either the top of a perched zone or the water table) as determined by the geologist. The presence of water was evaluated by checking split spoons for saturated soil. In cases where saturation was not obvious and the borehole was judged to be sufficiently deep by the geologist to encounter the water table, drilling was stopped and the borehole was checked for the presence of water. The augers were pulled up 10 feet to allow water to enter the borehole. If sufficient water was found, a water sample was collected using a 2-inch-diameter disposable bailer. Groundwater samples were successfully collected in this manner from boring SA-1 through SA-3, SA-5 through SA-7, and SA-10 through SA-16. If there was insufficient water in the borehole for immediate sample collection, a temporary well was installed to allow time for slower recharge zones to facilitate sample collection.

Temporary wells were required in borings SA-4, SA-8, and SA-9. These wells were constructed of 2-inch-diameter polyvinyl chloride with 5 feet of 20-slot well screen and sufficient 2-inch-diameter riser pipe to reach above the ground surface. A sand pack consisting of #2 sand was extended to 1 foot above the top of the well screen. Water levels were measured after 24 hours to evaluate whether sufficient water was available for sample collection. Groundwater samples were successfully collected from all three temporary wells using a 2-inch-diameter disposable bailer.

4.6.2 Analytical Program

Soil and groundwater samples were analyzed for perchlorate by ALS Laboratory Group (ALS) in Salt Lake City, UT. Prior to shipping, the soil samples were analyzed for chemical agents [lewisite, HD mustard, and the mustard breakdown products 1,4-dithiane and oxathiane (1,4)] by the Edgewood Chemical Biological Center (ECBC). ECBC refers to oxathiane (1,4) by its synonym, which is thioxane (1,4). All ECBC results were non-detect for chemical agents (**Appendix R**), and the soil samples were subsequently shipped to ALS for perchlorate analysis. **Appendix R** presents the ALS soil and groundwater perchlorate analytical results.

4.6.2.1 Soil

After sample collection and clearance by ECBC testing to confirm that the samples did not contain chemical agents, the samples were shipped under chain of custody to ALS in Salt Lake City, UT, where they were analyzed for perchlorate.

Sixteen soil samples were analyzed for perchlorate (SA-1 through SA-16), in addition to two duplicate samples and two matrix spike and matrix spike duplicates, for a total of 20 soil samples. Duplicate samples were taken at SA-5 and SA-15, and matrix spikes / matrix spike duplicates were taken at SA-5 and SA-10.

4.6.2.2 Groundwater

All groundwater samples were filtered (0.2 micron for perchlorate and 0.45 for metals) during sampling. In addition to collecting water samples from the soil borings, samples were collected from existing nearby wells MW-41, MW-42, PZ-4S, and PZ-4D.

Twenty-three groundwater samples were analyzed for perchlorate (SA-1 through SA-16, an SA-5 duplicate, MW-41, MW-42, PZ-4S, and PZ-4D). After collection, the groundwater samples were shipped to ALS Laboratory Group in Salt Lake City, UT, where they were analyzed for perchlorate.

4.6.3 Analytical Results

The analytical results are discussed below for soil and groundwater. The laboratory limits for the SVFUDS analytical program and whether they meet or do not meet the project decision thresholds are further evaluated in the support calculations section of **Appendix T**. The results of the limits comparison are discussed in the Uncertainty Assessment Section 5.6.1.

As noted earlier in Section 4, any “J”-flagged results presented in this section are rounded to one significant figure because it is an estimated value (i.e., is below the lowest calibration standards of the analytical program).

4.6.3.1 Soil

Table 4-28 presents the soil perchlorate results in micrograms per kilogram ($\mu\text{g}/\text{kg}$), and **Figure 4-12** plots the results. All soil sampling results were non-detect except for three J-flagged results: SA-5 (2 J $\mu\text{g}/\text{kg}$), SA-13 (5 J $\mu\text{g}/\text{kg}$), and SA-15 Dup (2 J $\mu\text{g}/\text{kg}$). These three results are below the RSL (January 2015 version) for perchlorate in residential soil, which is 55,000 $\mu\text{g}/\text{kg}$. These soil perchlorate results do not indicate an obvious perchlorate source that could be responsible for the observed groundwater perchlorate contamination. The highest of the three detected soil perchlorate concentrations (5 J $\mu\text{g}/\text{kg}$ at SA-13) corresponds to the location (SA-13) where the groundwater perchlorate concentration (see Section 4.6.3.2) is less than 1 $\mu\text{g}/\text{L}$.

4.6.3.2 Groundwater

Table 4-29 presents the groundwater perchlorate results in $\mu\text{g}/\text{L}$, and **Figure 4-12** plots the results. Perchlorate was detected in all of the groundwater samples, at concentrations ranging from 1 J to 22 $\mu\text{g}/\text{L}$. All of the results are below the interim DWHA of 15 $\mu\text{g}/\text{L}$ with the

exception of SA-7 (22 µg/L), SA-15 (16 µg/L), and PZ-4S (18 µg/L). The groundwater perchlorate results suggest a possible area of slightly higher groundwater perchlorate concentrations near Kreeger Hall. The highest perchlorate concentrations historically observed in this area are 146 µg/L in PZ-4S (June 2007) and 45 µg/L in PZ-4D (November 2011). These historical groundwater samples were collected using low-flow sampling techniques rather than the grab sample method employed during the current study.

4.6.4 Discussion

The soil boring program did not identify a definitive perchlorate source that would justify further investigations or actions. Soil perchlorate concentrations were almost entirely non-detect, with the exception of three soil samples that showed trace perchlorate concentrations below the analytical reporting limit and that are J-flagged to indicate that the trace concentrations are estimated.

The measured groundwater perchlorate concentrations were lower than historically measured in nearby piezometers, but in three instances (SA-7, SA-15, and PZ-4S) the concentrations exceed the perchlorate DWHA value of 15 µg/L. The spatial variability of the groundwater perchlorate concentrations measured during this investigation indicate that the groundwater perchlorate contamination is generally focused at the vicinity of the Kreeger Hall and diminishes outward from this location, indicating bounding of the impacted area. Although the source of the groundwater perchlorate contamination on AU near Kreeger Hall is not known precisely, it could relate to various soil and debris removal activities conducted at AU during the 2003 to 2010 timeframe. These include:

- Final Post Removal Action Report, Time Critical Removal Action – Child Development Center, Spring Valley, Washington, DC, dated 9 June 2003.
- Final Site-Specific Removal Report, Small Disposal Area, SVFUDS, Washington, DC, dated 30 September 2004.
- Final Site-Specific Anomaly Investigation Report, American University Lot 18, SVFUDS, Washington, DC, dated 29 August 2008.
- Final Post Removal Action Report, Time Critical Removal Action (TCRA), American University (AU) Athletic Fields and Other Critical Lots, SVFUDS, Washington, DC, dated 22 February 2010.
- Draft-Final Site-Specific Investigation Report, American University Public Safety Building (Phase 1 and Phase 2 Investigations), SVFUDS, Washington, DC, dated 23 December 2010.

4.7 STABLE OXYGEN AND CHLORINE ISOTOPE ANALYSIS

The groundwater monitoring discussed in Section 4.2.5 has confirmed two areas within the SVFUDS where groundwater is contaminated with perchlorate:

- Area 1: Vicinity of AU's Kreeger Hall and Glenbrook Road Disposal Areas

- Area 2: Vicinity of SMH

The nature of the perchlorate at these two locations was investigated by conducting stable oxygen and chlorine isotopes analysis of groundwater samples from PZ-4D (representative of Area 1) and Sibley Sump (representative of Area 2). These analyses were conducted in 2012 by the Environmental Isotope Geochemistry Laboratory associated with the Department of Earth and Environmental Sciences, University of Illinois at Chicago, Chicago, IL. **Appendix S** presents the stable oxygen and chlorine isotope analytic report.

The isotopic signature of perchlorate varies depending on the origin of the perchlorate. For example, manmade synthetic perchlorate is distinguishable from natural perchlorate sources such as mineral deposits located in Chile’s Atacama Desert, the southwestern United States’ southern high plains region, and the United States’ Death Valley. Therefore, the isotopic signature of perchlorate from the above two SVFUDS areas was measured to determine the origin of the perchlorate at each area.

Large volumes of groundwater samples were collected from PZ-4D and Sibley Sump, and the perchlorate was concentrated by passing the collected groundwater over a perchlorate adsorbing resin. A duplicate was collected from the Sibley Sump. The resin was then processed in the laboratory to extract the perchlorate from the resin and analyze the extract for three stable oxygen isotopes (¹⁶O, ¹⁷O, and ¹⁸O) and two stable chlorine isotopes (³⁵Cl and ³⁷Cl). The following ratios were then calculated for each sample: ¹⁸O/¹⁶O and ³⁷Cl/³⁵Cl. These sample ratios are also referred to as: ¹⁸O/¹⁶O_{sample} and ³⁷Cl/³⁵Cl_{sample}.

Additional ratios were then calculated for each element as follows:

$$\begin{aligned} \text{Oxygen: } \delta^{18}\text{O} &= [({}^{18}\text{O}/{}^{16}\text{O})_{\text{sample}} / ({}^{18}\text{O}/{}^{16}\text{O})_{\text{VSMOW}} - 1] \\ \text{Oxygen: } \delta^{17}\text{O} &= [({}^{17}\text{O}/{}^{16}\text{O})_{\text{sample}} / ({}^{17}\text{O}/{}^{16}\text{O})_{\text{VSMOW}} - 1] \\ \text{Chlorine: } \delta^{37}\text{Cl} &= [({}^{37}\text{Cl}/{}^{35}\text{Cl})_{\text{sample}} / ({}^{37}\text{Cl}/{}^{35}\text{Cl})_{\text{SMOC}} - 1] \end{aligned}$$

In the above, VSMOW is the standard ¹⁸O/¹⁶O ratio, referred to as Vienna Standard Mean Ocean Water. SMOC is the standard ³⁷Cl/³⁵Cl ratio, referred to as Standard Mean Ocean Chloride. The symbol “δ” is the lower case version of the fourth letter in the Greek alphabet (delta) and in the above equations signifies “difference.” The symbol “Δ” used below” is the upper case version of the same Greek letter and in the equation below also signifies “difference.”

A final ratio used in the analysis was:

$$\Delta^{17}\text{O} = [(1 + \delta^{17}\text{O}) / (1 + \delta^{18}\text{O})^{0.525}] - 1$$

Figure 4-13 is a scatter plot of δ³⁷Cl versus δ¹⁸O results for the PZ-4D and Sibley Sump samples and numerous other samples unrelated to the SVFUDS. The Sibley Sump and PZ-4D results plot very closely to the clustered results for other samples from Chile’s Atacama Desert. This indicates with high probability that the origin of the perchlorate at Sibley Sump and PZ-4D is imported material (nitrates) from Chile. **Figure 4-14** is a scatter plot of Δ¹⁷O versus δ¹⁸O for the same samples. It also indicates that the perchlorate in groundwater at Sibley Sump and PZ-4D was imported from Chile. These Sibley Sump and PZ-4D perchlorate isotopic signature results

indicate that perchlorate in groundwater at Areas 1 and 2 originated in Chile and was imported into the United States.

AUES activities likely involved using nitrates (which contained perchlorate) imported from Chile. Civil War and historical farming activities known to have occurred near SMH may also have involved using nitrates (which contained perchlorate) imported from Chile, as fertilizer during farming and as a component of the Civil War-era gunpowder. Thus, although the isotopic analysis confirms that perchlorate in groundwater at Areas 1 and 2 originated in Chile, the perchlorate in groundwater at Area 1 may be unrelated to historical activities at Area 2, and vice versa.

At the time the stable oxygen and chlorine isotope findings became available, MP-5 had not yet been installed. In light of the isotopic similarity of the perchlorate in groundwater at Areas 1 and 2, it was hypothesized that perchlorate-contaminated groundwater from Area 1 could have migrated to Area 2, along a pathway undetected between monitoring wells MP-3 and MP-4, where essentially no groundwater perchlorate has been detected. To test this hypothesis, another deep bedrock multiport well (MP-5) was installed roughly midway between MP-3 and MP-4.

As discussed in Section 4.2, no perchlorate has been detected in any water sample from any of the five MP-5 sampling intervals. This finding reduces the possibility that a groundwater perchlorate plume has migrated from Area 1 to Area 2, and reduces the possibility that historical AUES activities at Area 1 are the cause of the groundwater perchlorate at Area 2.

4.8 ENVIRONMENTAL FATE AND TRANSPORT

The two primary aqueous contaminants at the SVFUDS are arsenic and perchlorate.

4.8.1 Arsenic

Arsenic cannot be destroyed in the environment; it can only change its form or become attached to or separated from particles. It may change its form by reacting with oxygen or other molecules present in air, water, or soil, or by the metabolic action of plants or animals.

Arsenic readily changes valence states and reacts to form species with varying toxicity and mobility. The most common forms of arsenic in groundwater are their oxy-anions, arsenite (As^{+3}) and arsenate (As^{+5}). Under moderately reducing conditions, arsenite is the predominant species. In oxygenated water, arsenate is the predominant species. Both anions are capable of adsorbing to various subsurface materials such as ferric oxides and clay particles, which would impede movement in groundwater. Ferric oxides are particularly important to arsenate fate and transport, as ferric oxides are abundant in the subsurface and arsenate strongly adsorbs to these surfaces in acidic to neutral waters. An increase in the pH to an alkaline condition will cause both arsenite and arsenate to desorb, increasing mobility with moving groundwater in an alkaline environment. The arsenic oxy-anions are also sensitive to redox conditions, and the speciation differential between them will change with changing redox (Henkel and Polette, 1999).

The SVFUDS groundwater monitoring data suggest that the mobility of arsenic in groundwater at the SVFUDS is not sufficient to have caused widespread elevated arsenic concentrations in

groundwater. Elevated arsenic concentrations in groundwater are localized to the area of the Glenbrook Road Disposal Areas where elevated arsenic in groundwater was confirmed by the monitoring results for MW-24, MW-25, and MP-2. At this location, elevated arsenic occurs in both shallow groundwater and in deep groundwater up to 200 ft bgs in fractured bedrock.

Groundwater arsenic concentrations in this area have decreased during the time period of the SVFUDS RI, based on the trend analysis results (**Table 4-27**) for several MP-2 intervals. The implication is that the arsenic source has become depleted or removed. Ongoing SVFUDS remedial activities (Glenbrook Road Disposal Areas) and completed SVFUDS removal activities (Glenbrook Road Disposal Areas and Lot 18 Debris Area) removed arsenic contaminated soil and items and is likely responsible for the decreasing groundwater arsenic concentrations.

4.8.2 Perchlorate

Perchlorate is a naturally occurring and manmade anion commonly associated with the solid salts of ammonium, potassium, and sodium perchlorate. Perchlorate is composed of an oxygen tetrahedron with a chlorine atom at its center. The chlorine atom has an oxidation state of +7, which makes the molecule a strong oxidizing agent. Despite its strength as an oxidizing agent, perchlorate has a high kinetic barrier that makes it slow to react under normal environmental conditions. Perchlorate reduction is extremely slow as a result of the four oxygen atoms surrounding the chlorine atom that prevent potential reactants from accessing the chlorine (Roote, 2001). In addition to its resistance to reduction, perchlorate has a relatively low charge density. Consequently, it does not generally form complexes with metals the way other anions do (Urbansky, 2002). Perchlorate sorbs poorly to mineral surfaces and organic material (Logan, 2001).

Its general lack of reactivity, low adsorption, and the high solubility of its salts in water cause perchlorate to be very mobile in the subsurface. Although it is, to some extent, biodegradable in nature, attenuation by biodegradation tends to be overcome by its high mobility; therefore, perchlorate can migrate significant distances.

Perchlorate can persist in the environment for many decades under typical groundwater and surface water conditions because of its resistance to react with other available constituents. Although perchlorate is thermodynamically a strong oxidizing agent, it is a kinetically sluggish species, such that its reduction is generally very slow, rendering common reductants ineffective (Roote, 2001).

The SVFUDS groundwater monitoring data support the interpretation that perchlorate is mobile and persistent. Very low perchlorate concentrations near the analytical detection limit are frequently detected within the SVFUDS and at all background surface water and groundwater locations.

However, the relatively high perchlorate concentrations exceeding the perchlorate interim drinking water health advisory are limited to 1) the immediate vicinity of AU's Kreeger Hall and Glenbrook Road Disposal Areas, and 2) the immediate vicinity of SMH. There is some evidence of perchlorate mobility at both of these two locations.

In the vicinity of AU's Kreeger Hall and Glenbrook Road Disposal Areas, shallow groundwater is impacted with perchlorate at a historical maximum perchlorate concentration of 124 µg/L in MW-25 in July 2006. Its presence in the adjacent East Creek at a maximum concentration of 9.94 µg/L, also from July 2006, is evidence of its mobility. Elevated perchlorate concentrations on the order of a few µg/L persisted in East Creek over a distance of several thousand feet. Also proximate to MW-25, MP-2 confirmed that perchlorate concentrations above 20 µg/L had migrated into deep bedrock to the deepest measured depth interval of 145 to 160 ft bgs in fractured bedrock.

In the vicinity of SMH, elevated perchlorate is confirmed in shallow groundwater over the approximately 4-acre area encompassing three monitoring locations: Sibley Sump, MW-21, and MW-22. Historically (prior to 2007), there was evidence that the perchlorate had migrated in groundwater about 1,000 feet farther westward to the vicinity of the sample location at the hydroelectric vault.

Despite the fact that perchlorate tends to be persistent, monitoring data clearly indicate that the concentrations of perchlorate in SVFUDS groundwater and surface water are decreasing at various locations (see the discussion in Section 4.4.2). This trend implies that the perchlorate source has become depleted or removed. Ongoing SVFUDS remedial activities (Glenbrook Road Disposal Areas) and completed SVFUDS removal activities (Glenbrook Road Disposal Areas and Lot 18 Debris Area) have likely removed perchlorate sources, which may account for the decreasing groundwater perchlorate concentrations in this area and East Creek. Also, depletion of perchlorate sources could relate to various soil and debris removal activities conducted at AU during the 2003 to 2010 timeframe, discussed in Section 6.1.1.

SECTION FIVE: BASELINE HUMAN HEALTH RISK ASSESSMENT

An HHRA was performed in accordance with USEPA's *Risk Assessment Guidance for Superfund* (RAGS) (USEPA, 1989 and subsequent RAGS guidance, including USEPA, 1991; USEPA, 1992a; USEPA, 2001; USEPA, 2004; and USEPA, 2009a). A risk assessment can be a qualitative or quantitative process that characterizes site conditions and determines applicable risk to human health and the environment, based on potential exposure scenarios.

The HHRA results are presented in accordance with RAGS Volume 1, Part D, the standard planning table format (USEPA, 2001). This HHRA is organized into the following five steps within the risk assessment process:

- Data Collection and Evaluation (Section 5.1)
- Identification of Chemicals of Potential Concern (COPCs) (Section 5.2)
- Exposure Assessment (Section 5.3)
- Toxicity Assessment (Section 5.4)
- Risk Characterization (Section 5.5)

In addition, an uncertainty assessment (Section 5.6) is included to address key uncertainties identified during the HHRA process so that a level of confidence in the risk estimates can be considered when risk management decisions are made. The HHRA conclusions are summarized in Section 5.7. **Appendix T** provides the risk calculations in USEPA RAGS Part D format along with modeling output and supporting calculation tables.

5.1 DATA COLLECTION AND EVALUATION

Groundwater and surface water media were evaluated in the HHRA for both current and future site conditions. The soil HHRA was conducted and reported separately (USACE, 2015). The HHRA groundwater and surface water data derive from analysis of samples collected from the monitoring network discussed in Sections 3.2 and 3.3, respectively, for groundwater and surface water.

5.2 IDENTIFICATION OF CHEMICALS OF POTENTIAL CONCERN

The groundwater and surface water COPC results are discussed below.

5.2.1 Groundwater Chemicals of Potential Concern

The groundwater monitoring results were screened to identify groundwater COPCs. In preparation for screening, the groundwater monitoring locations were grouped into different groundwater EUs. The purpose was to ensure that HHRA exposure point concentrations were not biased low by mixing the data for locations with high groundwater chemical concentrations with the data for locations with low groundwater chemical concentrations (i.e., avoid numerical dilution).

Groundwater EU1 is represented by these groundwater monitoring locations proximate to SMH where high groundwater perchlorate concentrations have been confirmed: Sibley Sump and MW-21, MW-22, MW-46S, and MW-46D. **Groundwater EU2** is represented by these groundwater monitoring locations proximate to Kreeger Hall on AU and the adjacent Glenbrook Road/Rockwood Parkway area, where high groundwater perchlorate and/or arsenic concentrations have been confirmed: MP-2, MW-24, MW-25, MW-44, MW-45S, MW-45D, PZ-4S, and PZ-4D. **Groundwater EU3** is represented by all other groundwater monitoring locations where lower chemical concentrations occur and which are not grouped into groundwater EUs 1 or 2.

Groundwater screening and identification of COPCs were conducted for each groundwater EU following the process shown in **Figure 5-1**, resulting in three sets of COPCs. The screening steps were as follows:

- Available USEPA RSLs for tap water and corresponding to a THQ of 0.1 and target TCR of 1E-06 were identified for each detected chemical. Because the RSLs do not address the vapor intrusion pathway, the following values specific to the vapor intrusion pathway were also used as screening values: 1) USEPA Vapor Intrusion Screening Levels (VISLs; USEPA, 2014a), and 2) District of Columbia Risk-Based Corrective Action (DCRBCA) groundwater screening values for indoor inhalation (DDOE, 2011). Thus, the screening values are effectively the lowest of the RSL, VISL, and DCRBCA values.
- If a screening value was not available for a detected chemical, the chemical was not selected as a COPC; however, Section 5.6 discusses the following for each chemical lacking a screening value:
 - Essential nutrient status
 - A comparison of the detected concentrations to the background concentrations measured in MW-28, MW-29, and MW-30
- All detected chemical concentrations, excluding R-flagged (rejected) results, were compared to the screening values, and chemicals with maximum concentrations greater than the screening values were identified as tentative COPCs. At this stage of the screening process, B-flagged (blank contamination) results were included in the screening so that the effect of subsequent exclusion of the B-flagged results would be obvious.
- If all concentrations responsible for exceedance of a screening value were less than the maximum detected concentration in any background well (MW-28, MW-29, or MW-30), then the chemical was eliminated as a tentative COPC (this occurred only for manganese in groundwater EU1 and cadmium in groundwater EU3, as discussed in subsequent sections).

- Tentative COPCs were further evaluated by evaluating B-flagged results. If all of the screening value exceedances for a chemical were B-flagged, indicative of the concentration not being site-related, then the chemical was eliminated as a COPC.
- Finally, other factors were considered for each of the remaining tentative COPCs prior to identifying the final COPCs:
 - Detection frequencies
 - Whether the RSL is based on provisional toxicity data (this only applies to zirconium)
 - Persistence across multiple sampling events
- The final COPCs were identified for each groundwater EU.

It should be noted that risk-based corrective action programs tend to use background data as the first screening step before proceeding with risk-based screening criteria. However, these steps were reversed for the SVFUDS; the reversed order did not change the COPCs carried forward into the HHRA. The background screening was incorporated into the COPC selection process late due to gaining Partnership approval of background sample locations and developing a background data set. Following the preceding screening process, the groundwater COPCs for groundwater EUs 1 through 3 are summarized below.

5.2.1.1 Groundwater EU1 Chemicals of Potential Concern

The groundwater EU1 COPCs are listed below and the detailed screening results are presented in the RAGS Part D Table 2.1 in **Appendix T**. The number in parentheses after each chemical is the maximum concentration ever detected within the groundwater EU since monitoring began in 2005:

- Arsenic (5 µg/L)
- Cobalt (2.1 J µg/L)
- Perchlorate (48 µg/L)

Two other chemicals (manganese and zirconium) exceeded their screening levels; however, neither was selected as a COPC.

Manganese was not selected as a COPC because the only concentration (59.5 µg/L at MW-22) exceeding the RSL (43 µg/L) was less than the maximum detected background concentration (553 µg/L in MW-29). A two-sample hypothesis test was conducted where the EU1 groundwater data for manganese was compared with the background manganese groundwater data from monitoring wells MW-28, MW-29, and MW-30. Test results (support calculations section of **Appendix T**) indicate that the manganese groundwater results are not significantly different from the manganese results from the background wells.

Zirconium was not selected as a COPC because the only concentration (3.2 µg/L at MW-21) greater than the RSL (0.16 µg/L) was B-flagged.

5.2.1.2 Groundwater EU2 Chemicals of Potential Concern

The groundwater EU2 COPCs are listed below, and the detailed screening results are presented in the RAGS Part D Table 2.2 in **Appendix T**. The number in parentheses after each chemical is the maximum concentration ever detected within the groundwater EU since monitoring began in 2005:

- Arsenic (18 µg/L)
- Cobalt (2 J µg/L)
- Manganese (946 µg/L)
- Perchlorate (146 µg/L)

Zirconium was not selected as a COPC because the only concentration (3.2 µg/L at MW-25) greater than the RSL (0.16 µg/L) was B-flagged.

Two other chemicals (bis(2-ethylhexyl)phthalate and chloroform) exceeded their screening levels; however, neither was selected as a COPC based on the following other considerations:

- Bis(2-ethylhexyl)phthalate: The bis(2-ethylhexyl)phthalate concentration (6 J µg/L) exceeded the RSL (5.6 µg/L) at only one location (MW-25 sampled on December 22, 2005). MW-25 was subsequently sampled on June 13, 2007, and the bis(2-ethylhexyl)phthalate concentration (1 J µg/L) was less than the screening value. MW-25 was again sampled on November 3, 2009, and bis(2-ethylhexyl)phthalate was not detected in either the primary or duplicate samples. MW-25 was sampled three times for bis(2-ethylhexyl)phthalate analysis. This information supports excluding bis(2-ethylhexyl)phthalate as a final COPC.
- Chloroform: The single detection of chloroform (15 µg/L) in MW-25 was associated with the December 22, 2005 sampling event. During a subsequent sampling event, on June 13, 2007, chloroform was not detected. During another subsequent sampling event, on November 3, 2009, chloroform was not detected in the primary or duplicate sample. Chloroform was never detected at a nearby monitoring location (MW-24). MW-25 was sampled three times for chloroform analysis. This information supports excluding chloroform as a final COPC.

5.2.1.3 Groundwater EU3 Chemicals of Potential Concern

The groundwater EU3 COPCs are listed below and the detailed screening results are presented in the RAGS Part D Table 2.3 in **Appendix T**. The number in parentheses after each chemical is the maximum concentration ever detected within the groundwater EU since monitoring began in 2005:

- Arsenic (7.3 µg/L)
- Cobalt (159 µg/L)
- Manganese (14,400 µg/L)
- Strontium (2,240 µg/L)
- Perchlorate (10.6 µg/L)

Four other chemicals (ethylbenzene, methylene chloride, tetrachloroethylene, and vanadium) exceeded their screening levels; however, none were selected as COPCs based on the following considerations (e.g., B-flag data qualifiers and/or low frequency of detection):

- **Ethylbenzene:** Ethylbenzene was detected in one of 32 samples, indicating a low frequency of detection. The excluded B-flagged concentration is 3.2 µg/L in sample MW-3 collected on July 6, 2006.
- **Methylene chloride:** Methylene chloride was detected in two of 32 samples, indicating a low frequency of detection. The excluded B-flagged concentrations were 7.5 µg/L in sample MW-3 collected on July 6, 2006, and 7.6 µg/L in sample MW-8 collected on July 13, 2006.
- **Tetrachloroethylene:** Tetrachloroethylene was detected in 11 of 32 samples at concentrations ranging from 5 µg/L in sample MW-31 collected on June 7, 2007, up to 14 µg/L in sample PZ-1S collected on June 12, 2007. All 11 detections were B-flagged. The detection locations were: MW-3, MW-5, MW-8, MW-10, MW-31, MW-32, MW-33, MW-36, MW-40, PZ-1S, and PZ-1D.
- **Vanadium:** Vanadium was detected in 21 of 41 samples at concentrations ranging from 1.2 µg/L in sample MW-23 collected on November 2, 2009, up to 9.9 µg/L in sample MW-32 collected on June 12, 2007. Twenty of the 21 detections were B-flagged. The detection locations were: MW-3, MW-5, MW-8, MW-10, MW-15, MW-23, MW-31, MW-32, MW-33, MW-35, MW-36, MW-37, MW-38, MW-39, MW-40, PZ-1S, and PZ-1D.

Seven other chemicals (barium, bis-2-ethylhexylphthalate, chromium, dibromochloromethane, mercury, thallium, and zirconium) exceeded their screening levels; however, none were selected as COPCs based on the following other considerations:

- **Barium:** Barium was detected in 41 of 41 samples at concentrations ranging from 13.7 to 452 µg/L. The barium concentration (452 µg/L) exceeded the RSL (380 µg/L) at only one location (MW-38 sampled on June 14, 2007). MW-38 was subsequently sampled on November 3, 2009, and the measured barium concentration (357 µg/L) was less than the screening value. MW-38 was sampled two times for barium analysis. This information supports excluding barium as a final COPC.
- **Bis(2-ethylhexyl)phthalate:** bis(2-ethylhexyl)phthalate was detected in 14 of 31 samples with concentrations ranging from 1.2 to 8.3 µg/L. The bis(2-ethylhexyl)phthalate concentration (8 J K µg/L) exceeded the RSL (5.6 µg/L) at only one location (MW-3 sampled on December 22, 2005). The validation flag “K” indicates a probable biased high result. MW-3 was also sampled on July 6, 2006, and October 28, 2009, and analyzed for bis(2-ethylhexyl)phthalate. In both instances, bis(2-ethylhexyl)phthalate was not detected. Bis(2-ethylhexyl)phthalate concentrations measured in the background monitoring wells ranged up to 5 J µg/L

(MW-29). MW-3 was sampled three times for bis(2-ethylhexyl)phthalate analysis. This information supports excluding bis(2-ethylhexyl)phthalate as a final COPC.

- **Chromium:** Chromium was detected in 12 of 41 samples at concentrations ranging from 0.34 to 7.8 µ/l. The Table 8 screening assumes the form of chromium is hexavalent chromium, which has an RSL of 0.035 µg/L. The form of chromium detected in the SVFUDS groundwater samples is potentially trivalent chromium, in which case the appropriate screening value is 2,200 µg/L. For information purposes, the chromium MCL is 100 µg/L. At five of the six locations (MWs 26, 27, 32, 36, 38, and 39) where chromium concentrations exceeded the 0.035 µg/L hexavalent chromium screening value, the chromium concentrations were less than the background chromium concentration of 3 J µg/L measured in the sample collected from MW-30 on December 28, 2005. Chromium was not detected in the most recent sample from MW-30 collected on November 3, 2009. The chromium concentration (8 J µg/L) exceeded both the screening value and the background concentration only in the sample collected from MW-32 on June 14, 2007. This information supports excluding chromium as a final COPC.
- **Dibromochloromethane:** Dibromochloromethane was detected in 1 of 32 samples indicating a low frequency of detection. The dibromochloromethane concentration (11 µg/L) exceeded the RSL (0.17 µg/L) at only one location (MW-33 sampled on June 12, 2007). Dibromochloromethane was not detected in a subsequent sample collected from this well on November 2, 2009. Throughout groundwater EU3, dibromochloromethane was detected only once out of 32 analyses. This information supports excluding dibromochloromethane as a final COPC.
- **Mercury:** Mercury was detected in 8 of 41 samples with concentrations ranging from 0.021 to 0.16 µg/L. The mercury concentration (0.16 µg/L) exceeded the RSL (0.063 µg/L) at only one location (MW-14 sampled on August 9, 2005) in duplicate sample MW-14 (FD-2). Mercury was not detected in the primary sample. Throughout groundwater EU3, mercury was detected only five times out of 41 analyses. MW-14 was sampled once for mercury. This information supports excluding mercury as a final COPC.
- **Thallium:** Thallium was detected in 5 of 41 samples with concentrations ranging from 0.13 to 0.65 µg/L. Measured thallium concentrations (0.4 J µg/L in the MW-8 sample and 0.6 J µg/L in the MW-19 sample) exceeded the thallium RSL (0.02 µg/L) at only two locations (MW-8 sampled on July 13, 2006, and MW-19 sampled on October 26, 2009). However, during other sampling events, no sample from either MW-8 or MW-19 tested positive for thallium. Specifically, thallium was not detected in samples collected from MW-8 during subsequent sampling events on June 7, 2007, and October 27, 2009. Thallium was not detected in the sample collected from MW-19 during the prior sampling event on August 4, 2005. This information supports excluding thallium as a final COPC.

- **Zirconium:** Zirconium was detected in 16 of 41 samples with concentrations ranging from 0.12 to 6.9 µg/L. Measured zirconium concentrations (0.8 J µg/L in the MW-3 sample and 1 J µg/L in the MW-8 sample) exceeded the zirconium RSL (0.16 µg/L; based on provisional toxicity data) at only two locations (MW-3 sampled on July 6, 2006, and MW-8 sampled on July 13, 2006). However, zirconium was not detected in the sample collected from MW-3 during a subsequent sampling event on October 28, 2009, and was not detected in a subsequent sample from MW-8 collected on October 27, 2007. This information supports excluding zirconium as a final COPC.

Two chemicals, cadmium and chloroform, exceeded their screening levels, but were eliminated as EU3 groundwater COPCs based on the observation that the maximum site concentration was less than the background concentration. This finding was further assessed by conducting a two-sample hypothesis test where the EU3 groundwater data for these analytes were compared with the background groundwater data set from monitoring wells MW-28, MW-29, and MW-30. The two-sample hypothesis testing results (support calculations section of **Appendix T**) for cadmium and chloroform are:

- **Cadmium:** EU3 groundwater cadmium results are not significantly different from the detected cadmium results in the background wells. Cadmium was detected at maximum concentration (1.7 J µg/L) in site well MW-38 and at 2.3 µg/L J in a background well.
- **Chloroform:** EU3 groundwater chloroform results are significantly different from the detected chloroform results in the background wells. Nonetheless, these additional chloroform observations supported the decision to not select chloroform as a COPC:
 - The single detected result (8 JB µg/L) is both J- and B-flagged, indicating that it is an estimated value and may be attributed to blank contamination, respectively.
 - The highest detected concentration of chloroform in the background data set is 11 µg/L.

5.2.2 Surface Water Chemicals of Potential Concern

The surface water monitoring results were screened to identify surface water COPCs. In preparation for screening, the surface water monitoring locations were grouped into different surface water EUs. The purpose was to avoid numerical dilution as described for groundwater in Section 5.2.1.

Surface water EU1 is represented by these surface water locations proximate to the Lot 18 Debris Area and Glenbrook Road Disposal Areas, where surface water is most likely impacted by groundwater seepage into East Creek: Lot 18 Drain, SW-1, SW-11, and SW-21. **Surface water EU2** is represented by all other SVFUDS surface water locations where lower chemical concentrations occur, with the exception of SW-24 and SW-25, which concern an unknown perchlorate source unrelated to the SVFUDS and are not included in any surface water EU. SW-

24 and SW-25 are not downgradient for the SVFUDS locations where perchlorate contamination is confirmed. SVFUDS activities did not occur upgradient of SW-24 and SW-25.

Surface water screening and the identification of COPCs was conducted for both surface water EUs following the process shown in **Figure 5-2**, resulting in two sets of surface water COPCs. No suitable surface water body was identified to derive a background data set for the SVFUDS surface water analysis. Therefore, a background comparison was not conducted as a first surface water screening step.

The screening process recognizes that there are no SVFUDS sources located in streams and directly leaching contaminants into surface water. Therefore, no direct contaminant transport from a SVFUDS source into surface water is occurring. However, historical SVFUDS activities have impacted groundwater, which may have then seeped into various unnamed tributaries and East Creek within the SVFUDS. Further, the screening process recognizes that none of the unnamed tributaries or East Creek are used for drinking water or for swimming; therefore, screening values based on drinking water ingestion or incidental ingestion during swimming were not considered. The screening values are based on an assumption of exposure by dermal contact. The dermal contact screening values are from the RSL dermal values for the residential scenario. These values are conservative (low) compared to recreational values that could potentially be estimated for the SVFUDS unnamed tributaries and East Creek and, therefore, result in identification of more surface water COPCs than might otherwise occur.

The **Figure 5-2** screening steps are:

- All chemicals (including B-flagged results) detected in surface water that were also groundwater COPCs were selected as tentative surface water COPCs.
- The maximum concentrations of the tentative COPCs were compared to water dermal pathway RSLs protective of a TCR of 1E-06 and a THQ of 0.1. Chemicals with maximum concentrations exceeding these screening values were retained as tentative surface water COPCs.
- Tentative surface water COPCs were then further evaluated for possible selection as final surface water COPCs by evaluating data qualifiers, such as B-flags, and then again comparing the remaining maximum detected concentrations in surface water to the water dermal pathway RSLs. Chemicals with maximum concentrations exceeding these screening values were selected as final surface water COPCs.

The screening results are presented separately below for surface water surface water EUs 1 and 2.

5.2.2.1 Surface Water EU1 Chemicals of Potential Concern

The surface water EU1 COPC is listed below, and the detailed screening results are presented in the RAGS Part D Table 2.4 in **Appendix T**. The number in parentheses is the maximum concentration ever detected within the surface water EU since monitoring began in 2005:

- Manganese (949 µg/L)

Four other chemicals (arsenic, cobalt, strontium, and perchlorate) were detected in at least one surface water EU1 sample and are also groundwater COPCs. However, their maximum detected surface water concentrations are less than their surface water screening levels; therefore, none of these four chemicals was selected as a surface water EU1 COPC. The maximum detected concentration of arsenic (3 J $\mu\text{g/L}$), cobalt (5 J $\mu\text{g/L}$), strontium (314 $\mu\text{g/L}$), and perchlorate (9.94 $\mu\text{g/L}$) were below their respective screening values of 9.3 $\mu\text{g/L}$, 340 $\mu\text{g/L}$, 270,000 $\mu\text{g/L}$, and 320 $\mu\text{g/L}$.

5.2.2.2 Surface Water EU2 Chemicals of Potential Concern

There are no surface water EU2 COPCs. The detailed screening results are presented in the RAGS Part D Table 2.5 in **Appendix T**.

Five chemicals (arsenic, cobalt, manganese, strontium, and perchlorate) were detected in at least one surface water EU2 sample and are also groundwater COPCs. However, their maximum detected surface water concentrations are less than their surface water screening levels; therefore, none of these four chemicals was selected as a surface water EU1 COPC. The maximum detected concentration of arsenic (2 J $\mu\text{g/L}$), cobalt (2 J $\mu\text{g/L}$), manganese (271 $\mu\text{g/L}$), strontium (367 $\mu\text{g/L}$), and perchlorate (3.14 $\mu\text{g/L}$) were below their respective screening values of 9.3 $\mu\text{g/L}$, 340 $\mu\text{g/L}$, 440 $\mu\text{g/L}$, 270,000 $\mu\text{g/L}$, and 320 $\mu\text{g/L}$.

5.2.3 Detected Chemicals With No Regional Screening Levels

This section addresses detected chemicals in groundwater or surface water that do not have readily available RSLs. Toxicity values are not available for these chemicals to derive screening values; these chemicals are qualitatively addressed in the HHRA uncertainty assessment (Section 5.6).

5.2.3.1 Groundwater

Table 5-1 lists 11 chemicals detected in groundwater that do not have RSLs. The detected concentrations of eight of these chemicals exceeded the concentrations detected in the background monitoring wells. **Table 5-2** identifies these eight chemicals and the locations where the detected concentrations exceeded background.

5.2.3.2 Surface Water

Table 5-3 lists six chemicals detected in surface water that do not have RSLs. **Table 5-4** identifies the locations where these eight chemicals were detected.

5.2.4 Chemicals of Potential Concern for the Human Health Risk Assessment

In summary, the screening evaluation identified the following COPCs for the HHRA:

- Groundwater at EU1: arsenic, cobalt, and perchlorate
- Groundwater at EU2: arsenic, cobalt, manganese, and perchlorate
- Groundwater at EU3: arsenic, cobalt, manganese, perchlorate, and strontium

- Surface water at EU1: manganese

No surface water COPCs were identified at EU2.

5.3 EXPOSURE ASSESSMENT

Exposure assessment is the qualitative or quantitative evaluation of the magnitude, frequency, duration, and route of exposure to COPCs at a site (USEPA, 1989 and 1992b). **Table 5-5** identifies the exposure scenarios and exposure pathways evaluated in the HHRA. **Figure 5-3** illustrates the human health conceptual site model used to gain the current understanding of the site's conditions with respect to known and suspected contaminant sources, potential transport mechanisms and migration pathways, and human receptors.

RAGS Part D Table 1 in **Appendix T** provides the rationale for selection or exclusion of onsite receptors and exposure pathways.

The original release mechanism for the COPCs identified in Section 5.2 was from materials leaching into groundwater, and subsequently surface water, from buried ordnance and chemical items discarded in the historical ordnance burial pits located at SV, and from historical ordnance testing that occurred during operation of the AUES. On-site human receptors may be exposed to contaminated groundwater and surface water through incidental contact and recreational activities.

The current use of the site as private residential and university property is not likely to change in the future. Although groundwater is not currently used onsite, current pathways for incidental exposure to groundwater COPCs are discussed in Section 5.2; for example, it is assumed that SV groundwater is used for watering lawns and gardens in the HHRA as potentially complete exposure pathways. Future potable use of groundwater is also assessed.

Impacted subsurface groundwater may seep into unnamed tributaries of East Creek. None of these tributaries are currently used for drinking, swimming, or fishing activities. However, residents and AU students may wade in these small streams or downstream in East Creek; as such, wading scenarios are addressed in the HHRA.

No volatile groundwater or surface water COPCs were identified during the selection process (Section 5.2); as such, inhalation of vapors in indoor air from vapor intrusion and showering scenarios are considered incomplete pathways and, thus, not addressed in this HHRA. However, dermal contact while bathing is still assessed for the potable-use-of-groundwater exposure scenarios. Exposure to soil contamination is addressed separately in the complementary soil investigation HHRA (USACE, 2015).

5.3.1 Potential Exposure Receptors

Table 5-5 summarizes the exposure scenarios and exposure pathways evaluated for the site. Potential onsite receptors/populations that could theoretically be exposed to groundwater and surface water COPCs were evaluated for this exposure assessment. No offsite receptors were evaluated in the HHRA.

The HHRA addresses two exposure scenario timeframes: current/future and future. The current/future scenarios represent current site conditions and the populations that are exposed to the media at SV. The “future” portion of this timeframe assumes that the exposure or use of SV groundwater and surface water will not change in the future. Hereafter, the current/future scenario will be referred to as the current scenario.

The future timeframe represents a change in the accessibility of groundwater at SV; these scenarios assume that a drinking water well is installed at the EU and the future receptors are using the groundwater for potable purposes (e.g., drinking water, bathing, cleaning, etc.) in accordance with DOEE and USEPA Region III recommendations.

The HHRA evaluates a reasonable maximum exposure (RME) and central tendency (CT) scenario for each receptor. The RME scenario refers to people who are at the high end of the exposure distribution (approximately the 95th percentile). The RME scenario is intended to assess exposures that are higher than average, but are still within a realistic range of exposure. The CT scenario refers to individuals who have average or typical intake of environmental media.

The **current adult and child resident** currently lives onsite in SV. Standard USEPA child and adult resident exposure parameters are used (e.g., 350 days/year for 26 years). Both the current and future child and adult resident are potentially exposed to groundwater if it is used to water lawns or run sprinklers. Groundwater exposure pathways include incidental ingestion and dermal contact. For surface water, the resident may go wading at East Creek or any of the tributaries. The surface water exposure pathway includes dermal contact with surface water; East Creek and its tributaries are too shallow for full immersion swimming.

The **future adult and child resident** are assumed to use groundwater as a future source of tap water. Currently, the city supplies water to the residences at the SVFUDS. If the future resident installs a potable well on his/her property, the potable groundwater pathways include ingestion of groundwater as a tap water source and dermal contact while showering or bathing. The risk-based screening results identified no volatile COPCs in the groundwater; therefore, inhalation of vapors while showering/bathing or inhalation of vapors in indoor air (i.e., vapor intrusion) is not addressed in this HHRA.

The **current AU student** is assumed to be a young adult who lives on campus year-round while pursuing a bachelor’s degree for 4 years. Currently, the city supplies drinking water to the university, so potable use of the groundwater is not a complete exposure pathway. Also, the AU student is not likely to be regularly watering lawns or gardens as part of his/her on-campus activities. The current and future AU student may come into dermal contact with surface water while recreationally wading in East Creek and its tributaries.

The **future AU student** is a student assumed to use the groundwater as a future source of tap water. Similar to the future resident, the potable use of groundwater exposure pathways include ingestion of groundwater as tap water and dermal contact while showering or bathing. The risk-based screening results identified no volatile COPCs in the groundwater; therefore, inhalation of

vapors while showering/bathing or inhalation of vapors in indoor air (i.e., vapor intrusion) is not addressed for the future AU student.

The **current indoor office worker** is assumed to spend 8 hours per day for 250 days per year working in a commercial or university building. No complete exposure pathways exist for the indoor office worker because no volatile COPCs were identified in the groundwater, and city-supplied water is used for tap water.

The **future indoor office worker** is an office worker assumed to use groundwater as a future tap water source. Groundwater pathways include ingestion of groundwater as tap water and dermal contact while showering or bathing. The risk-based screening results identified no volatile COPCs in the groundwater; therefore, inhalation of vapors while showering/bathing or inhalation of vapors in indoor air (i.e., vapor intrusion) is not addressed for the future indoor office worker. Surface water exposure is not evaluated; the office worker is not likely to recreationally wade in East Creek or its tributaries while working onsite.

The **current outdoor worker** is assumed to be a landscaper who maintains the grounds around the university or commercial/industrial buildings. Groundwater exposure pathways include incidental ingestion and dermal exposure while watering the lawns. Future use of groundwater as a tap water source is addressed under the future indoor office worker scenario. Surface water exposure is not likely for this receptor; extensive landscaping activities are not conducted along East Creek and its tributaries.

The **current construction/utility worker** is assumed to dig into the subsurface for land re-development construction projects or to access utility lines. This receptor is not likely to be exposed to groundwater during excavation activities given the depth below typical excavation zones at which SVFUDS groundwater generally occurs. Furthermore, construction/utility workers are not likely to be building near East Creek or within its flood zones, so surface water exposure is not evaluated for this receptor currently or in the future. As such, this receptor is not addressed in this HHRA.

5.3.2 Exposure Point Concentrations

Table 5-6 presents the summary statistics and exposure point concentrations (EPCs) for each COPC and EU for the RME and CT evaluations of the HHRA. RAGS Part D Tables 3.1.RME through 3.3.RME and 3.1.CT through 3.3.CT in **Appendix T** present the EPCs used in the HHRA.

Data from the 2 most recent years of sampling were used to calculate the arsenic and perchlorate EPCs within each EU (USEPA, 2009b and 2014c). By using the most recent 2 years' worth of data, the EPCs better represent the increasing (higher) or decreasing (lower) concentrations of arsenic and perchlorate that were noted in groundwater trend analysis results (see **Table 4-26**). In cases where no trend was noted, the range of concentrations in the earlier arsenic and perchlorate groundwater data are not likely to influence the EPC calculations; enough sample points are available for the most recent 2-year timeframe to derive a representative 95% upper confidence limit (UCL) of the mean concentration.

For the remaining groundwater COPCs (cobalt, manganese, and strontium) as well as manganese in surface water, all the available data were used to derive the EPCs, where possible. Relatively limited data sets are available for these COPCs because the SVFUDS Partners limited the scope of the analytical programs (i.e., existing data pre-dates 2010). An attempt was made to identify data sets with a sufficient number of detected observations per COPC so that meaningful statistics could be generated by ProUCL. Where this was not feasible, the maximum observed concentration was selected as the EPC.

Exceptions to the 2-year criterion were made where particular COPCs were not analyzed for extended periods of time. For instance, sampling at SVFUDS was not conducted during of 2008. Data used in the calculation of the EPCs span the following dates:

Exposure Unit	COPC(s)	Data range (month/year)
EU1	<i>Surface Water</i>	
	Manganese	8/05 – 11/09
	<i>Groundwater</i>	
	Cobalt	8/05 – 6/07
	Arsenic and perchlorate	4/13 – 9/14
EU2	<i>Groundwater</i>	
	Cobalt and manganese	12/05 – 11/09
	Arsenic and perchlorate	9/12 – 9/14
EU3	<i>Groundwater</i>	
	Cobalt, manganese, and strontium	6/07 – 11/09
	Arsenic and perchlorate	9/12 – 9/14

USEPA’s statistical software program, ProUCL 5.0, was used to analyze the data sets and calculate the UCLs of the mean for both dissolved surface water and groundwater COPCs. Prior to the UCL calculation, ProUCL 5.0 was used to conduct an outlier test with the surface water and groundwater data for each EU. Identified outliers were individually assessed for validity; the highest concentrations (outliers) were the result of dilutions to capture detections of multiple chemicals at the well. No data points were eliminated from the groundwater and surface water data sets. The outlier test results as well as the graphs used to analyze the data are provided in the support calculations section of **Appendix T**.

ProUCL Version 5.0 tests the distribution of the data sets (Singh et al., 2010) and computes a conservative and stable 95% UCL based on the appropriate distribution of the data. For those data sets that do not fit the normal, lognormal, or gamma distributions, several parametric and distribution-free non-parametric methods are available to calculate an appropriate 95% UCL (e.g., bootstrap methods). The ProUCL Version 5.0 program was run assuming left-censored

data (i.e., with non-detects). The ProUCL 5.0 inputs and outputs are provided in the support calculation tables (Tables S-4 through S-15) at the end of **Appendix T**.

Following USEPA (1989) guidance, the lower of the maximum detected concentration and the 95% UCL was selected as the EPC for the RME and CT scenarios.

5.3.3 Quantification of Exposure: Calculation of Daily Intakes

Exposure is defined as the contact rate (CR) of an organism with a chemical or physical agent. Intake is exposure normalized for time and body weight (BW) and is expressed in units of milligram (mg) constituent per kilogram (kg) body weight-day (USEPA, 1989). Where possible, the HHRA used USEPA's most current exposure parameters from the 2011 *Exposure Factors Handbook* (EPA, 2011) as well as the February 2014 Office of Solid Waste and Emergency Response (OSWER) Directive (USEPA, 2014b).

The measure of chronic exposure is the chronic daily intake (CDI). The CDI for each COPC is estimated by combining the EPC with exposure parameters, such as ingestion rate, frequency of contact, duration, and frequency of exposure. In addition, intake parameters are selected so the combination of intake variables results in an individual estimate of both the RME and CT for that pathway (USEPA, 1989).

The generic equation (USEPA, 1989) for calculating intake is:

Equation 1:

$$I = (C \times CR \times EFD) / (BW \times AT)$$

Where:

I = intake; the amount of constituent at the exchange boundary (mg/kg body weight-day)

Constituent-specific variable

C = constituent concentration; the representative concentration contacted over the exposure period (mg/L water)

Variables that describe the exposed population

CR = contact rate; the amount of contaminated medium contacted per unit time or event (liters per day [L/day water or mg/day soil])

EFD = exposure frequency and duration; describes how long and how often exposure occurs; often calculated using two terms (EF and ED):

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight; the average body weight (kg) over the exposure period

Assessment-determined variable

AT = averaging time; period over which exposure is averaged (days)

The HHRA generally focuses on potential impacts of long-term (chronic) exposure to contaminants present at the site, except for exposure scenarios, such as the AU student, when exposure is in the subchronic range (defined by USEPA to be 2 weeks to 7 years).

RAGS Part D Tables 4.1 through 4.3 in **Appendix T** document the CDI equations and the exposure parameters used to evaluate each complete exposure pathway for the current and future adult and child resident, AU student, indoor worker, and outdoor worker scenarios.

Chemical-specific data used in the dermally absorbed dose calculations (surface water and groundwater), such as the permeability coefficient, are provided in the support calculations section of **Appendix T**.

5.4 TOXICITY ASSESSMENT

RAGS Part D Tables 5.1 and 6.1 in **Appendix T** present the oral and dermal toxicity data used in the HHRA. RAGS Part D Table 5.1 presents the non-cancer chronic and subchronic oral/dermal toxicity values along with the target organ(s) associated with each value. RAGS Part D Table 6.1 presents the oral/dermal cancer toxicity data as well as the cancer guideline classifications for each COPC.

USEPA (2003) guidance recommends using the following hierarchy for selecting toxicity values:

Tier 1 – USEPA’s Integrated Risk Information System (IRIS) (USEPA, 2015b)

Tier 2 – USEPA’s Provisional Peer Reviewed Toxicity Values (PPRTVs) – The Office of Research and Development/National Center for Environmental Assessment/Superfund Health Risk Technical Support Center develops PPRTVs on a chemical-specific basis.

Tier 3 – Other Toxicity Values – Tier 3 includes additional USEPA and non-USEPA sources of toxicity information. Priority should be given to those sources of information that are the most current, the basis for which is transparent and publicly available, and which have been peer reviewed. Some examples of Tier 3 sources include the following:

- The California Environmental Protection Agency (Cal EPA) toxicity values are peer reviewed and address both cancer and non-cancer effects (Cal EPA, 2015). Cal EPA toxicity values are available on the Cal EPA website at <http://www.oehha.org/risk/ChemicalDB/index.asp>.
- The Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs) are estimates of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. The ATSDR MRLs are peer reviewed and are available at <http://www.atsdr.cdc.gov/mrls/index.asp> on the ATSDR website (ATSDR, 2014).
- Health Effects Assessment Summary Tables (HEAST), dated July 1997 (USEPA, 1997).

Dermal toxicity values are not available in IRIS or other USEPA sources. The most recent USEPA dermal guidance was followed (USEPA, 2004) for evaluating risk/hazard from dermal routes of exposure. This guidance recommends adjusting oral toxicity values using gastrointestinal absorption factors to evaluate dermal exposure routes for some constituents. The oral-to-dermal adjustment is not required for all constituents. The equations used for deriving dermal toxicity values are provided in the RAGS Part D Tables 5.1 and 6.1 in **Appendix T**.

5.4.1 Noncarcinogenic Health Effects

Evaluation of noncarcinogenic effects is based on the assumption that noncarcinogenic toxicological effects of chemicals occur only after a threshold dose is achieved. The reference dose (RfD) is used to evaluate ingestion and dermal exposure pathways. USEPA defines a chronic RfD as an estimate of a daily exposure level for the human population that is unlikely to result in deleterious effects during a lifetime (i.e., 70 years). A chronic RfD is used to evaluate the potential non-carcinogenic hazards associated with long-term chemical exposures.

Subchronic RfDs have been developed for a few chemicals to characterize potential non-carcinogenic hazards associated with shorter-term chemical exposures. USEPA defines subchronic exposure as periods ranging from 2 weeks to 7 years (USEPA, 1989). Cobalt is the only COPC with an available subchronic RfD, which was used in the AU student non-cancer hazard calculations. Chronic RfDs were used for the remaining COPCs because no other subchronic values were available.

5.4.2 Carcinogenic Health Effects

USEPA requires that potential carcinogens be evaluated as if minimum threshold doses do not exist (USEPA, 1989). USEPA has established a weight-of-evidence approach to evaluating whether a particular chemical is a carcinogen (USEPA, 1986). This weight-of-evidence classification is:

- Group A chemicals are known carcinogens for which there is sufficient evidence to support a causal association between exposure to the agents in humans and cancer.
- Group B1 chemicals are probable human carcinogens for which there is limited evidence of carcinogenicity in humans.
- Group B2 chemicals are probable human carcinogens for which there is sufficient evidence of carcinogenicity in animals but inadequate or no human data.
- Group C chemicals are possible human carcinogens for which there is limited evidence of carcinogenicity in animals and inadequate or no human data.
- Group D chemicals are not classifiable as to human carcinogenicity as there is inadequate human and animal evidence of carcinogenicity or no data are available.
- Group E chemicals show evidence of noncarcinogenicity in humans as there is no evidence of carcinogenicity from either human or animal studies.

USEPA published new guidelines for carcinogenic risk assessment in 2005 (USEPA, 2005). The 2005 guidelines recognize the growing sophistication of research methods; therefore, USEPA is revising the weight-of-evidence classification system. Weighing of the evidence includes addressing not only the likelihood of human carcinogenic effects of the agent but also the conditions under which such effects may be expressed, to the extent that these are revealed in the toxicological and other biologically important features of the agent. There are five recommended standard hazard descriptors under the new guidance:

- “Carcinogenic to Humans”
- “Likely to Be Carcinogenic to Humans”
- “Suggestive Evidence of Carcinogenic Potential”
- “Inadequate Information to Assess Carcinogenic Potential”
- “Not Likely to Be Carcinogenic to Humans”

USEPA is currently re-examining the carcinogenic classification for numerous chemicals; where available, the new classification is provided in RAGS Part D Table 6.1 in **Appendix T** for the COPCs evaluated in this HHRA.

The cancer slope factor (CSF) is used to estimate the incremental risk from exposure to a carcinogenic COPC. CSFs are developed based on a dose response curve for carcinogenicity of the specific chemical. In estimating risks posed by potential carcinogens, USEPA generally assumes that any exposure level is associated with a finite probability, however minute, of producing a carcinogenic response. This mechanism for carcinogenicity is referred to as “non-threshold” because there is theoretically no level of exposure for such a substance that does not pose a small, though finite, probability of producing a carcinogenic response.

The CSF, expressed in units of $(\text{mg}/\text{kg}\text{-day})^{-1}$, is used to convert the CDI of a chemical from ingestion and dermal exposures, normalized over a lifetime, directly to a cancer risk. Arsenic is the only groundwater COPC with an available oral/dermal CSF and is classified as a “Class A” carcinogen. Also, cobalt is identified as a “Likely to Be Carcinogenic to Humans” carcinogen, but does not have an oral/dermal CSF.

5.5 RISK CHARACTERIZATION

RAGS Part D Table 7s for surface water and groundwater in **Appendix T** provide the non-cancer hazards and cancer risks for each receptor. RAGS Part D Table 9s for surface water and groundwater in **Appendix T** summarize the receptor risks and hazards associated with each COPC. A table of contents is provided in **Appendix T** to direct the reader to each EU’s results. No USEPA RAGS Part D Table 8s (USEPA, 2001) were required for this HHRA; USEPA’s standard Table 8s are used to address radionuclides, which were not identified as COPCs at the SVFUDS.

5.5.1 Target Cancer Risk and Non-Cancer Thresholds

The site remediation goal set forth in the NCP allows a cumulative cancer risk of 1×10^{-4} (one in 10,000) to 1×10^{-6} (one in one million). In effect, estimated risks that are less than 1×10^{-6} are generally considered negligible. Risks that are greater than 1×10^{-4} are usually considered sufficient justification for undertaking remedial action. Risks in the intermediate range between these two values can be considered acceptable on a case-by-case basis. The SVFUDS project is using the cancer risk of 1×10^{-6} as the risk goal for individual carcinogens, with a not-to-exceed EU risk of 1×10^{-4} for all carcinogens.

For non-cancer hazards, potential adverse health effects cannot be ruled out if the target hazard index (HI) is greater than 1. If the HI exceeds 1, chemicals may be segregated based on the target organ, and separate hazard indices may be calculated. Only chemicals that act upon the same target organ would actually be expected to be additive. The SVFUDS project is using the non-cancer HI of 1 as a cumulative and target organ-specific threshold.

COPCs that contribute to the cancer risk and/or non-cancer hazard estimates that are above the target cumulative thresholds are identified as chemicals of concern in the HHRA.

5.5.2 Carcinogenic Risks

The CSF converts estimated daily intakes to an estimate of incremental cancer risk. As noted earlier, the CSFs are generally upper bound estimates. This means “true risk” probably does not exceed the risk estimate generated using the CSFs and is likely to be less than the risk predicted using this method. The cancer risk estimate, which is unitless, represents an estimation of an upper bound incremental lifetime probability that an individual will develop cancer as a result of exposure to a potential carcinogen.

Carcinogenic risk is calculated for each constituent and exposure pathway (ingestion and dermal) by multiplying the estimated CDI by the CSF, as follows:

Equation 2:

$$\text{Cancer Risk (unitless)} = \text{CDI (mg/kg-day)} \times \text{CSF (mg/kg-day)}^{-1}$$

Chemical-specific risks for all COPCs associated with a specific pathway are summed to assess exposure to multiple chemicals. The pathway-specific risks for all pathways are then summed to determine the total cumulative risk for the exposure scenario. The total cumulative risk estimate assumes that different carcinogens affect the same target organ to produce a cancer response, ignoring potential antagonistic or synergistic effects or disparate effects on different target organs. **Tables 5-7 and 5-8** summarize the RME and CT cumulative cancer risk results, respectively, for each EU and exposure scenarios.

5.5.2.1 Reasonable Maximum Exposure Cancer Risk Results

This section summarizes the RME cancer risk results for each receptor. Arsenic is the only SVFUDS COPC with cancer toxicity data; the cancer risk results presented in **Table 5-7** are attributed to exposure to arsenic.

Groundwater and Surface Water at EU1

- For the current scenarios, the RME cumulative cancer risk estimates for groundwater (watering) are below the cancer risk threshold of 1×10^{-4} (1E-04).
- For the future scenarios, the RME cumulative cancer risk estimates for groundwater (potable use) are below the cancer risk threshold of 1×10^{-4} (1E-04).
- No carcinogenic COPCs were identified in surface water; no cancer risk results were estimated.

Groundwater at EU2

- For the current scenarios, the RME cumulative cancer risk results for groundwater (watering) are below the cancer risk threshold of 1×10^{-4} (1E-04).
- For the future lifetime resident, the RME cumulative cancer risk estimate for groundwater (potable use) equals, but does not exceed the cancer risk threshold of 1×10^{-4} (1E-04). For conservatism, arsenic is identified as a chemical of concern and the pathway of concern is ingestion of groundwater as tap water.
- For the future AU student and indoor office worker, the RME cumulative cancer risk estimates for groundwater (potable use) are below the cancer risk threshold of 1×10^{-4} (1E-04).

Groundwater at EU3

- For the current scenarios, the RME cumulative cancer risk estimates for groundwater (watering) are below the cancer risk threshold of 1×10^{-4} (1E-04).
- For the future scenarios, the RME cumulative cancer risk estimates for groundwater (potable use) are below the cancer risk threshold of 1×10^{-4} (1E-04).

5.5.2.2 Central Tendency Cancer Risk Results

This section summarizes the CT cancer risk results for each receptor. Arsenic is the only SVFUDS COPC with cancer toxicity data; the cancer risk results presented in **Table 5-8** are attributed to exposure to arsenic.

Groundwater and Surface Water at EU1

- Like the RME results, the CT cumulative cancer risk estimates for the current (groundwater watering) and future (potable use of groundwater) scenarios are below the cancer risk threshold of 1×10^{-4} (1E-04).
- Like the RME results, no carcinogenic COPCs were identified in surface water; no cancer risk results were estimated.

Groundwater at EU2

- Like the RME results, the CT cumulative cancer risk results for current (groundwater watering) scenarios are below the cancer risk threshold of 1×10^{-4} (1E-04).

- The CT cumulative cancer risk estimate for the future lifetime resident scenario (potable use of groundwater) drops below the cancer risk threshold of 1×10^{-4} (1E-04).
- The CT results did not identify arsenic as a chemical of concern for the lifetime resident.

Groundwater at EU3

- Like the RME results, the CT cumulative cancer risk estimates for the current (groundwater watering) and future (potable use of groundwater) scenarios are below the cancer risk threshold of 1×10^{-4} (1E-04).

5.5.3 Noncarcinogenic Hazards

To characterize potential noncarcinogenic effects, comparisons are made between projected intakes of substances over a specified time period and toxicity values, primarily RfDs and reference concentrations (RfCs). The ratio of exposure to toxicity value is the hazard quotient (HQ). The HQ is calculated for each constituent and exposure pathway (ingestion and dermal) by dividing the CDI by the RfD as follows:

Equation 3:

$$\text{Non-cancer HQ (unitless)} = \text{CDI (mg/kg-day)} / \text{RfD (mg/kg-day)}$$

The HQ is not a statistical probability of a noncarcinogenic effect occurring. If the exposure level is less than the appropriate toxicity value (i.e., the HQ is less than 1), adverse health effects are not likely, even with a lifetime of exposure. Given the uncertainty factors used in deriving RfDs, an HQ greater than 1 may not indicate a higher risk of adverse effect than an HQ of 1 or less than 1.

Estimated HQs for noncarcinogenic effects are generated on a chemical-by-chemical basis for each relevant pathway of exposure. The chemical-specific HQs are summed for all chemicals associated with a specific pathway to determine the pathway-specific HI. The HIs for all pathways are then summed to determine the total cumulative HI for the exposure scenario.

If the total cumulative HI for an exposure scenario is greater than 1, indicating potential cause for concern, the HI is segregated by critical effect and mechanism of action (USEPA, 1989). HQs only for chemicals that affect the same target organ are summed to derive target organ-specific HIs. **Tables 5-9 and 5-10** summarize the RME and CT cumulative HI results, respectively, for each receptor and EU.

5.5.3.1 Reasonable Maximum Exposure Non-Cancer Hazard Results

This section summarizes the RME non-cancer HIs for each receptor. The non-cancer risk results are summarized in **Table 5-9**. A target organ-specific HI analysis is conducted for cumulative non-cancer HIs that are above 1.

Groundwater and Surface Water at EU1

- For the current scenarios, the RME non-cancer HIs for groundwater (watering) and surface water (recreational) are below the target non-cancer HI of 1.
- For the future adult resident, child resident, and AU student scenarios, the RME non-cancer HIs for groundwater (potable use) either equal or exceed the target non-cancer HI of 1.
 - The target organ-specific HIs for the future adult resident and AU student are below the target non-cancer HI of 1.
 - The target organ analysis for the future child resident indicates that perchlorate is a chemical of concern because perchlorate's target organ (thyroid) has a non-cancer HI that equals but does not exceed the target non-cancer HI of 1, but is the main contributor to the cumulative HI of 2. The ingestion of groundwater as tap water is the pathway of concern.
- For the future indoor office worker, the RME non-cancer HI for groundwater (potable use) is below the target non-cancer HI of 1.

Groundwater at EU2

- For the current scenarios, the RME non-cancer HIs for groundwater (watering) are below the target non-cancer HI of 1.
- For the future adult resident, child resident, and AU student scenarios, the RME non-cancer HIs are above the target non-cancer HI of 1. A target organ analysis was conducted and the following chemicals of concern were identified for each scenario:
 - Perchlorate (thyroid): adult resident (HI = 2), child resident (HI = 4), and AU student (HI = 3)
 - Arsenic (skin and vascular system): child resident (HI = 1)
 - Manganese [central nervous system (CNS)]: child resident (HI = 2) and AU student (HI = 1)
- Ingestion of groundwater as tap water is the pathway of concern for the future adult resident, child resident, and AU student.
- Even though cobalt's target organ is also the thyroid, cobalt's chemical-specific HIs are below 1 for all three receptors.
- For the future indoor office worker, the RME non-cancer HI for groundwater (potable use) is below the target non-cancer HI of 1.

Groundwater at EU3

- For the current scenarios, the RME non-cancer HIs for groundwater (watering) are below the target non-cancer HI of 1.

- For the future (potable use) scenarios, the RME non-cancer HIs are above the target non-cancer HI of 1. A target organ analysis was conducted and the following chemicals of concern were identified for each scenario (the perchlorate contribution is well below 1 and is insignificant):
 - Cobalt (thyroid): adult resident (HI = 9), child resident (HI = 15), and AU student (HI = 1)
 - Manganese (CNS): adult resident (HI = 7), child resident (HI = 11), AU student (HI = 8), and indoor office worker (HI = 1)
- Even though perchlorate's target organ is also the thyroid, its chemical-specific HIs are below 1 for all four receptors.
- Ingestion of groundwater as tap water is the pathway of concern for cobalt and manganese. Dermal contact with manganese in groundwater also contributes to the non-cancer HIs.

5.5.3.2 Central Tendency Non-Cancer Hazard Results

This section summarizes the CT non-cancer HIs for each receptor. The non-cancer risk results are summarized in **Table 5-10**. A target organ-specific HI analysis is conducted for cumulative non-cancer HIs that are above 1.

Groundwater and Surface Water at EU1

- For the current scenarios, the CT non-cancer HIs for groundwater (watering) and surface water (recreational) are below the target non-cancer HI of 1.
- For the future scenarios, the CT non-cancer HIs for groundwater (potable use) are below the target non-cancer HI of 1.
- The CT evaluation eliminates perchlorate as a chemical of concern for the future child resident.

Groundwater at EU2

- For the current scenarios, the CT non-cancer HIs for groundwater (watering) are below the target non-cancer HI of 1.
- For the future adult resident, child resident, and AU student scenarios, the CT non-cancer HIs are above the target non-cancer HI of 1. A target organ analysis was conducted and perchlorate remains a chemical of concern for the following scenarios:
 - Perchlorate (thyroid): adult resident (HI = 1), child resident (HI = 2), and AU student (HI = 1)
 - CT results eliminate arsenic and manganese as chemicals of concern for the ingestion of groundwater as tap water exposure pathway.

- The future indoor office worker non-cancer HI for groundwater (potable use) remains below the target non-cancer HI of 1.

Groundwater at EU3

- The current non-cancer HIs for groundwater (watering) remain below the target non-cancer HI of 1.
- For the future adult resident, child resident, and AU student scenarios, the CT non-cancer HIs for groundwater (potable use) remain above the target non-cancer HI of 1. The following are still chemicals of concern:
 - Cobalt (thyroid): adult resident (HI = 4) and child resident (HI = 7)
 - Manganese (CNS): adult resident (HI = 4), child resident (HI = 6), and AU student (HI = 3)
- The indoor office worker CT non-cancer HI for groundwater (potable use) equals, but does not exceed the target non-cancer HI of 1; the target organ HI results were below the target non-cancer HI of 1.
- Ingestion of groundwater as tap water remains the pathway of concern for cobalt and manganese. Also, dermal contact with manganese in groundwater still contributes to the non-cancer HIs above 1.

5.5.4 Chemicals of Concern

Arsenic, cobalt, manganese, and perchlorate were identified as chemicals of concern with the RME analysis if the groundwater at the SVFUDS is used as a tap water source. Currently, the city supplies water to the residences and university, so the groundwater exposure pathway is considered incomplete.

5.6 UNCERTAINTY ASSESSMENT

Uncertainties are inherent in every aspect of a quantitative risk assessment. Certain assumptions are made as part of the risk assessment process, and these assumptions may lead to an over- or underestimation of the actual risks associated with the site. The assumptions made for this risk assessment were conservative, so that an overestimation of the actual risks posed by site conditions is more likely.

Uncertainties associated with each step in the risk assessment process are discussed in further detail below.

5.6.1 Uncertainties Associated with the Identification of Chemicals of Potential Concern

Samples Representing Site Media – If the samples did not adequately represent media at the site, hazard/risk estimates could be overestimated or underestimated. However, the surface water and groundwater media at the SVFUDS have undergone extensive review by the SVFUDS Partners throughout the duration of the monitoring program. Section 5.2 describes the screening process

the SVFUDS Partners used to investigate and target COPCs from past waste handling practices at the site. The potential to underestimate is reduced because of the review process and combined experience of the SVFUDS Partners.

Analytical Methods Used to Test Samples – The analytical methods at the site were selected to address all constituents known or suspected to be present on the basis of the site history, so the potential for underestimation was reduced.

Detection Limit Adequacy – Chemical-specific detection limits were compared with current tap water RSLs to determine whether the detection limits were adequate to measure concentrations of concern. Tables S-16 and S-17 at the end of **Appendix T** present the results.

For 30 of the SVFUDS chemicals, RSLs were not available to compare to the detection limits; there is increased uncertainty about whether the limits are protective of potential risk-based exposure. The HHRA screening process used other lines of evidence to qualitatively determine whether these chemicals are site-related COPCs. It is unknown if the cancer risk/non-cancer hazards are under-estimated.

Seventy of the SVFUDS chemicals have minimum and maximum detection limits that are lower than the tap water RSL. The minimum limit or method detection limit (MDL) cannot reliably quantify the chemical concentration due to laboratory limitations; however, the maximum limit or reporting limit (RL) meets project threshold requirements and can reliably quantify the data. These chemicals have adequate detection limits to measure concentrations of concern for either evaluating it in the HHRA or eliminating it from further evaluation. The uncertainty with under- or overestimating the cancer risk and/or hazards is minimized.

Forty-five SVFUDS chemicals have MDLs that are below the tap water RSL but the RLs are above it. As noted in the MDL definition in Table S-16, there is a 50 percent chance that the analyte will be detected using the MDL. It is possible that the cancer risk/non-cancer hazards are underestimated due to the laboratory not being able to reliably detect all concentrations.

Forty-seven SVFUDS chemicals have MDLs and RLs that are higher than the tap water RSL and therefore are not protective of drinking water exposure. The cancer risk/non-cancer hazards are likely underestimated, especially for the future potable use of groundwater scenarios. The laboratories were asked to meet the lowest reporting requirements provided in the project QAPP; however, it is not always technically feasible to achieve conservative risk-based screening levels.

Data Adequacy – RAGS Part D Data Usability worksheets were prepared for the groundwater and surface water data sets to identify potential data issues that might impact the HHRA results (**Appendix T**). With the exception of “R” flagged data (i.e., rejected result), all other flagged data were carried forward into the risk-based screening evaluation and HHRA calculations. The following “R”-flagged data were eliminated from the groundwater and surface water data sets:

Baseline Human Health Risk Assessment

Chemicals	EU	Medium	Number of R-flags
Benzoic Acid	EU1	Groundwater	1
		Surface Water	1
	EU2	Groundwater	3
	EU3	Groundwater	17
Diphenyl Ether (Phenylether)	EU1	Groundwater	1
	EU2	Groundwater	2
	EU3	Groundwater	3
Acetic Acid	EU1	Groundwater	1
	EU3	Groundwater	10
Iodide	EU2	Groundwater	1
HMX	EU3	Groundwater	1
Phenyl Isocyanate	EU3	Groundwater	1
Oxathiane (1,4)	EU3	Groundwater	1
Cyclotetrasiloxane, octamethyl (VOC)	EU3	Groundwater	4
Hexamethylcyclotrisiloxane (VOC)	EU1	Groundwater	1
	EU3	Groundwater	1
N-Hexadecanoic Acid (SVOC)	EU3	Groundwater	1

Detected concentrations (i.e., not “R”-flagged results) for benzoic acid were carried forward into the EU3 risk-based screening; it was eliminated as a groundwater COPC. With the removal of the “R”-flagged result for HMX, it is now considered non-detect in the EU3 groundwater data set. Diphenyl ether, acetic acid, iodide, phenyl isocyanate oxathiane (1,4), and n-hexadecanoic acid results are addressed in Section 5.2.3 and the next subsection below. The remaining VOA results were “B”-flagged and eliminated in the risk-based screening evaluation.

Phthalates such as bis(2-ethylhexyl)phthalate and di-n-butyl phthalate were detected in the SVFUDS groundwater EUs as well as the background well locations. Most of the detections were “J”-flagged, indicating that the concentration is an estimated value. Phthalates are often associated with laboratory contamination and are not likely to be site-related COPCs. The risk-based screening process eliminated the phthalates as groundwater COPCs; the uncertainty with under- or overestimating the cancer risk and/or hazards is minimized.

Chemicals with no RSLs – In Tables 5-1 through 5-4 of Section 5.2.3, chemicals with no USEPA RSLs available were identified during the risk-based screening. USEPA has not developed toxicity values to derive risk-based screening levels for these chemicals. USEPA does not recognize these chemicals as potential priority pollutants in Superfund site investigations. The HHRA screening process used other lines of evidence to qualitatively determine whether these chemicals are site-related COPCs. Since the HHRA was unable to quantitatively evaluate these chemicals, the cancer risks and/or non-cancer hazard estimates may be underestimated.

5.6.2 Uncertainties Associated with the Exposure Assessment

Exposure Groups – The groundwater data were grouped into EU1 and EU2 where high arsenic and/or perchlorate concentrations were confirmed so as not to "dilute" the groundwater EPCs with wells data not impacted by historical AUES activities. This approach does not take into consideration populations potentially at risk or a future individual well that is used for a home or business. It is unknown if the groundwater EPCs for EU1 and EU2 are representative of potential future exposure to an individual home/business or specific populations; cancer risk/non-cancer hazards may be under- or overestimated.

Exposure Media Not Addressed in the HHRA – The soil exposure medium was addressed under a separate RI, and the soil risk assessment results are not incorporated into this HHRA (USACE, 2015). The cumulative results of this HHRA do not reflect exposure to all potentially affected exposure media at Spring Valley FUDS. However, the public health is currently protected due to SVFUDS groundwater not being used as a potable water source. Also, various soil and debris removal activities have been conducted at EU2 (i.e., AU) from 2003 to 2010, thus reducing potential risks/hazards associated with soil exposure. The cumulative results of this HHRA may be underestimated due to the exclusion of the soil medium. The level of uncertainty is reduced due to the potable use of groundwater being an incomplete exposure pathway and the soil removal activities at EU2.

Pathways Not Evaluated – The HHRA assessed the primary exposure pathways (i.e., ingestion and dermal contact) for surface water and groundwater media. Inhalation pathways were qualitatively assessed because no volatile COPCs were identified. Future use of groundwater as a source of tap water was also evaluated, even though the tap water exposure route is not currently a risk because the city supplies tap water to both residents and commercial/university properties. Therefore, the hazard/risk estimates are likely biased high with the inclusion of the tap water exposure pathway.

Use of Measured Concentrations to Represent Current and Future Concentrations in the Exposure Media – Even though only the most recent rounds of COPC data were used, risk estimates for the current scenarios do not necessarily represent future risk because concentrations of the COPCs have been observed to decrease over time. The hazard/risk estimates are likely biased high for the future scenarios because present day detected results were used to represent future conditions.

Estimation of Exposure Point Concentration – USEPA's ProUCL 5.0 was used to derive the 95% UCLs for groundwater and surface water. The number of sample points was below 10 for the following COPCs: manganese in surface water (EU1), manganese in groundwater (EU2), and cobalt in groundwater (EU1 and EU2). A higher level of uncertainty is associated with any 95% UCL that is derived using less than 10 sample points.

USEPA (1989) recommends using the lower of the 95% UCL and maximum detected concentration in the HHRA. Depending on the shape of the underlying distribution of measurements, the maximum detected concentration may underestimate the population mean when the sample size is small and the distribution is positively skewed. The maximum detected

concentration was used as the EPC for the following COPCs: cobalt (EU1 and EU2) and perchlorate (EU2). Therefore, the use of the maximum detected concentration as the EPC may either under- or overestimate the hazard/cancer risk results.

ProUCL 5.0 recommended several 95% UCLs for arsenic in groundwater at EU2 with concentrations ranging from 6.574 to 8.456 $\mu\text{g/L}$. If the highest UCL had been selected as the groundwater EU2 EPC, the residential scenario (potable use of groundwater) results would increase to $2\text{E-}04$ (2×10^{-4}), which is above the cumulative cancer risk threshold of 1×10^{-4} . It is possible that the cancer risk results for the future residential scenario are underestimated in the HHRA. This does not change the conclusions of the HHRA; arsenic was identified as a groundwater chemical of concern for EU2 due to the ingestion of groundwater exposure pathway. The level of uncertainty associated with the EU2 groundwater risk results is reduced.

5.6.3 Uncertainties Associated with the Toxicity Assessment

Bases for Derivation of Toxicity Values – Sources of uncertainty in the derivation of toxicity values (e.g., modifying factors) affect all HHRA and are not specific to the HHRA for SVFUDS.

Subchronic toxicity data were used, where available, for the AU student scenario. The RAGS Part D Table 5.1 in **Appendix T** presents the subchronic toxicity values used. The only COPC identified with subchronic values was cobalt. Chronic toxicity values were used for the other COPCs in the AU student non-cancer hazard evaluation. The non-cancer hazard results may be biased high.

Use of Unverified Toxicity Values – The chronic and subchronic toxicity values for cobalt are provisional values that have not been verified and listed in IRIS. There is a higher level of uncertainty associated with provisional values than there is for consensus values listed in IRIS. Cobalt is identified as a non-cancer hazard driver; whether the use of the provisional values could overestimate or underestimate the hazard is unknown until the toxicity data are verified by USEPA.

Toxicological Review of Toxicity Values for the Risk Drivers – Arsenic and perchlorate are the primary risk drivers in SVFUDS groundwater. USEPA's IRIS states that arsenic is currently undergoing toxicological review which began in 2005. In 2010, USEPA released a draft inorganic arsenic assessment (focused on cancer health effects following oral exposure to inorganic arsenic) for public comment. Once the assessment is completed, it will undergo peer review by the National Research Council (USEPA, 2015b). It is likely that toxicity values may undergo changes in the future.

Cal EPA (2010) has developed an oral reference dose of 3.7×10^{-4} mg/kg-day that is roughly twice as conservative as the IRIS oral reference dose of 7×10^{-4} mg/kg-day. If USEPA were to review and adopt the Cal EPA oral reference dose for perchlorate, the non-cancer HI results for perchlorate in this HHRA would roughly double. As described for arsenic above, the toxicity value would undergo extensive scientific peer review by USEPA before any changes are made.

5.6.4 Uncertainties Associated with the Risk Characterization

Risk characterization uncertainties include possible synergistic or antagonistic effects of exposure to multiple chemicals and applicability of cancer risk estimation methodology to less than lifetime exposure duration. These uncertainties are generic to the risk assessment process and not specific to this site.

5.7 RISK ASSESSMENT SUMMARY

This section identifies the cancer risk and non-cancer hazard drivers of the RME scenario results and examines additional lines of evidence to determine the chemicals of concern for each exposure medium and EU. The CT scenario results are not evaluated in this analysis as a risk management decision to be more protective of the potential human receptors at the Spring Valley FUDS by focusing on the RME scenario results.

5.7.1 Current Scenario

For the current scenarios, the cumulative cancer risk and non-cancer HIs are below the cancer risk threshold ($1E-04$) and non-cancer HI threshold (1) for the surface water media and groundwater media at all EUs. This indicates no requirement to take any actions to influence chemical concentrations in groundwater or surface water to be protective of the human health current scenarios.

5.7.2 Future Scenario

For the future scenario involving use of groundwater as potable water, **Table 5-11** summarizes the cumulative cancer risks that equal or exceed the cancer risk threshold (results are shaded pink), and non-cancer HIs that exceed the non-cancer HI thresholds (results are also shaded pink). Cumulative cancer risks that are less than the cancer risk threshold are shaded green, and non-cancer HIs that are equal to or less than the non-cancer HI thresholds are shaded green. All three groundwater EUs have non-cancer cumulative HI threshold exceedances. Only groundwater EU2 has a cumulative cancer risk estimate that equals or exceeds the cancer risk threshold.

Table 5-12 summarizes the individual chemicals that contribute to the cumulative non-cancer hazard and cancer risk estimates shaded pink in **Table 5-11**. **Table 5-12** results for each groundwater EU are discussed further below.

5.7.2.1 Groundwater EU1

Table 5-12 indicates that no chemicals drive a non-cancer target organ-specific HI greater than the non-cancer threshold of 1, or cancer risk equal to or greater than the cancer risk threshold of $1E-04$. Actions to control exposure to chemicals in groundwater EU1 do not warrant consideration.

5.7.2.2 Groundwater EU2

Table 5-12 indicates that arsenic drives a cancer risk of 1E-04, and perchlorate drives a non-cancer target organ-specific HI that exceeds the non-cancer threshold of 1. Arsenic and perchlorate are groundwater EU2 chemicals of concern. Actions to control exposure to arsenic and perchlorate in groundwater EU2 would warrant consideration, if groundwater is to be used for potable water.

5.7.2.3 Groundwater EU3

Table 5-12 indicates that cobalt and manganese each drive non-cancer target organ-specific HIs that exceeds the non-cancer threshold of 1.

Cobalt is a non-cancer hazard driver with a maximum target organ-specific HI of 15 for the thyroid. However, excluding the cobalt results for MW-33, which range upward to a concentration about nine times higher than observed at any other EU3 location, the cobalt target organ-specific HIs drop below the threshold of 1, as indicated in **Table 5-13**. Cobalt is eliminated as a groundwater chemical of concern at EU3 because the uniquely high concentration measured in MW-33 appears to be an outlier outside the SVFUDS boundary and unrelated to any historic AUES activities. MW-33 is proximate to a known area of perchlorate groundwater concentrations near Sibley Memorial Hospital; the well was installed only to determine whether perchlorate groundwater concentrations have migrated offsite.

Manganese is a non-cancer hazard driver with a maximum target organ-specific HI of 11 for the CNS. The groundwater EU3 locations with the highest measured manganese concentrations are: MWs 3, 8, 15, 19, 33, and 37 and PZ-1S. These locations are not associated with known or suspected SVFUDS disposal areas. This and the rather random distribution of these locations across EU3 suggest that the manganese concentrations are influenced by natural occurrence of manganese. Also, concentrations of arsenic and perchlorate (confirmed SVFUDS contaminants) at these high manganese concentration locations were relatively low, with the exception of MW-8 where the arsenic concentrations historically ranged up to 7.3 µg/L. Therefore, the manganese target organ-specific HI results in **Table 5-13** are not shaded pink, indicating manganese is eliminated as a groundwater chemical of concern at EU3.

Upon examining the additional lines of evidence at EU3, no groundwater chemicals of concern were identified. Actions to control exposure to chemicals in groundwater EU3 do not warrant consideration.

SECTION SIX: SUMMARY, CONCLUSIONS, AND RECOMMENDATION

6.1 SUMMARY

A summary of the nature and extent of contamination, fate and transport, and the risk assessment are discussed below.

6.1.1 Nature and Extent of Contamination

The nature and extent of contamination is summarized below for:

- Groundwater EU2 and Surface Water EU1, representative of the vicinity of AU's Kreeger Hall and Glenbrook Road Disposal Areas
- Groundwater EU1, representative of the vicinity of SMH
- Groundwater EU3 and Surface Water EU2, representative of the remainder of SVFUDS

6.1.1.1 Groundwater EU2 and Surface Water EU1

Historic AUES activities have caused groundwater to be locally impacted by arsenic and perchlorate, and surface water to be locally impacted by perchlorate, as summarized below.

EU	Location	Chemicals Causing Impact
Groundwater EU2:	Vicinity of AU's Kreeger Hall and Lot 18 Debris Area	Perchlorate
	Vicinity of Glenbrook Road Disposal Areas	Perchlorate and Arsenic
Surface Water EU1:	East Creek near groundwater EU2	Perchlorate

The source of the groundwater perchlorate contamination on AU near Kreeger Hall, originally evidenced by groundwater perchlorate monitoring data for several locations (PZ-4S, PZ-4D, and PZ-5), is not known precisely, but is bounded based on soil borings and groundwater monitoring. Perchlorate was detected in only two soil samples at low estimated concentrations. Groundwater perchlorate concentrations were observed to diminish radially outward from the center of the soil boring program investigation area, indicating the source is residual and diffuse in nature. The source could relate to various soil and debris removal activities conducted at AU during the 2003 to 2010 timeframe. Perchlorate waste was identified and removed from Lot 18, as reported in the *Site-Specific Anomaly Investigation Report – American University* dated August 2008.

Near the Glenbrook Road Disposal Areas, arsenic- and perchlorate-impacted groundwater is present within the bedrock aquifer to a confirmed depth of about 145 to 160 ft bgs.

6.1.1.2 Groundwater EU1

Groundwater is impacted by perchlorate in the vicinity of SMH. Here, elevated perchlorate concentrations are present in shallow groundwater and deep bedrock groundwater down to the monitored bedrock interval between about 72 and 92 ft bgs in MW-46. Perchlorate has not been detected in the underlying deepest interval of 108 to 118 ft bgs in MW-46.

The perchlorate stable oxygen and chlorine isotope analyses confirmed that the perchlorate in groundwater proximate to SMH (EU1) and in the vicinity of AU's Kreeger Hall (EU2) was imported from Chile. However, the historic activities that have caused perchlorate in groundwater proximate to SMH may be unrelated to the historical activities responsible for perchlorate in groundwater in the vicinity of AU's Kreeger Hall and the Glenbrook Road Disposal Areas. Groundwater perchlorate at SMH may be from nitrates imported from Chile and used as fertilizer associated with historic farming activities at the current SMH location, or used to manufacture gunpowder used during historic Civil War activities at the current SMH location. Additional evidence that the perchlorate in groundwater at SMH derives from activities unrelated to historic AUES activities is the observation that the groundwater monitoring well network situated between SMH and the vicinity of AU's Kreeger Hall and Glenbrook Road Disposal Areas confirms absence of a continuous groundwater perchlorate plume.

6.1.1.3 Groundwater EU3 and Surface Water EU2

These EUs encompass all SVFUDS locations not included in groundwater EUs 1 and 2, and surface water EU1. No contamination from AUES is indicated at any groundwater EU3 or surface water EU2 locations.

6.1.2 Fate and Transport

The fate and transport of the AUES contaminants are summarized below for:

- Groundwater EU2 and Surface Water EU1, representative of the vicinity of AU's Kreeger Hall and Glenbrook Road Disposal Areas
- Groundwater EU1, representative of the vicinity of SMH

6.1.2.1 Groundwater EU2 and Surface Water EU1

The groundwater EU2 contaminants of concern are arsenic and perchlorate.

Arsenic in EU2 groundwater will have a tendency to migrate with moving groundwater. Such migration will be hindered by natural attenuation by a combination of mixing with uncontaminated groundwater, adsorption to various subsurface materials such as ferric oxides and clay particles, and source depletion associated with AUES waste removal activities that have been conducted in groundwater EU2. Although there is evidence that groundwater in EU2 seeps into East Creek (Surface Water EU1), there has been no evidence of contamination of East Creek with arsenic, which suggests that the natural attenuation processes described above afford protection to East Creek, relative to arsenic.

Elevated arsenic concentrations in EU2 groundwater have generally decreased during the time period of the SVFUDS RI, based on the trend analysis results for several MP-2 intervals and MP2-All. However, no trend was identified at MW-24. Residual dissolved arsenic in EU2 is anticipated to remain localized within EU2, consistent with the fact that historically higher EU2 groundwater arsenic concentrations have been localized.

Perchlorate in EU2 groundwater also has a tendency to migrate with moving groundwater, possibly to a greater extent than arsenic since perchlorate is relatively persistent in groundwater and sorbs poorly to mineral surfaces and organic material. Accordingly, the most significant attenuation mechanisms are likely to be mixing with uncontaminated groundwater and source depletion associated with AUES waste removal activities that have been conducted in soil within the groundwater EU2 area. The greater persistence of perchlorate is suggested by the historical East Creek (Surface Water EU1) monitoring data, which revealed perchlorate contamination in East Creek in the past. There is evidence of decrease of perchlorate concentrations at some EU2 groundwater locations and also in East Creek (Surface Water EU1). Future concentration decreases are expected based on source depletion and mixing.

6.1.2.2 Groundwater EU1

The groundwater EU1 contaminant of concern is perchlorate.

Shallow groundwater perchlorate concentrations in the vicinity of SMH have been decreasing through time. Deeper bedrock well MW-46 has been monitored only once and, therefore, provides no information concerning deeper bedrock groundwater concentration trends in the vicinity of SMH. The decreasing concentrations imply natural depletion of the perchlorate source. The depletion mechanism would be reduction in mass flux from the source into groundwater, since perchlorate is otherwise estimated to be rather persistent. As discussed in Section 6.1.1.2, the decreasing concentrations appear unrelated to remedial activities proximate to AU's Kreeger Hall and the Glenbrook Road Disposal Areas.

Residual perchlorate in EU1 groundwater will have a tendency to migrate with moving groundwater west-southwestward toward the Washington Aqueduct and the Potomac River, ultimately discharging into the Potomac River. Based on the flux modeling conducted for the Dalecarlia Reservoir, it is probable that associated potential changes in Potomac River perchlorate concentrations would be too small to be detectable. The single MW-46D monitoring result indicates that perchlorate has not migrated into deep bedrock at SMH.

6.1.3 Risk Assessment

For the current scenarios, the cumulative cancer risk and non-cancer HIs are below the cancer risk threshold (1E-04) and non-cancer HI threshold (1) for the surface water media and groundwater media at all EUs. This indicates no requirement to take any actions to influence chemical concentrations in groundwater or surface water to be protective of the human health current scenarios.

For the future surface water, the risk assessment findings are the same as for the current surface water scenarios. The groundwater future scenarios risk assessment findings are summarized below for each groundwater EU.

6.1.3.1 Groundwater EU1

For the current scenarios, the cumulative cancer risk and non-cancer HIs are below the cancer risk threshold (1E-04) and non-cancer HI threshold (1). This indicates no requirement to take any actions to control exposure to groundwater or surface water.

For the future scenarios, no chemicals drive a non-cancer target organ-specific HI greater than the non-cancer threshold of 1, or cancer risk equal to or greater than the cancer risk threshold of 1E-04. Actions to control exposure to chemicals in groundwater EU1 do not warrant consideration.

6.1.3.2 Groundwater EU2

For the current scenarios, the cumulative cancer risk and non-cancer HIs are below the cancer risk threshold (1E-04) and non-cancer HI threshold (1). This indicates no requirement to take any actions to control exposure to groundwater or surface water.

For the future scenarios, the arsenic cancer risk is 1E-04, and the perchlorate non-cancer target organ-specific HI exceeds the non-cancer threshold of 1. Arsenic and perchlorate are groundwater EU2 chemicals of concern. Actions to control exposure to arsenic and perchlorate in groundwater EU2 would warrant consideration, if groundwater is to be used for potable water.

6.1.3.3 Groundwater EU3

For the current scenarios, the cumulative cancer risk and non-cancer HIs are below the cancer risk threshold (1E-04) and non-cancer HI threshold (1). This indicates no requirement to take any actions to control exposure to groundwater or surface water.

For the future scenarios, cobalt and manganese each drive non-cancer target organ-specific HIs that exceeds the non-cancer threshold of 1. However, for the reasons discussed in section 5.7.2.3, actions to control exposure to chemicals in groundwater EU3 do not warrant consideration.

6.2 CONCLUSIONS AND DATA LIMITATIONS / RECOMMENDATION

6.2.1 Conclusions

Chemical releases from historical AUES activities have impacted groundwater and surface water proximate to the Lot 18 Debris Area and Glenbrook Road Disposal Areas. The impacts are due to arsenic and perchlorate in groundwater and, during the early phases of the remedial investigation, perchlorate in surface water. The perchlorate detected in groundwater along Glenbrook Road and in East Creek could partially, or in total, originate from the nearby upgradient area proximate to AU's Kreeger Hall where perchlorate-impacted shallow and deep groundwater has been confirmed.

The source of the groundwater perchlorate contamination on AU near Kreeger Hall, originally evidenced by groundwater perchlorate monitoring data for several locations (PZ-4S, PZ-4D, and PZ-5) is not known precisely, but is bounded based on soil borings and groundwater monitoring. Perchlorate was detected in only two soil samples at low estimated concentrations. Groundwater perchlorate concentrations measured during the soil boring program were observed to diminish

radially outward from the center of the investigation area, indicating the source is residual and diffuse. The source could relate to various soil and debris removal activities conducted at AU during the 2003 to 2010 timeframe. Perchlorate waste was identified and removed from Lot 18, as reported in the *Site-Specific Anomaly Investigation Report – American University* dated August 2008.

The available groundwater monitoring data indicate that the groundwater perchlorate plume is not continuous between the above-mentioned impacted areas and SMH, where perchlorate is also present in shallow and deep groundwater. Therefore, although the perchlorate at both locations originated from Chile, the non-continuous plume finding suggests the possibility of a non-AUES source for the perchlorate at SMH. Historically, nitrates containing perchlorate were imported into the United States as fertilizer for farming and to manufacture gunpowder used during the Civil War. Historic farming activities were conducted at SMH, and a Civil War battery also was located at SMH.

Cancer risks and non-cancer hazards associated with SVFUDS groundwater and surface water are well below the threshold levels protective of the health of AU students and Spring Valley residents. Groundwater should not be used as potable water without first taking actions to control exposure to chemicals in the groundwater. Impacted groundwater within the SVFUDS will have no influence on the Dalecarlia Reservoir water quality.

6.2.2 Data Limitations / Recommendation for Future Work

6.2.2.1 Data Limitations

Data limitations associated with assessing health risks are discussed in Sections 5.6.1, 5.6.2, 5.6.3, and 5.6.4). Limitations also primarily relate to: 1) the impracticalities of installing a dense groundwater monitoring network throughout such a large study area comprising primarily privately owned property, 2) the inherently complex nature of a fractured bedrock aquifer, and 3) lack of historical information precisely describing all locations where chemicals may have been released to the environment.

6.2.2.2 Recommendation for Future Work

A Feasibility Study is recommended to determine the best alternative to remediate the groundwater risk to future residential users.

SECTION SEVEN: REFERENCES

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FIGURES

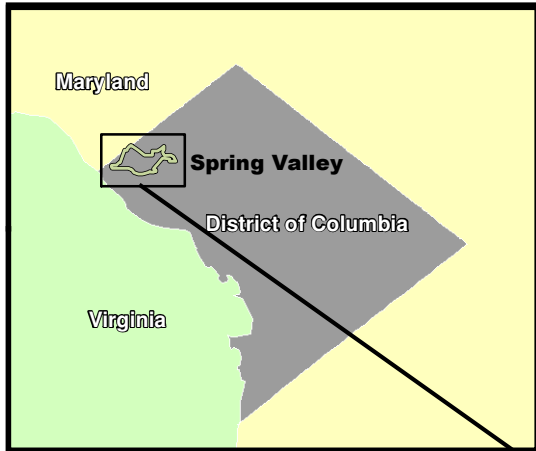
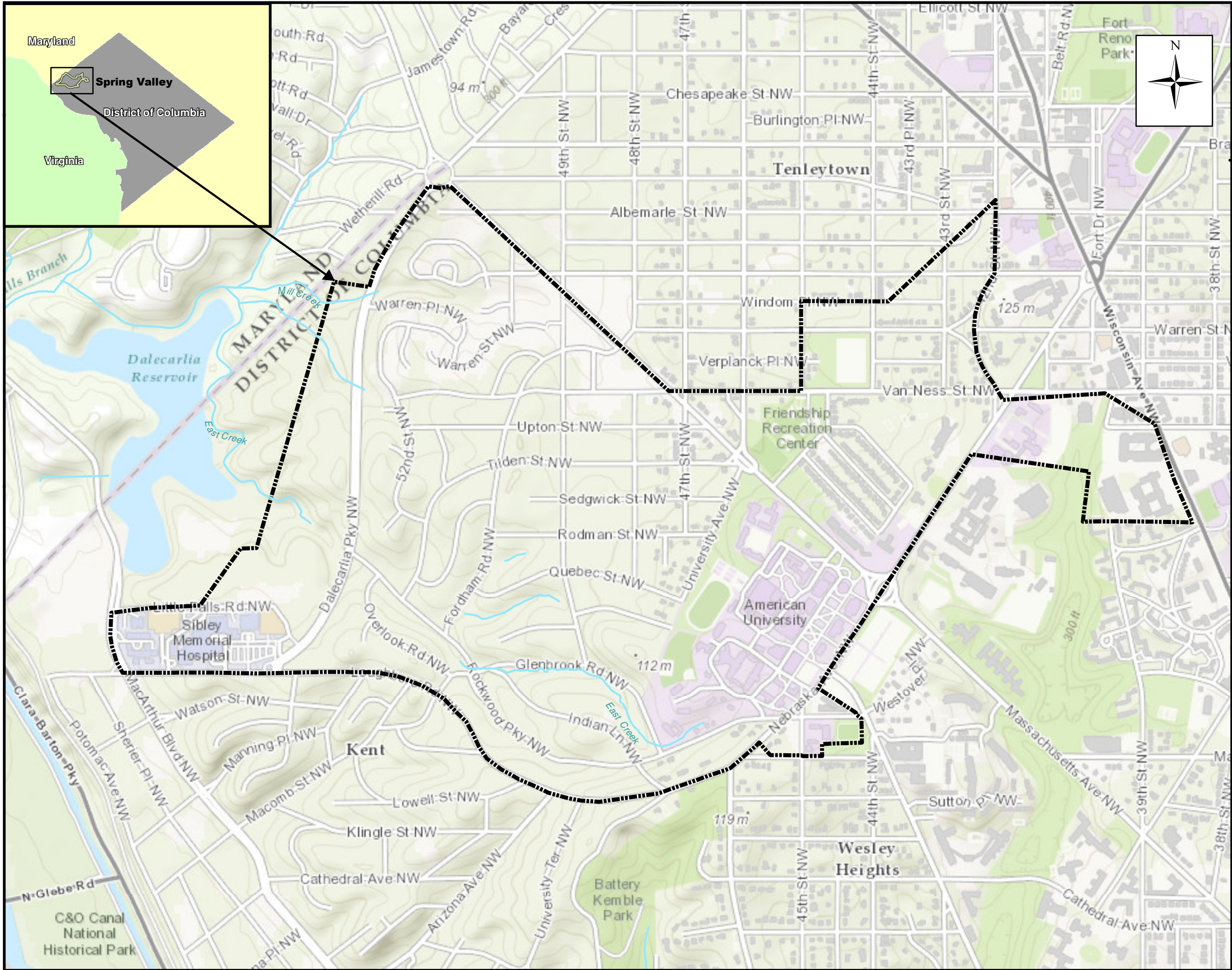
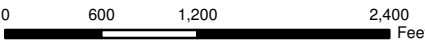


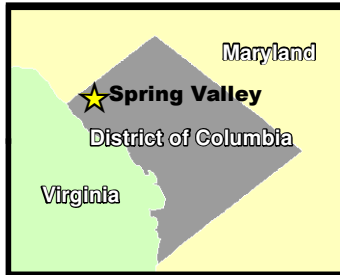
Figure 1-1
Spring Valley FUDS Location
Spring Valley FUDS
Washington, DC

- Legend**
- Spring Valley FUDS Boundary
 - Base Map**
 - Building/Structure
 - Non-Residential Urban
 - Parks and Recreation
 - Water
 - Stream or Creek
 - Topographic Contour
 - Road



Original Scale: 1:14,400
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 GIS: AER
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Map Source: World Topographic Map, ESRI ArcGIS Online and data partners, 2011.

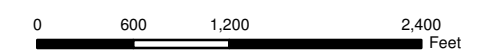


**Figure 2-1
Geologic Map**

**Spring Valley FUDS
Washington, DC**

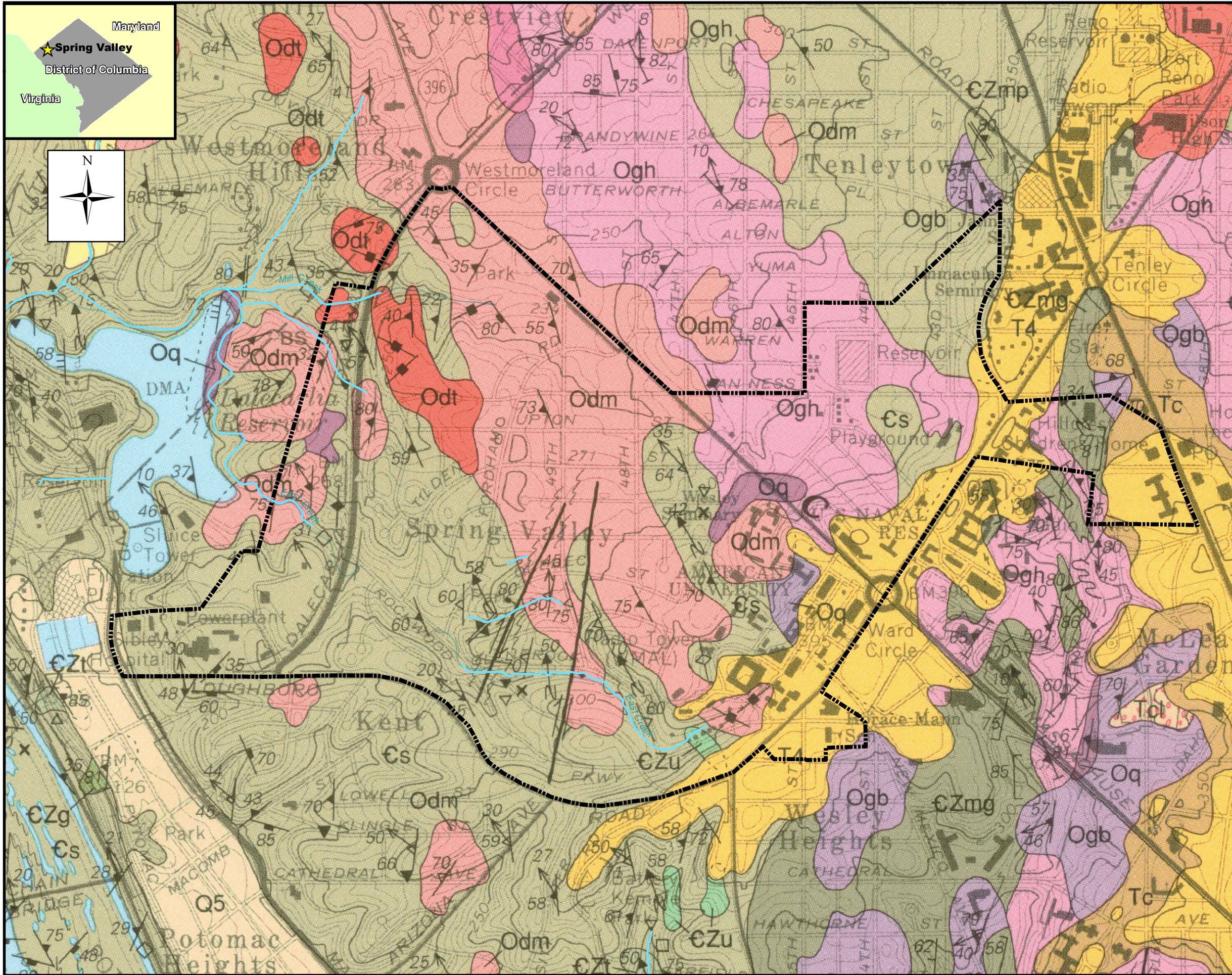
Legend

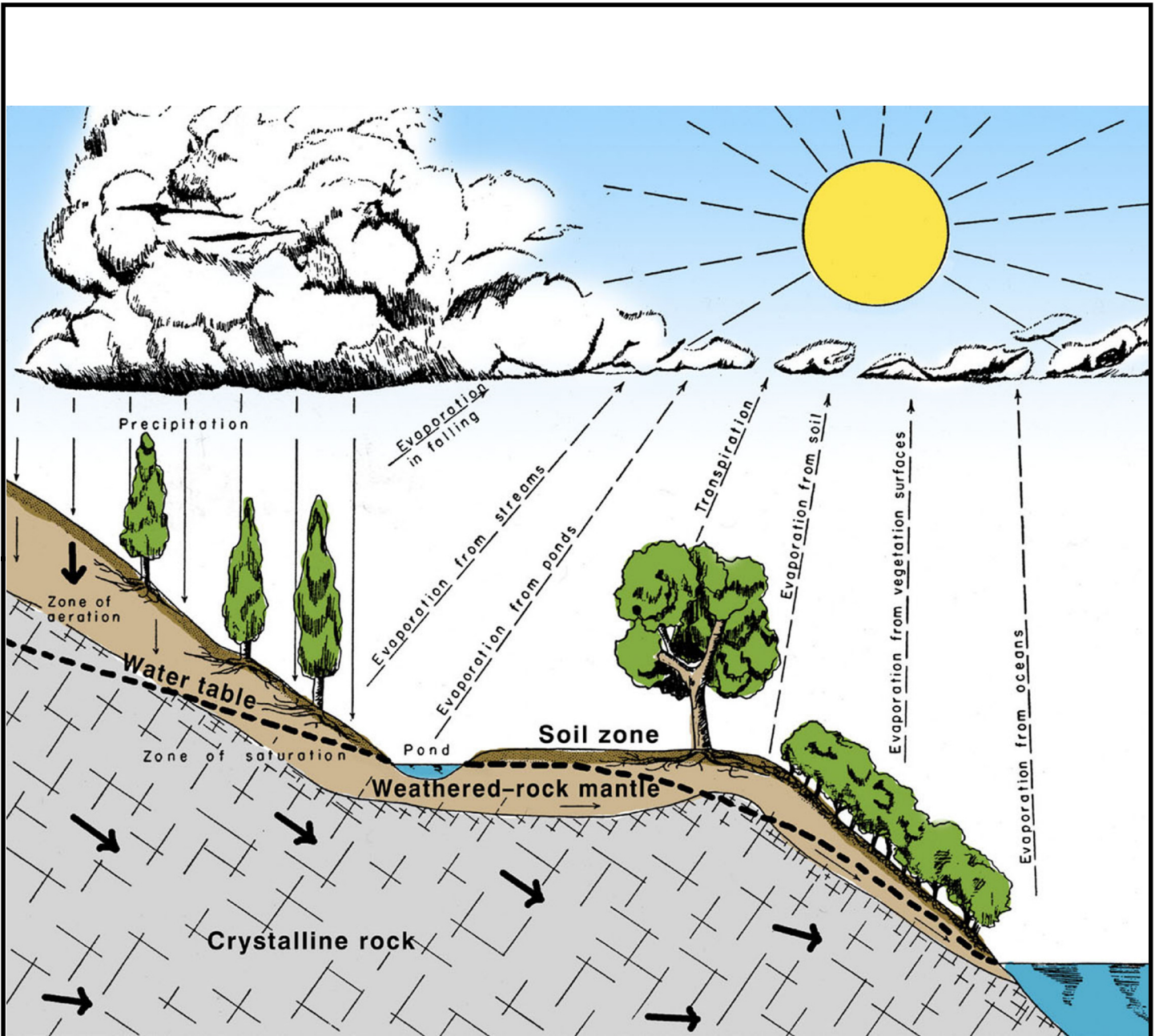
- Spring Valley FUDS Boundary
- Stream or Creek
- = Sykesville Formation
- = Actinolite Schist
- = Georgetown Intrusive Suite
- = Dalecarlia Intrusive Suite
- = Dalecarlia Intrusive Suite
- = Terrace Formation
- Fault
- Inclined Strike and Dip of Foliation
- Vertical Strike and Dip of Foliation
- Inclined Strike and Dip of Joints
- Vertical Strike and Dip of Joints
- Bearing and Plunge
- Minor Asymmetric Fold



Original Scale: 1:14,400
 Date: 2/23/2015
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Map Source: Geologic Map of the Washington West Quadrangle, District of Columbia, Montgomery and Prince Georges Counties, Maryland, and Arlington and Fairfax Counties, Virginia, by A.H.Fleming, A.A.Drake, and L.McCartan, USGS, 1994.





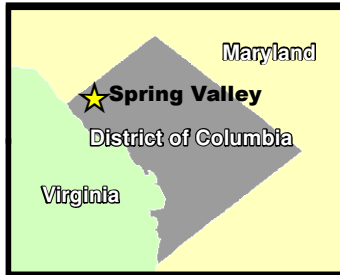
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Figure 2-2
Conceptual Groundwater Flow

Spring Valley FUDS
Washington, DC

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 Date: 2/24/2015
 Revised: 2/25/2015
 GIS: AER
 PM: BE
 G:\Projects\SpringValley\GISData\Projects\2015\Fig2-2_SpringValley_ConceptualGWFlow.mxd

Source: FLUTE™ Flexible Liner Underground Technologies, LLC.



**Figure 2-3
Topography**
**Spring Valley FUDS
Washington, DC**

Legend

Spring Valley FUDS Boundary

Base Map

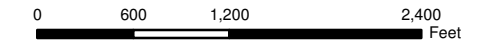
- Building/Structure
- Non-Residential Urban
- Parks and Recreation
- Road
- Water
- Stream or Creek

Topography within FUDS (USACE)

- 50-Foot Contour
- 10-Foot Contour

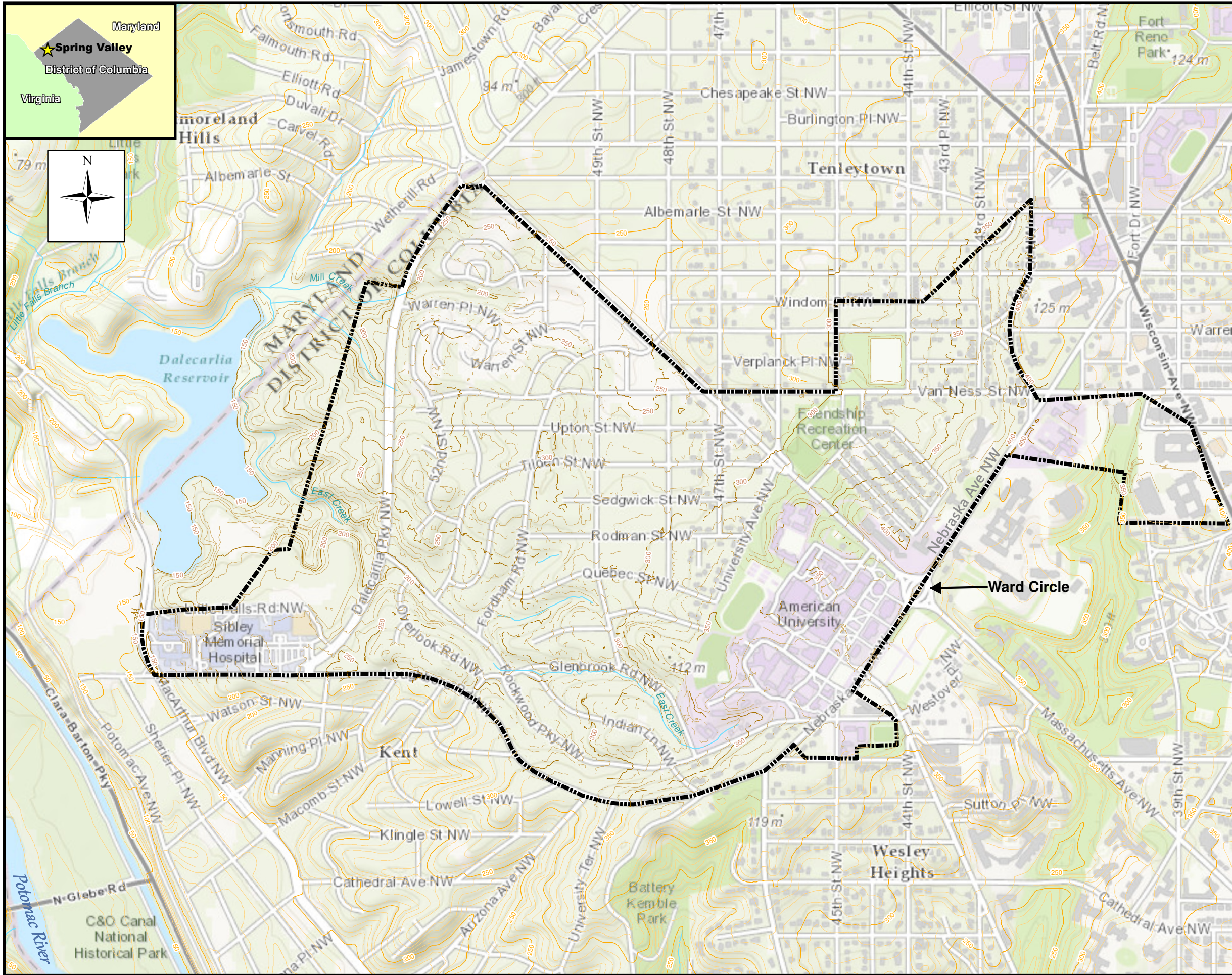
Topography outside FUDS (USGS)

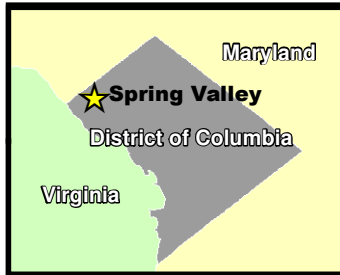
- 50-Foot Contour
- 10-Foot Contour



Original Scale: 1:14,400
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Map Source: National Geographic World Map, ESRI ArcGIS Online and data partners.





**Figure 3-1
Groundwater Monitoring Network**

**Spring Valley FUDS
Washington, DC**

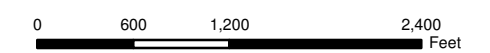
Legend

- Spring Valley FUDS Boundary
- Piezometer
- Monitoring Well
- Multiport Well
- Sibley Sump
- Hydroelectric Unit Vault

S/D = monitoring well or piezometer with two screened intervals in the same borehole.

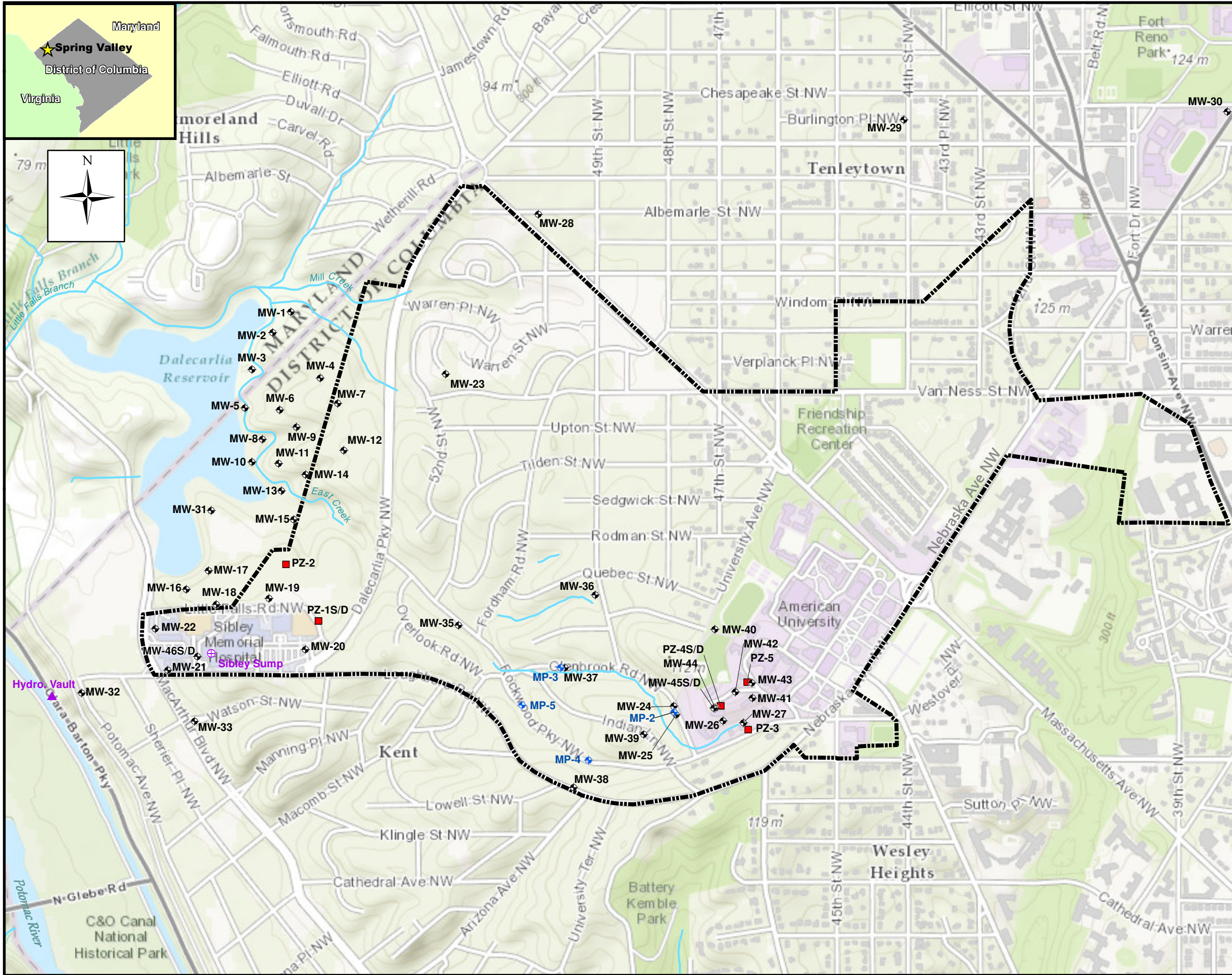
Base Map

- Building/Structure
- Non-Residential Urban
- Parks and Recreation
- Water
- Stream or Creek
- Topographic Contour
- Road



Original Scale: 1:14,400
 Date: 2/23/2015
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 GIS: AER
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Map Source: World Topographic Map, ESRI ArcGIS Online and data partners, 2011.



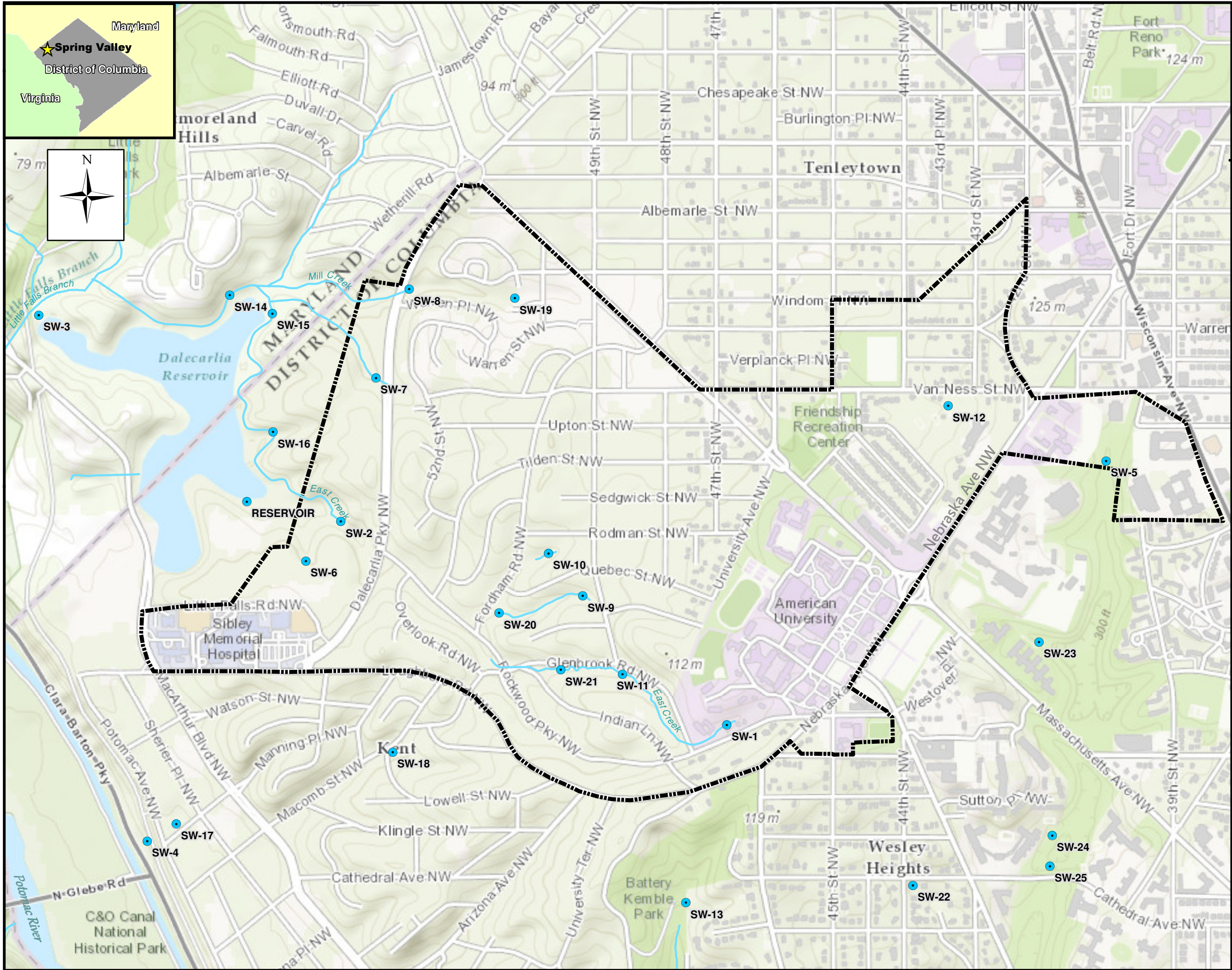
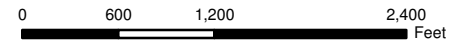


Figure 3-2
Surface Water Monitoring Network
Spring Valley FUDS
Washington, DC

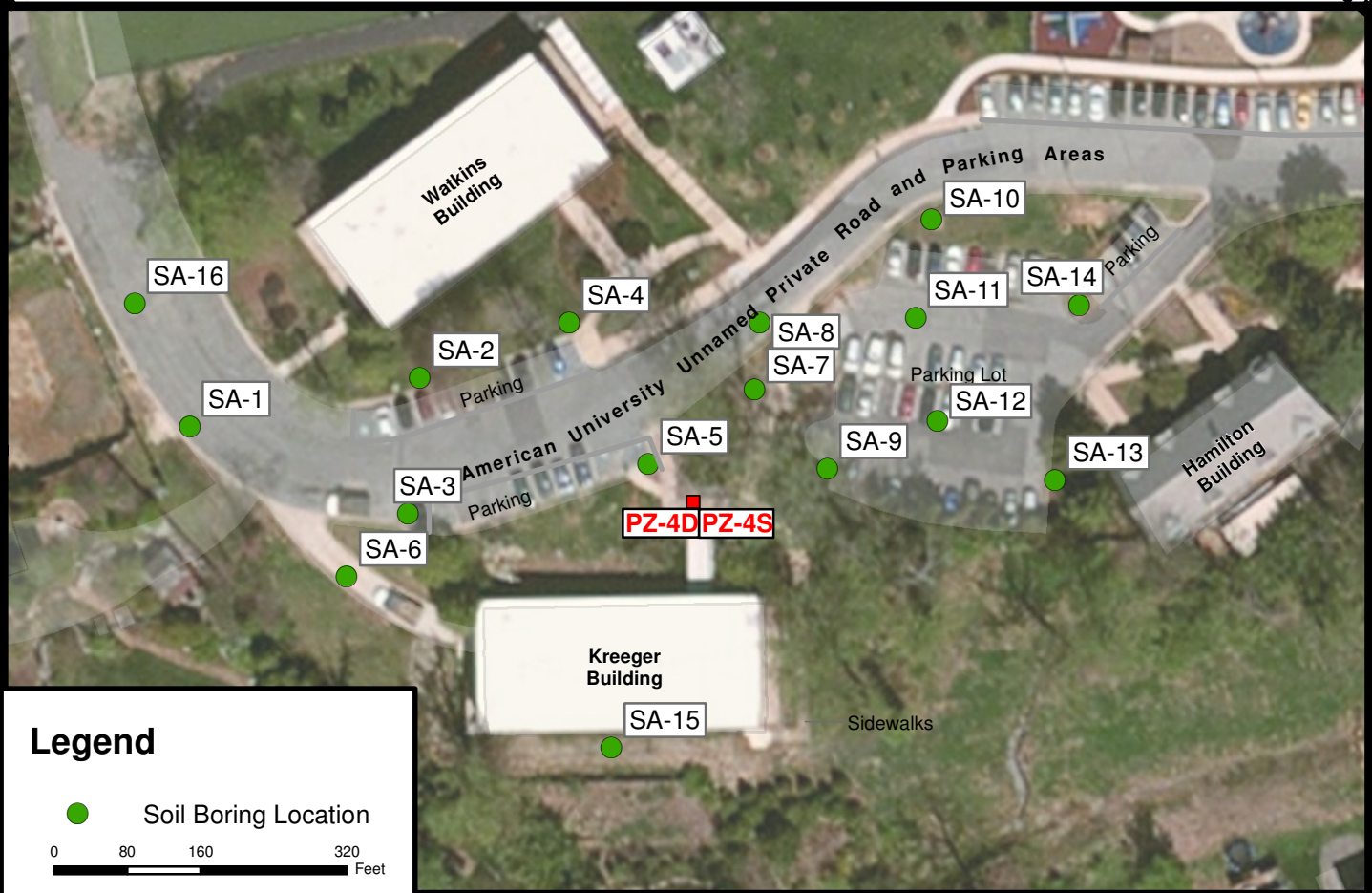
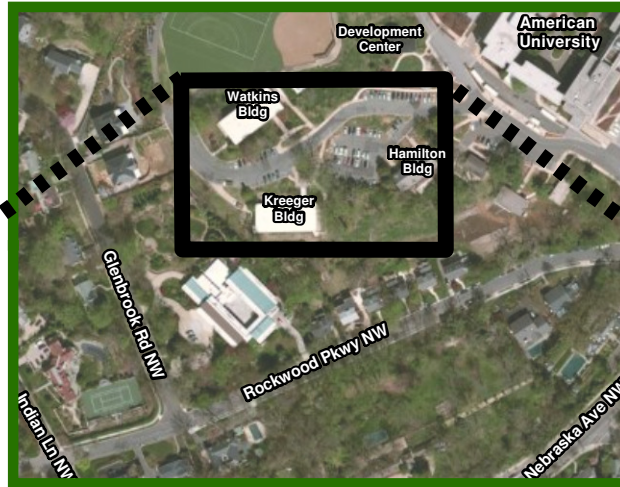
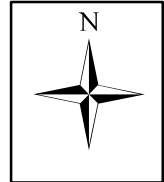
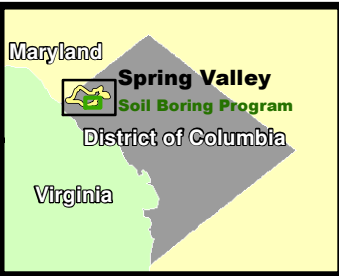
Legend

- Spring Valley FUDS Boundary
 - Surface Water Monitoring Location
- Base Map**
- Building/Structure
 - Non-Residential Urban
 - Parks and Recreation
 - Water
 - Stream or Creek
 - Topographic Contour
 - Road

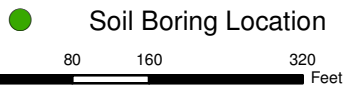


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Map Source: World Topographic Map, ESRI ArcGIS Online and data partners, 2011.



Legend



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Source: FLUTE™ Flexible Liner Underground Technologies, LLC.

Figure 3-3
Soil Boring Network

Spring Valley FUDS
Washington, DC

**Figure 4-1
Rose Diagrams for Bedrock Borings**

**Spring Valley FUDS
Washington, DC**

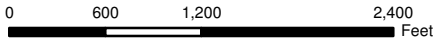
Legend

- Spring Valley FUDS Boundary
- Multiport Well
- Nested Bedrock Wells

S/D = monitoring well or piezometer with two screened intervals in the same borehole.

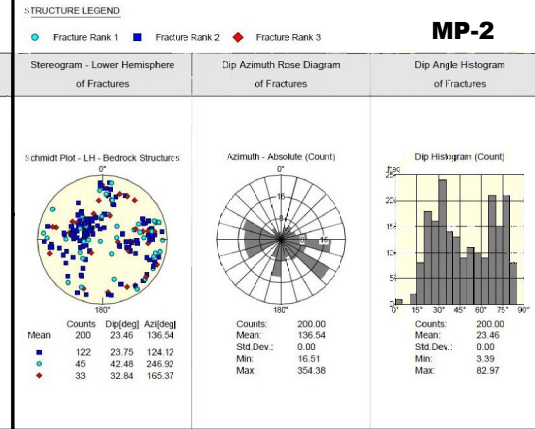
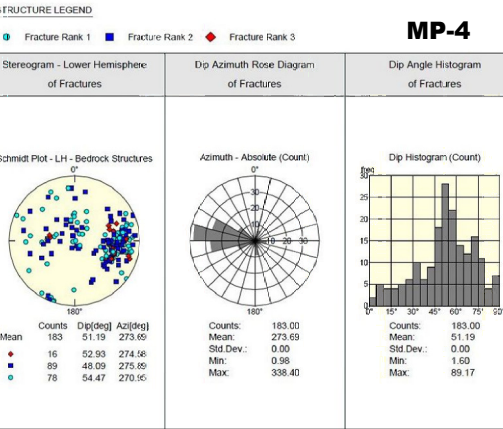
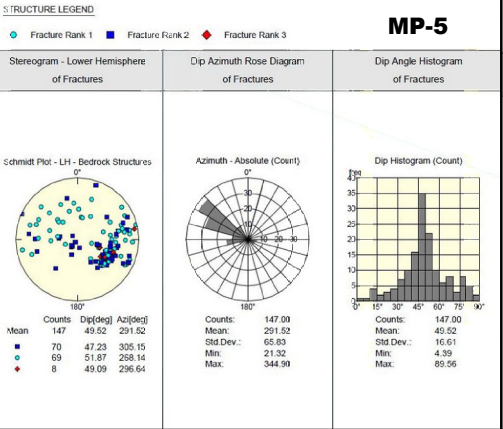
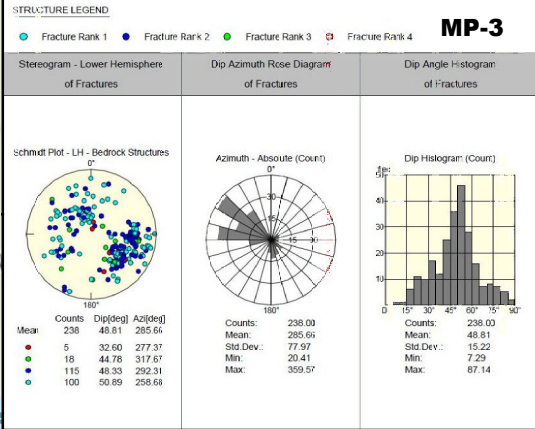
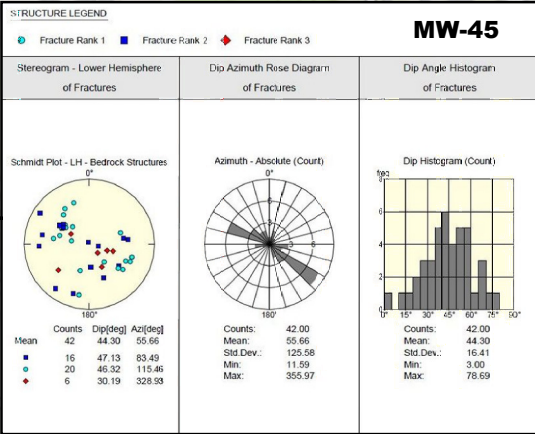
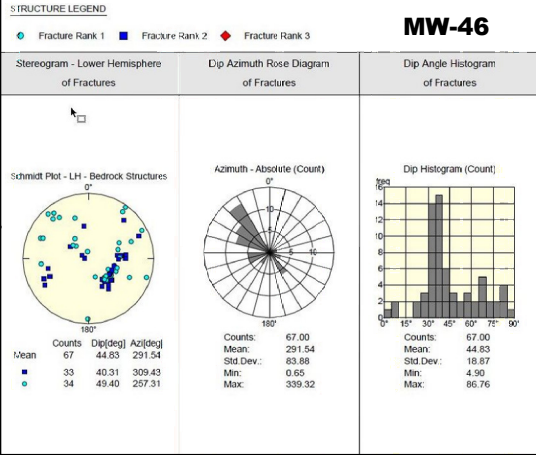
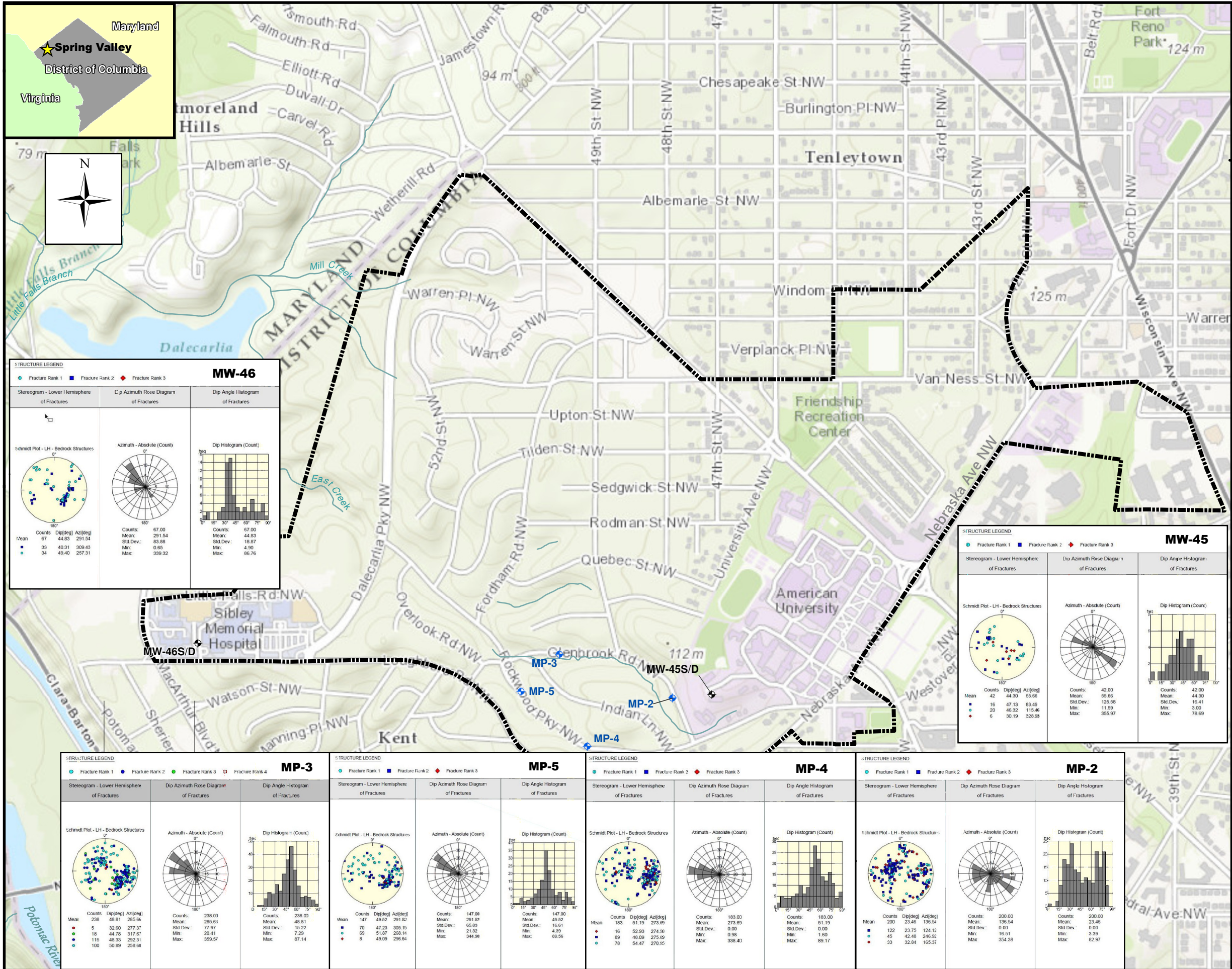
Base Map

- Building/Structure
- Non-Residential Urban
- Parks and Recreation
- Water
- Stream or Creek
- Topographic Contour
- Road

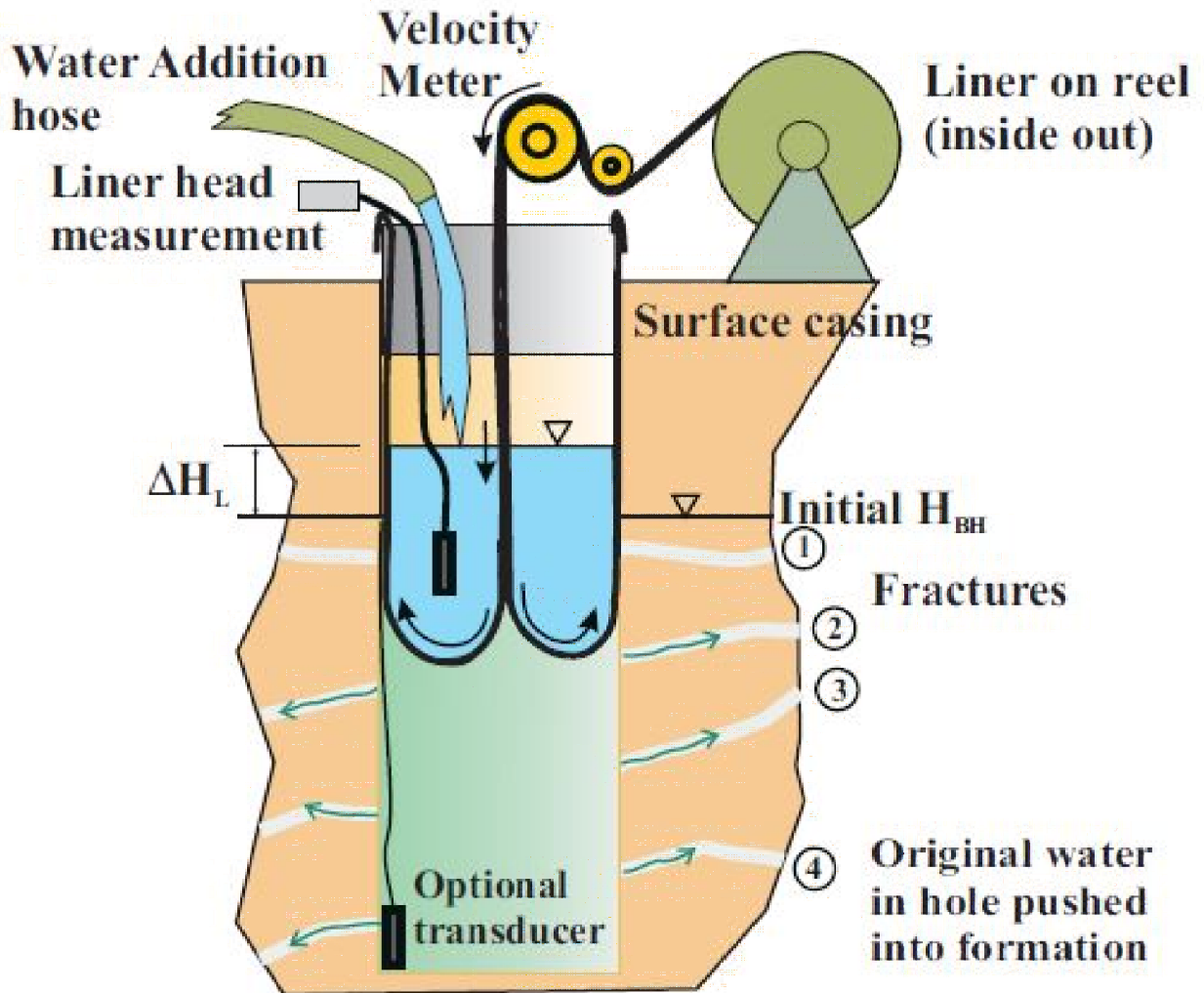


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Map Source: World Topographic Map, ESRI ArcGIS Online and data partners, 2011.



The liner installation



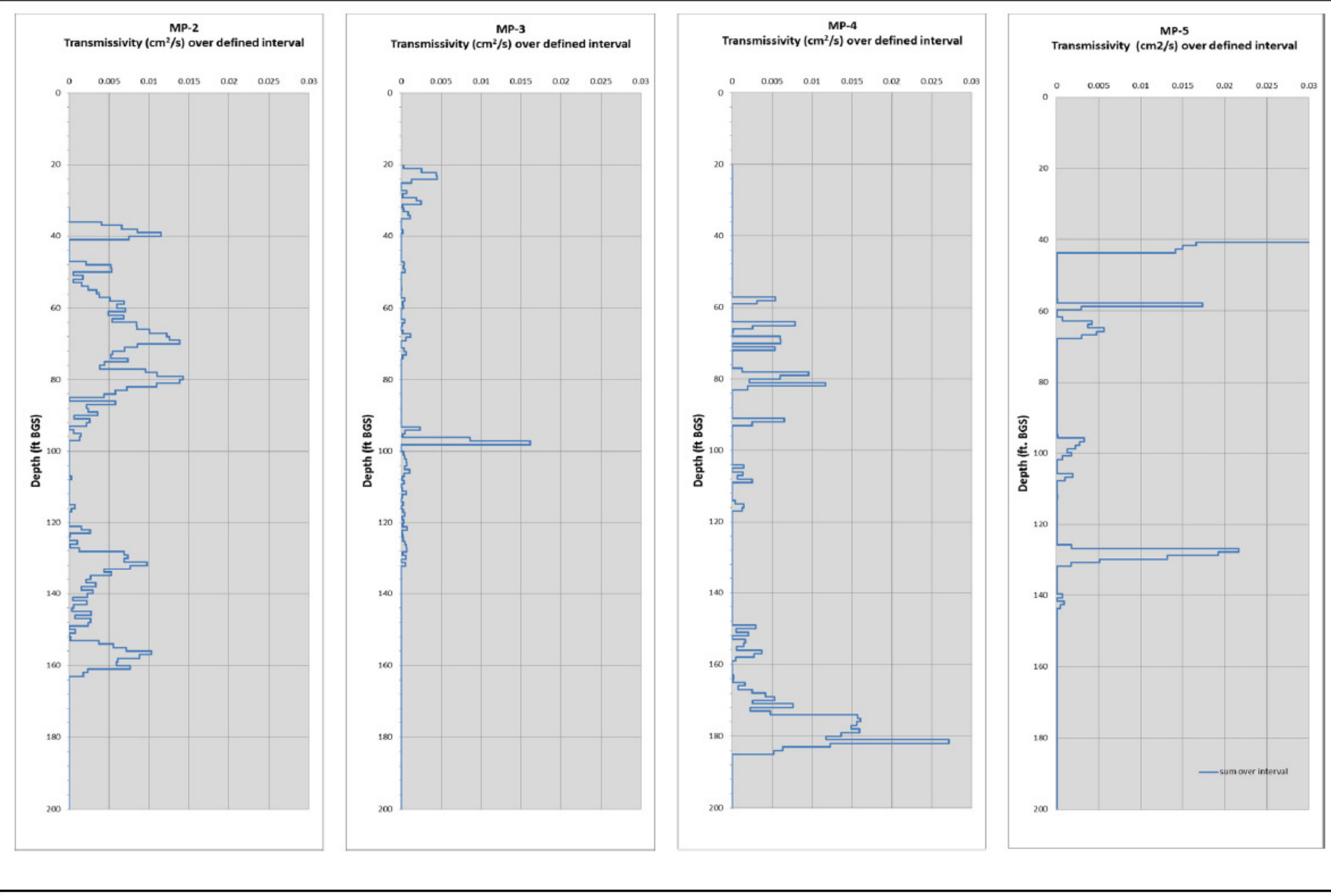
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Figure 4-2
FLUTE Liner Installation

Spring Valley FUDS
Washington, DC

Original Scale: NA
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 Revised: 2/25/2015
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Source: FLUTE™ Flexible Liner Underground Technologies, LLC.

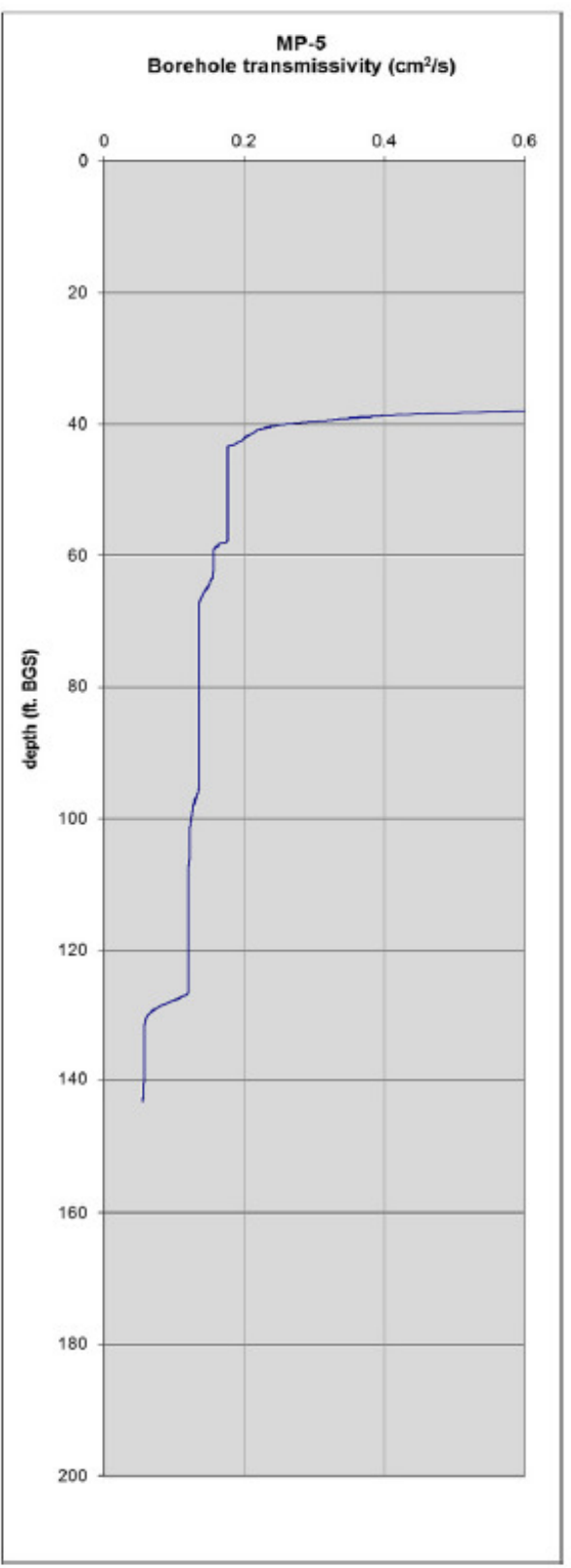
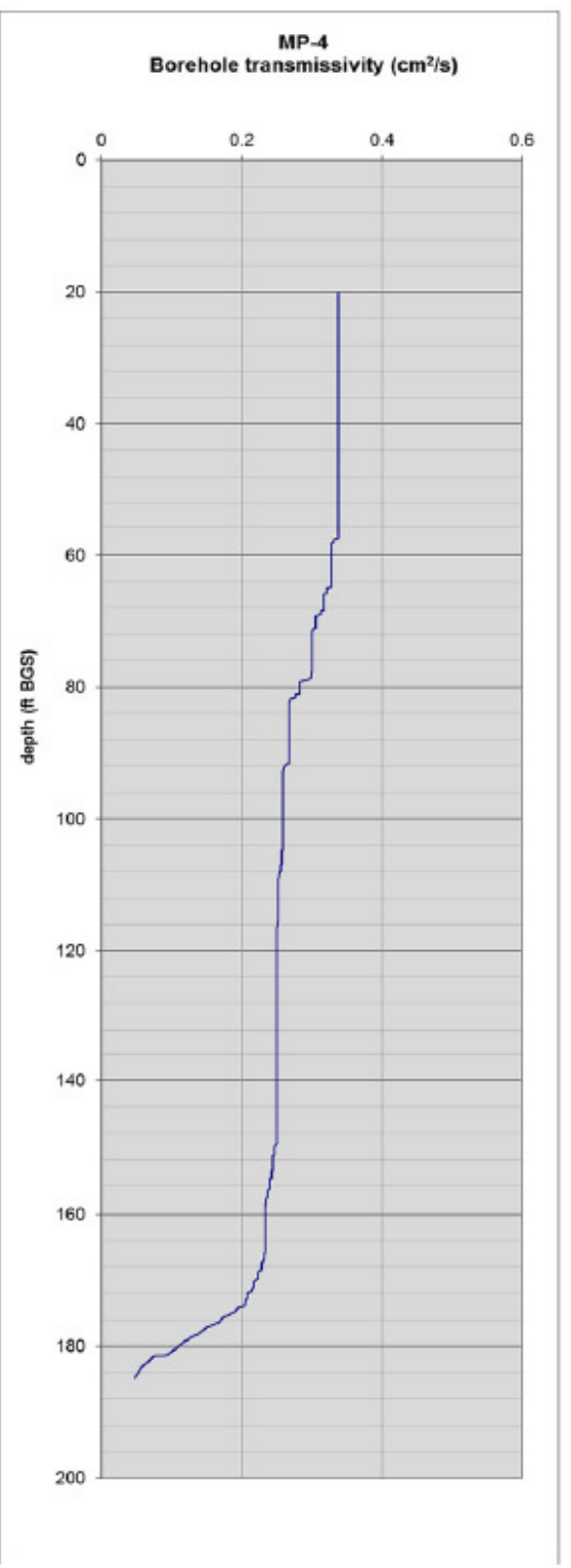
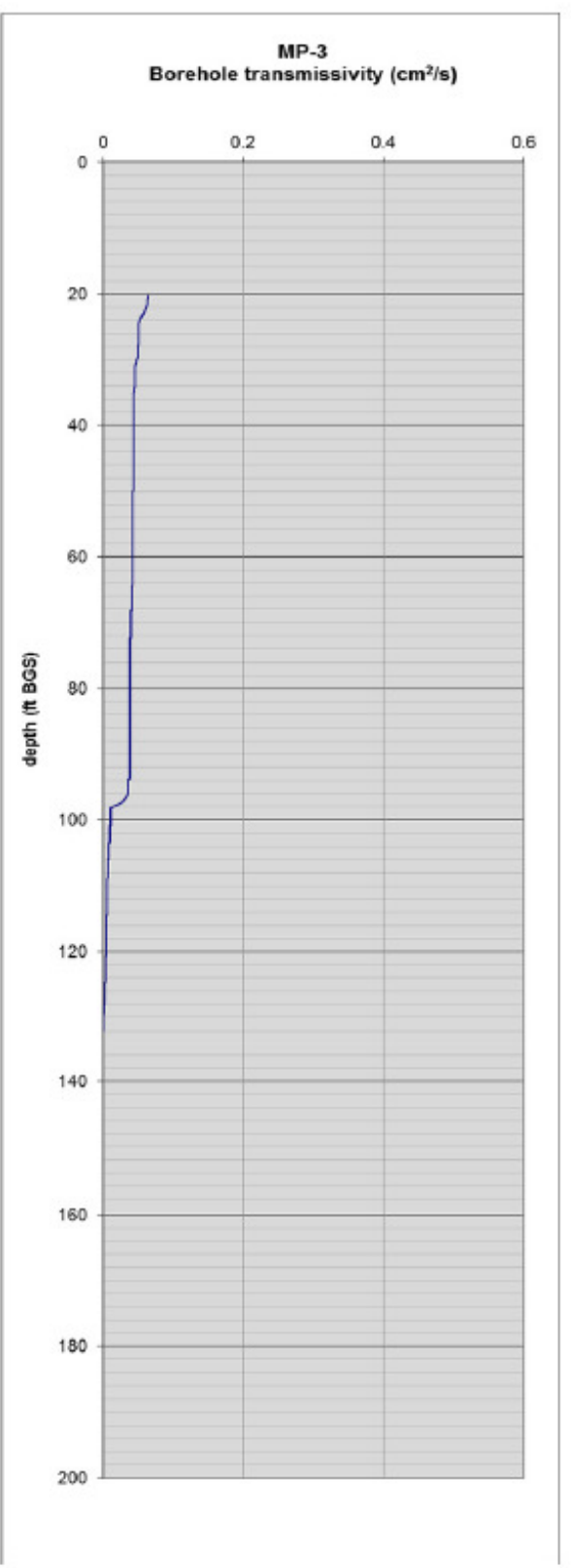
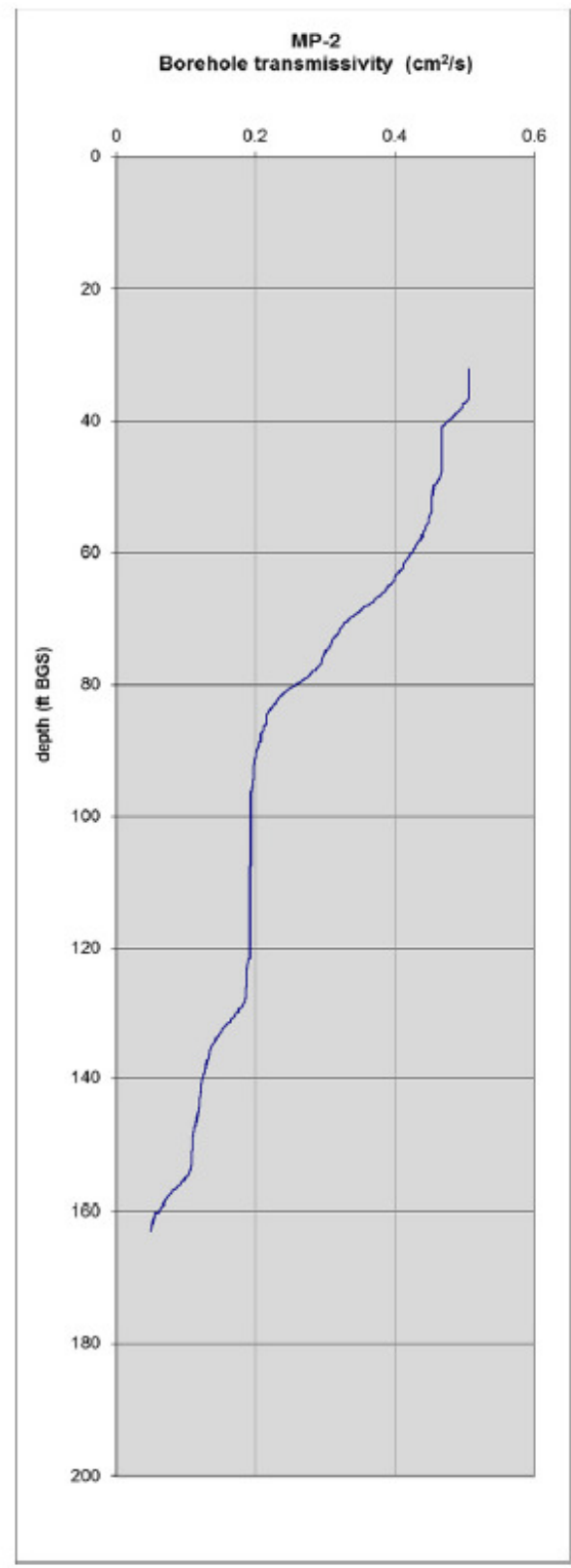


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Original Scale: NA
 Date: 3/31/2015
 Revised: 3/31/2015
 GIS: AER
 PM: BE
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Figure 4-3
Borehole Transmissivities
Over Defined Intervals

Spring Valley FUDS
Washington, DC



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301-820-3000

Original Scale: NA
Date: 3/31/2015
Revised: 3/31/2015
GIS: AER
PM: BE
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Figure 4-4
Borehole Transmissivities
Spring Valley FUDS
Washington, DC

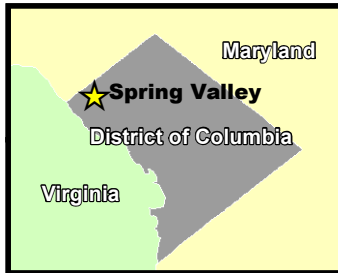
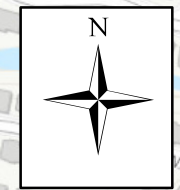
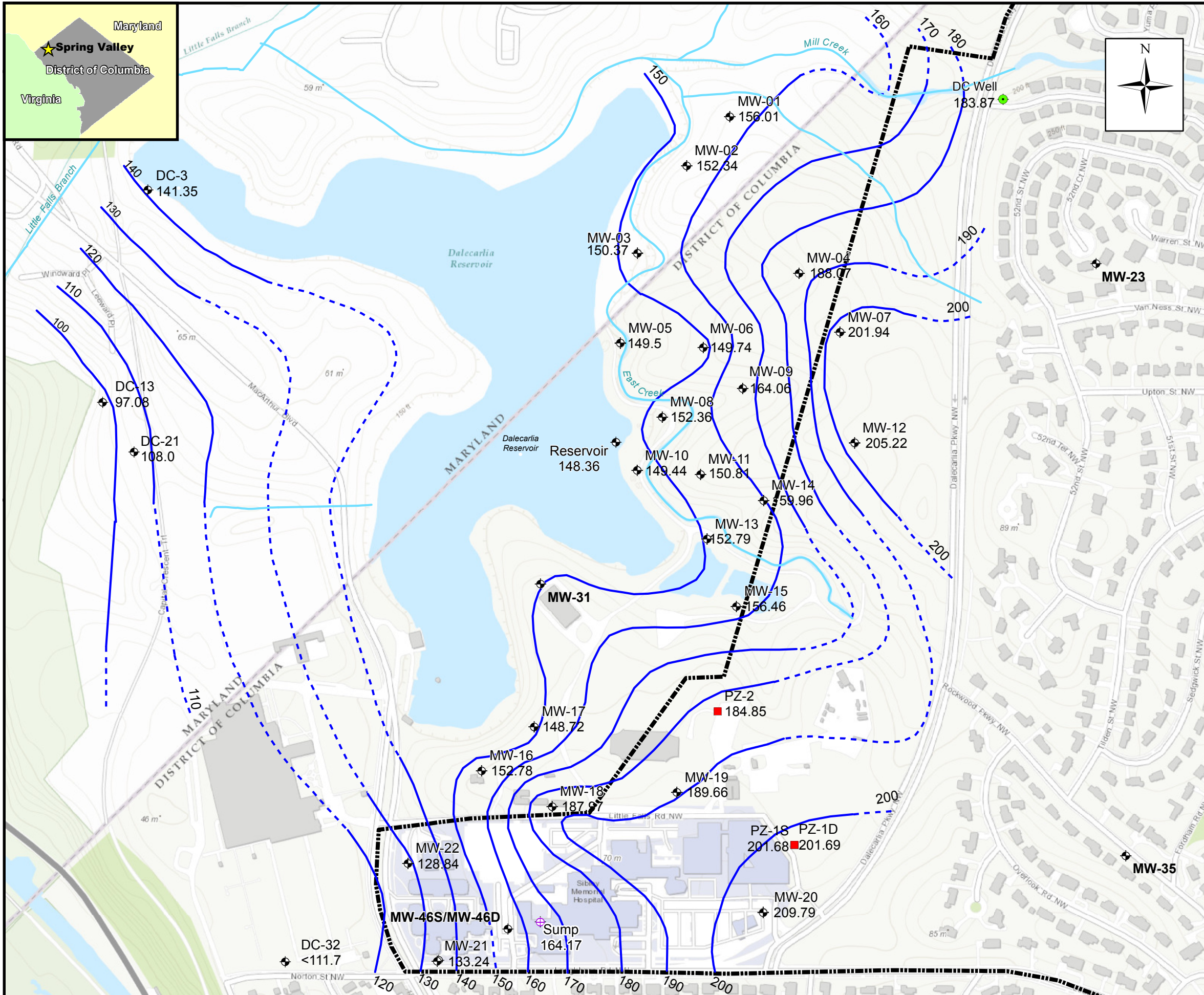


Figure 4-5
Water Table Contour Map
 December 2005
Spring Valley FUDS
Washington, DC



- Legend**
- Spring Valley FUDS Boundary
 - Piezometer
 - Monitoring Well
 - District of Columbia Well
 - Sibley Sump
 - Groundwater Contour (in feet)
 - Groundwater Contour (inferred)
- Base Map**
- Building/Structure
 - Non-Residential Urban
 - Parks and Recreation
 - Water
 - Stream or Creek
 - Topographic Contour
 - Road



Original Scale: 1:14,400
 Date: 2/24/2015
 Revised: 4/1/2015
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Map Source: World Topographic Map, ESRI ArcGIS Online and data partners, 2011.

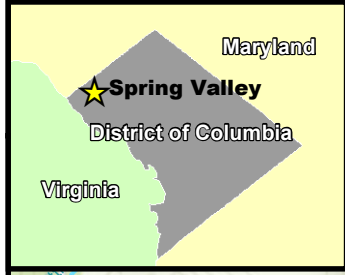
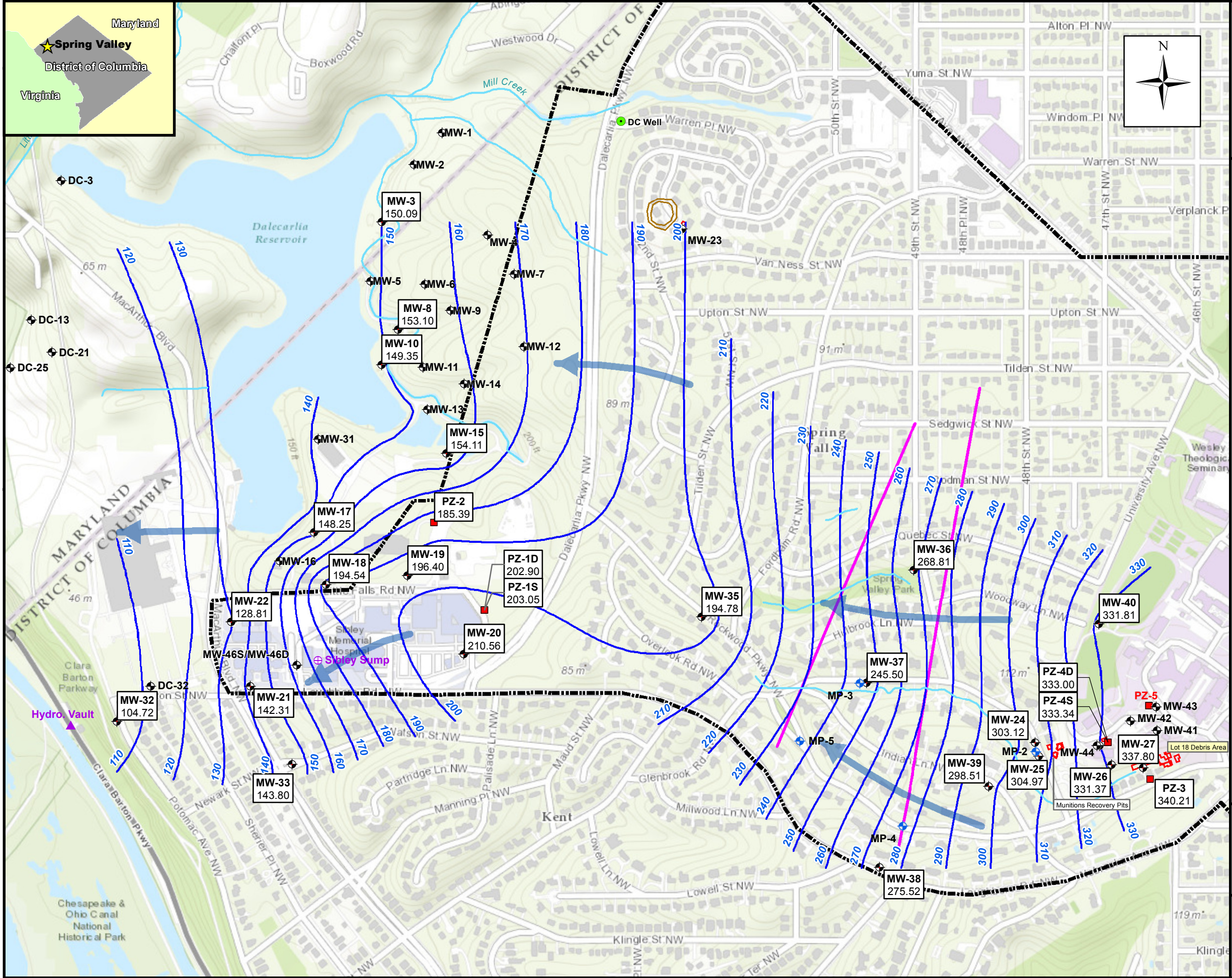
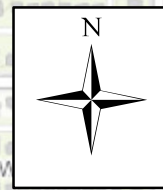


Figure 4-6
Water Table Contour Map
October 2009

Spring Valley FUDS
Washington, DC



Legend

- Spring Valley FUDS Boundary
 - Piezometer
 - Monitoring Well
 - District of Columbia Well
 - Sibley Sump
 - Hydroelectric Unit Vault
 - Groundwater Elevation Contour (feet)
 - Inferred Groundwater Flow Direction
- Base Map**
- Building/Structure
 - Non-Residential Urban
 - Parks and Recreation
 - Water
 - Stream or Creek
 - Topographic Contour
 - Fault (Fleming, et al. 1994)
 - Pit
 - Trench
 - Road



Original Scale: 1:14,400
Date: 2/24/2015
Revised: 4/1/2015
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Map Source: World Topographic Map, ESRI ArcGIS Online and data partners, 2011.

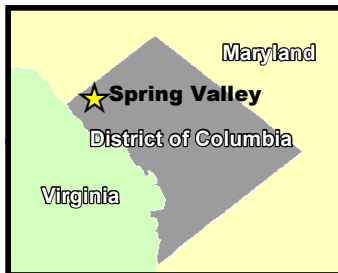
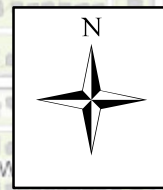
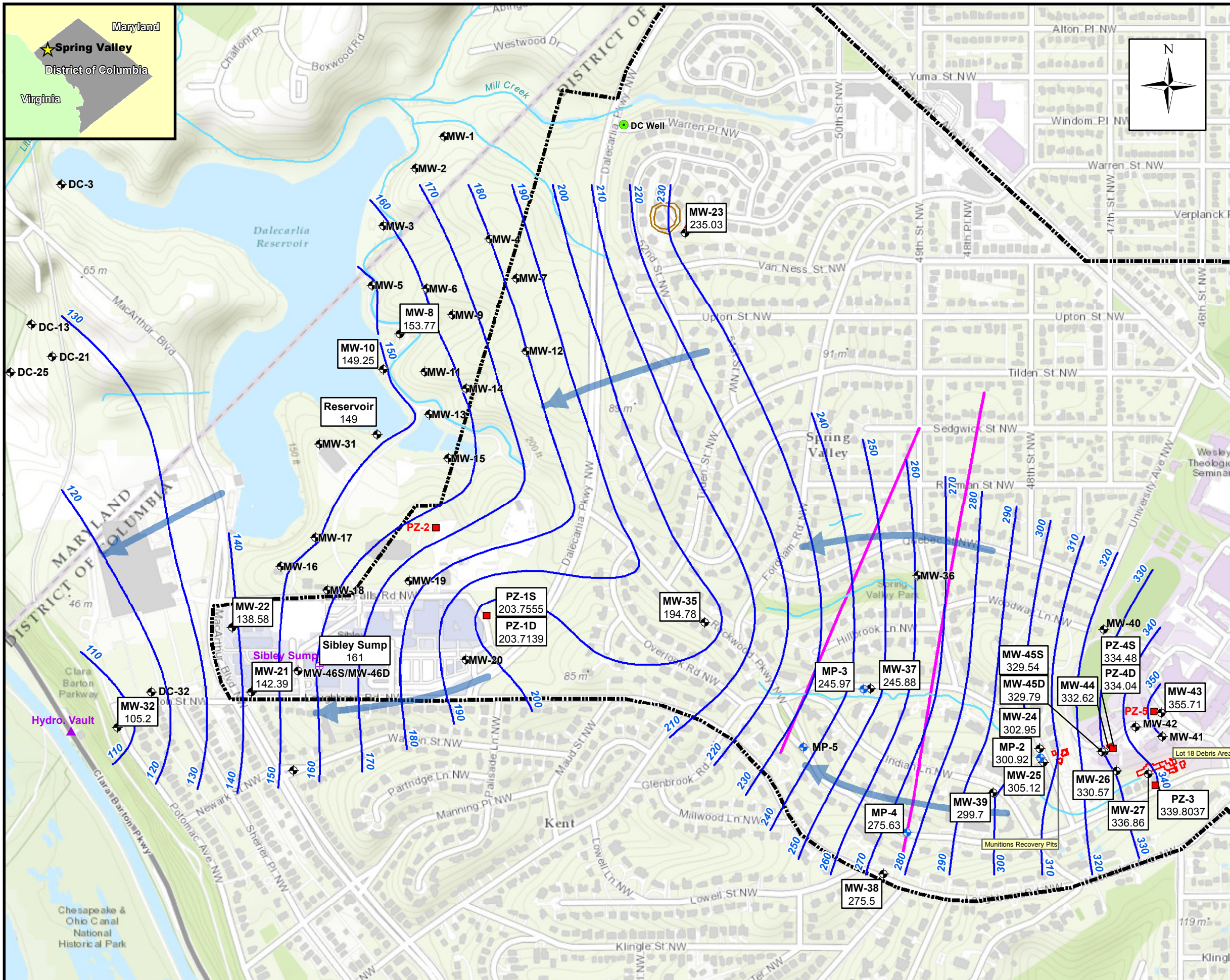
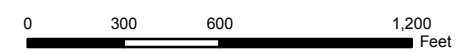


Figure 4-7
 Watertable Contour Map
 September 2012
Spring Valley FUDS
 Washington, DC



- Legend**
- Spring Valley FUDS Boundary
 - Piezometer
 - Monitoring Well
 - District of Columbia Well
 - Sibley Sump
 - Hydroelectric Unit Vault
 - Groundwater Elevation Contour (feet)
 - Inferred Groundwater Flow Direction
- Base Map**
- Building/Structure
 - Non-Residential Urban
 - Parks and Recreation
 - Water
 - Stream or Creek
 - Topographic Contour
 - Fault (Fleming, et al. 1994)
 - Pit
 - Trench
 - Road



Original Scale: 1:14,400
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Map Source: World Topographic Map, ESRI ArcGIS Online and data partners, 2011.

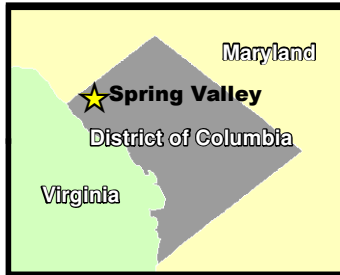


Figure 4-8
Location of Sections A-A' and B-B'
Spring Valley FUDS
Washington, DC

- Legend**
- Spring Valley FUDS Boundary
 - Cross-Section
 - Piezometer
 - Monitoring Well
 - Multiport Well
 - Sibley Sump
 - Hydroelectric Unit Vault
 - Surface Water Sample Location

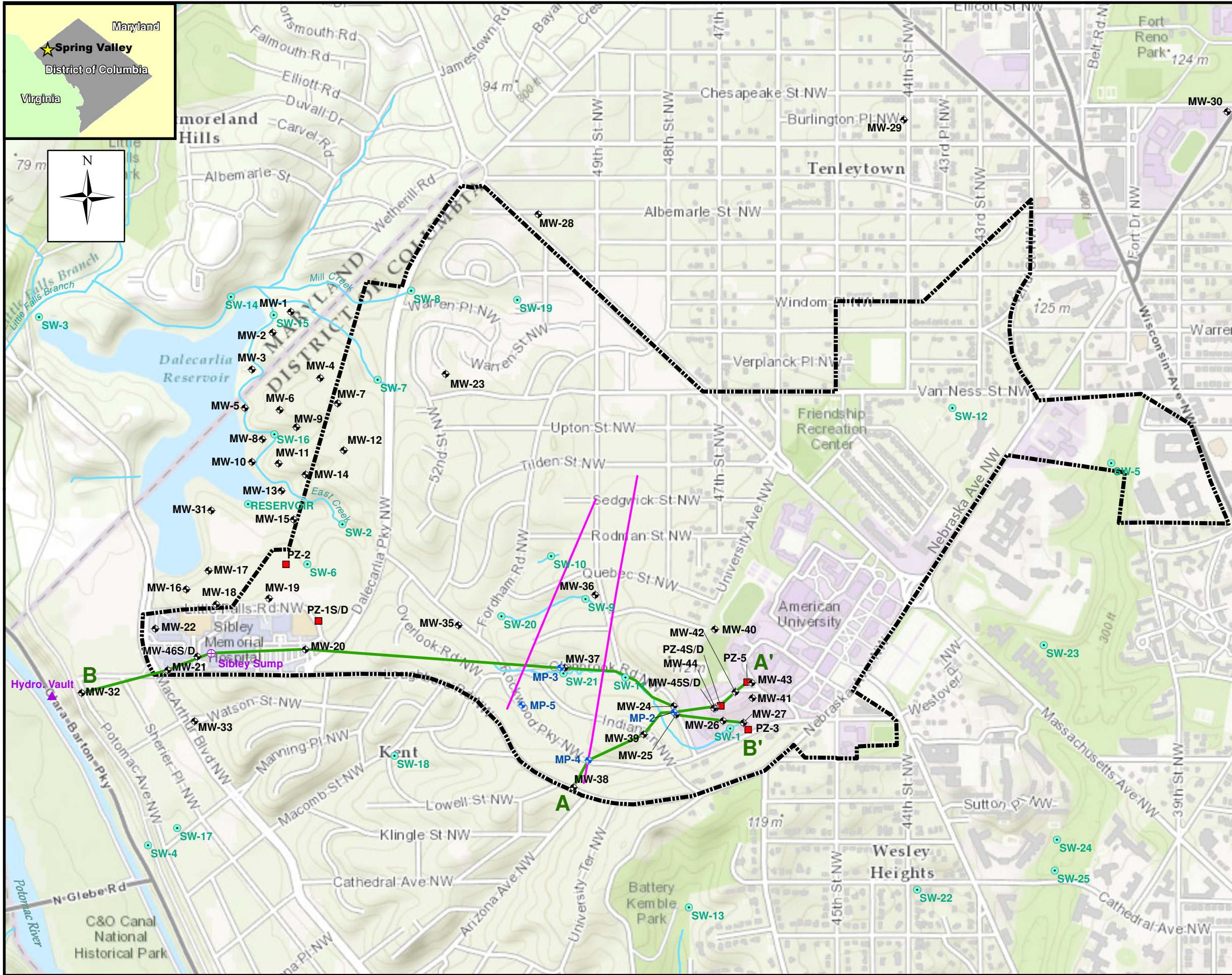
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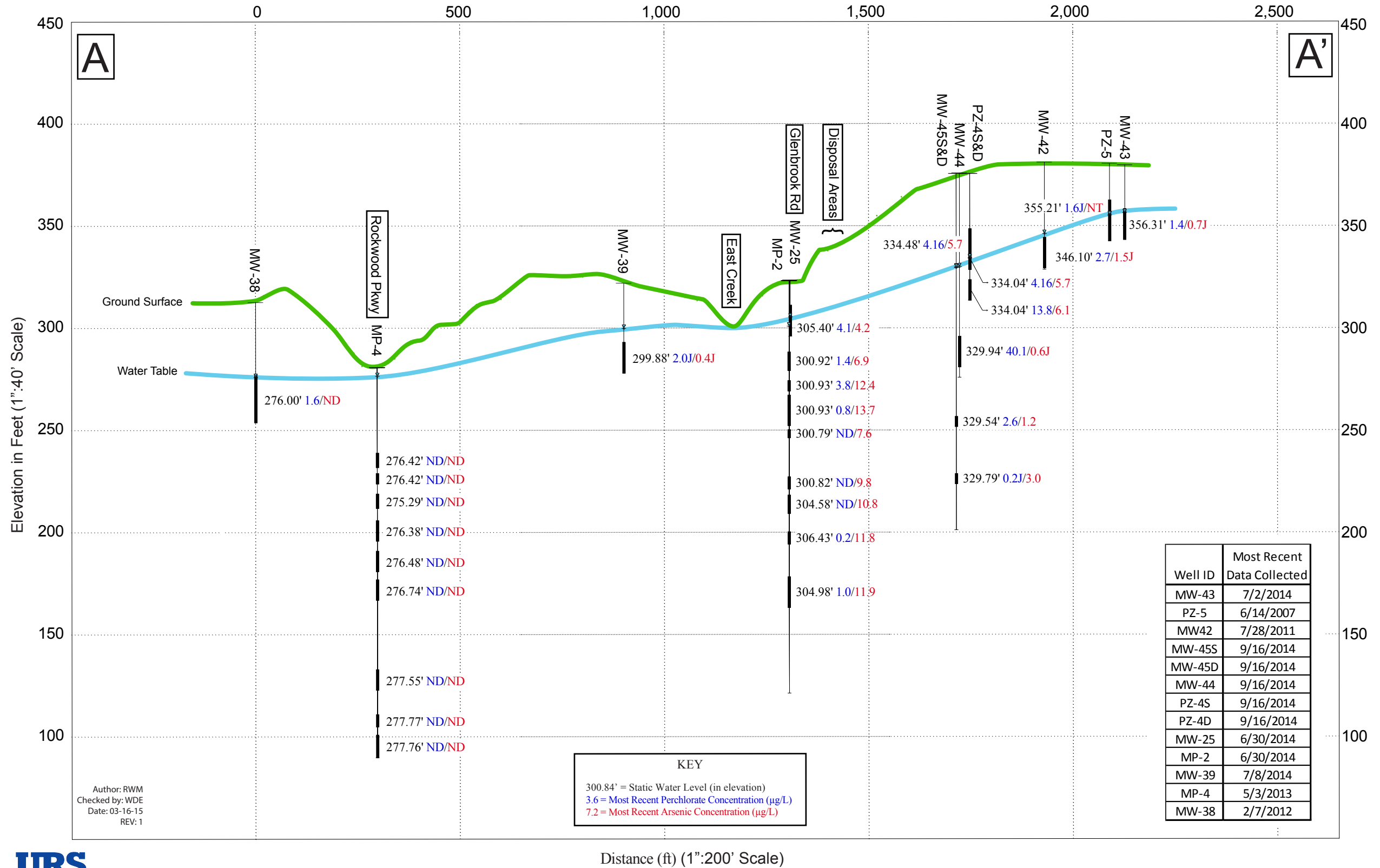
- Base Map**
- Building/Structure
 - Non-Residential Urban
 - Parks and Recreation
 - Water
 - Stream or Creek
 - Topographic Contour
 - Road
 - Fault (Fleming, et al. 1994)



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 Revised: 4/23/2015
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Map Source: World Topographic Map, ESRI ArcGIS Online and data partners, 2011.



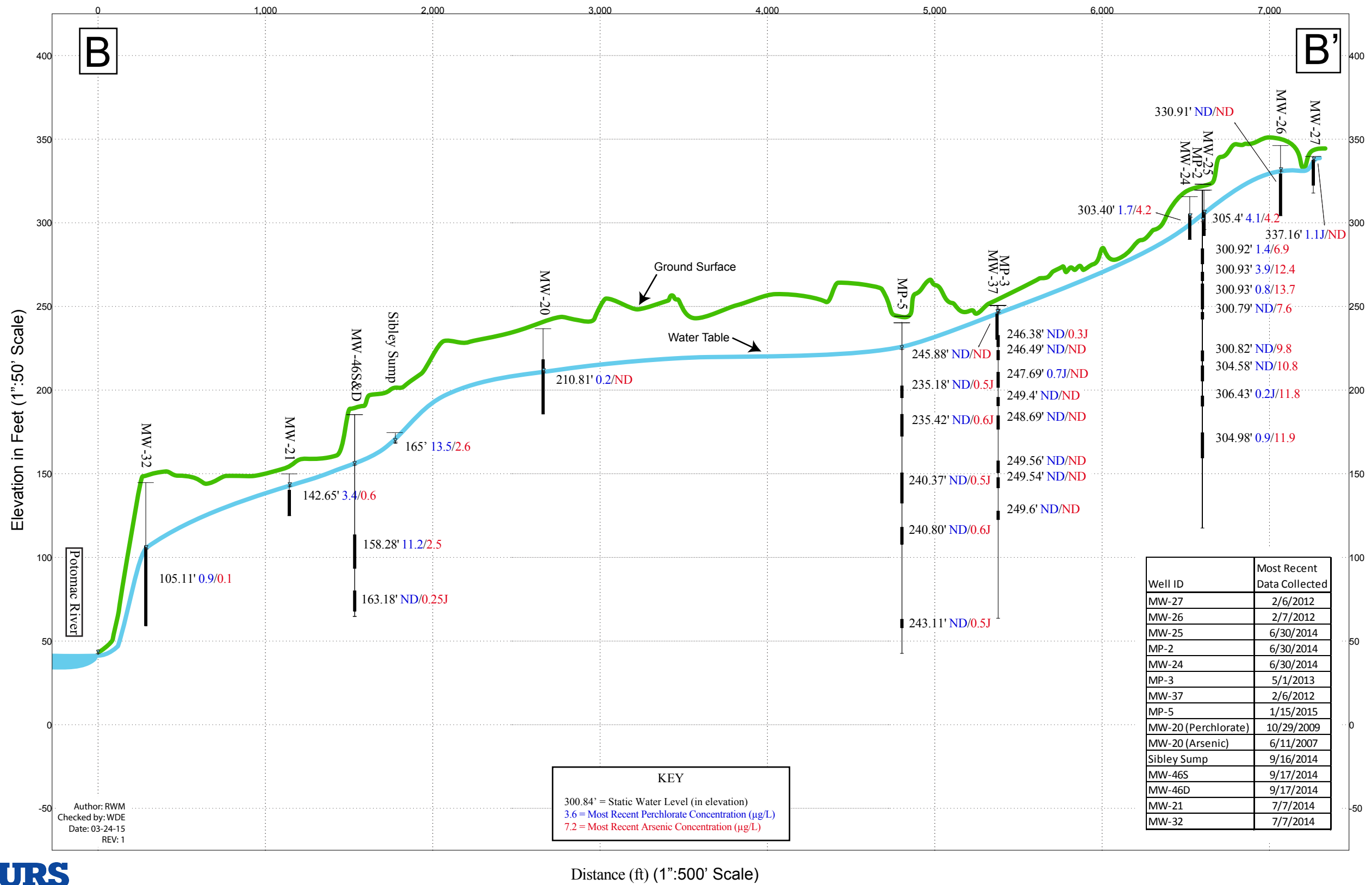


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 GIS: AER
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Figure 4-9
 Cross Section Along A-A'

Spring Valley FUDS
 Washington, DC



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Original Scale: NA
 Date: 3/26/2015
 Revised: 3/26/2015
 GIS: AER
 PM: BE
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Figure 4-10
 Cross Section Along B-B'
 Spring Valley FUDS
 Washington, DC

Figure 4-11
Arsenic and Perchlorate Results
Spring Valley FUDS
Washington, DC

Legend

- MW-16 Well ID
 - Surface Water Sample Location
 - USACE Monitoring Wells
 - USACE Piezometer
 - District of Columbia Monitoring Well
 - Sump
 - Hydroelectric Unit Vault
 - Lot 18 Drain Pipe
 - Possible SW-24 Storm Drain
 - Multiport Well
 - Nested Bedrock Wells
- MW: Monitoring Well
 MP: Multiport Well
 PZ: Piezometer
 SW: Surface Water
- Spring Valley Boundary
 - Pit
 - Trench
 - Building
 - Water
- Topography (USACE)
- 50-Foot Contour
 - 10-Foot Contour
 - 2-Foot Contour
- Topography (USGS)
- 50-Foot Contour
 - 10-Foot Contour
- Fault (Fleming, et al. 1994)
 - State Boundary

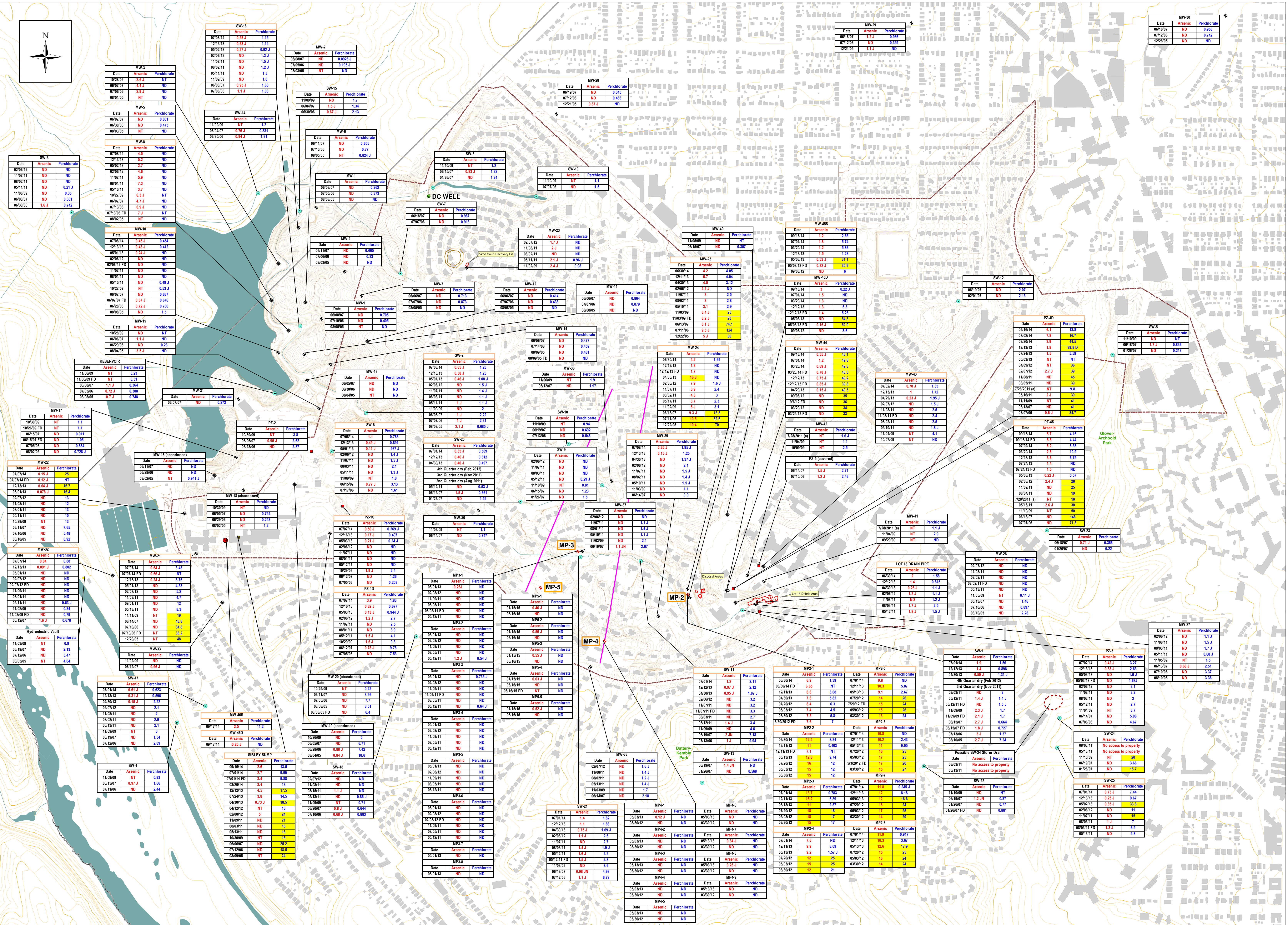
Sampling Location, Most Recent Sampling Event

All concentrations in ug/L
 FD = Field Duplicate
 ND = Not Detection
 NT = Not Tested
 J = Estimated Concentration
 (a) = Samples collected as grab samples (not low flow) during the Kreeger Hall area soil boring program.

MCL for Arsenic = 10 ug/L (ppb)
 Interim Drinking Water Health Advisory (DWHA) for Perchlorate = 15 ug/L (ppb)

Yellow background: Detections above MCL or DWHA

Original Scale: 1:14,400
 Date: 3/26/2015
 Revised: 3/29/2016
 GIS: AGR
 PM: BE
 G:\Projects\SpringValley\GISData\Projects\2016\Fig4-11_Arsenic_perchlorate_allLocations_20160225_Arche.mxd
 Map Source: Project base map, c.2004.



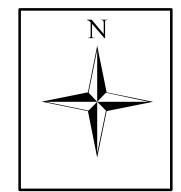
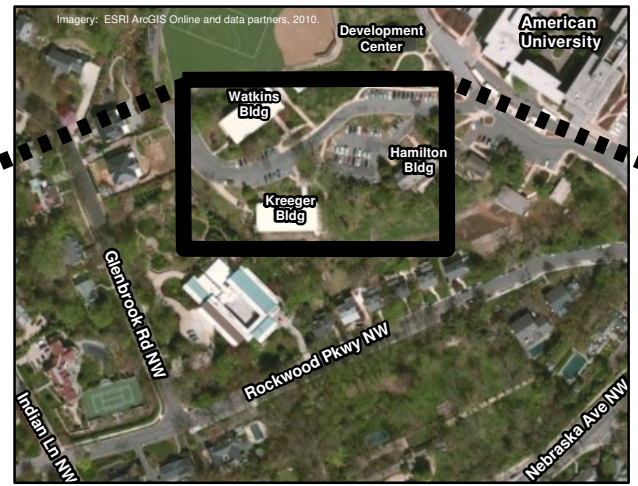
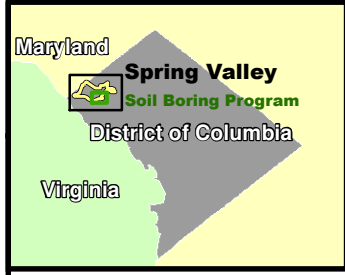
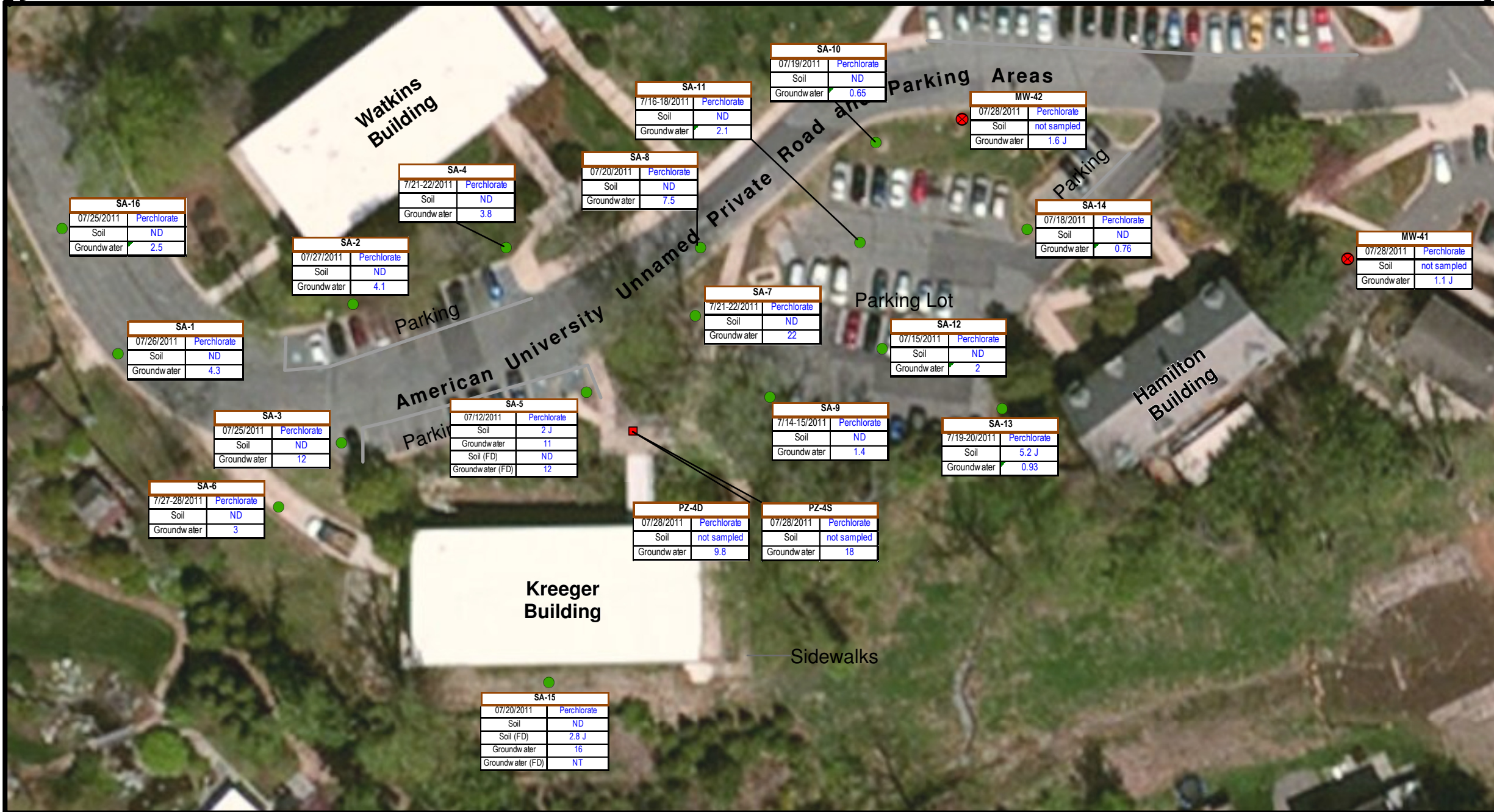


Figure 4-12
Source Area Investigation
American University Property
Spring Valley FUDS
Washington, DC

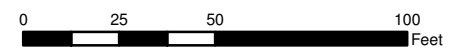
Legend

- Spring Valley FUDS Boundary
- Shallow Soil Boring Location
- Monitoring Well
- USACE Piezometer

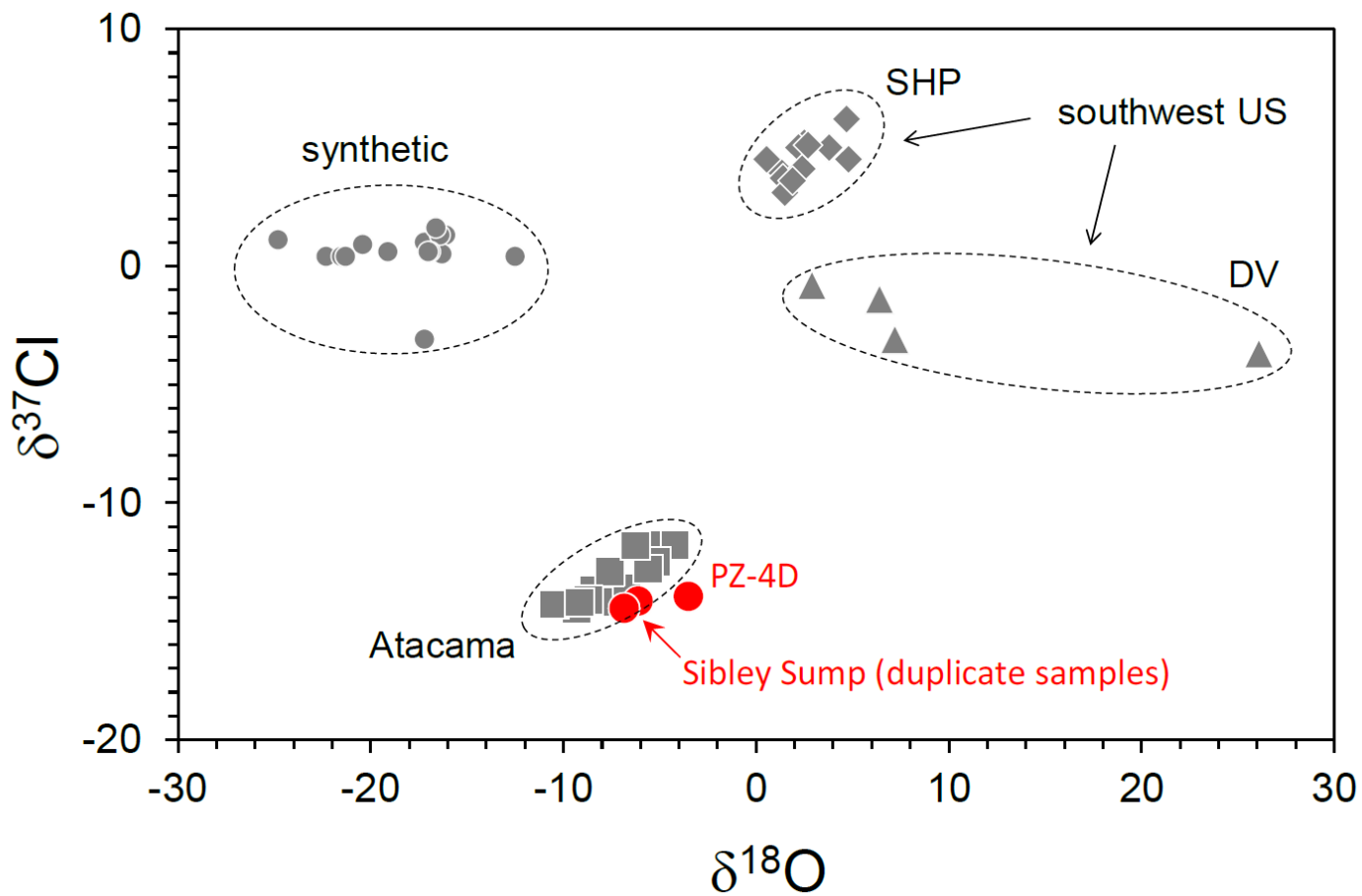


Boring	Groundwater Sample Type	Soil Sample Interval (ft, bgs)	Borehole Bottom (ft, bgs)
SA-1	OB	16-18	45
SA-2	OB	14-16	52
SA-3	OB	14-16	55
SA-4	TW	16-18	54
SA-5	OB	16-18	51
SA-6	OB	16-18	40
SA-7	OB	14-16	55
SA-8	TW	14-16	55
SA-9	TW	17.5-19.5	54
SA-10	OB	16-18	54
SA-11	OB	15-17	54
SA-12	OB	15-17	56
SA-13	OB	14-16	52
SA-14	OB	10-12	50
SA-15	OB	16-18	33
SA-16	OB	14-16	37

"TW" indicates Temporary Well
 "OB" indicates Open Borehole



Original Scale: 1:14,400
 Date: 2/23/2015
 Revised: 3/26/2015
 GIS: AER
 PM: BE
 G:\Projects\SpringValley\GISData\Projects\2015\Fig4-12_SpringValley_AU_BoringData_201107.mxd
 Imagery: ESRI ArcGIS Online and data partners, 2009.



Legend

SHP = Southern High Plains of the Southwestern United States
 DV = Death Valley of the United States



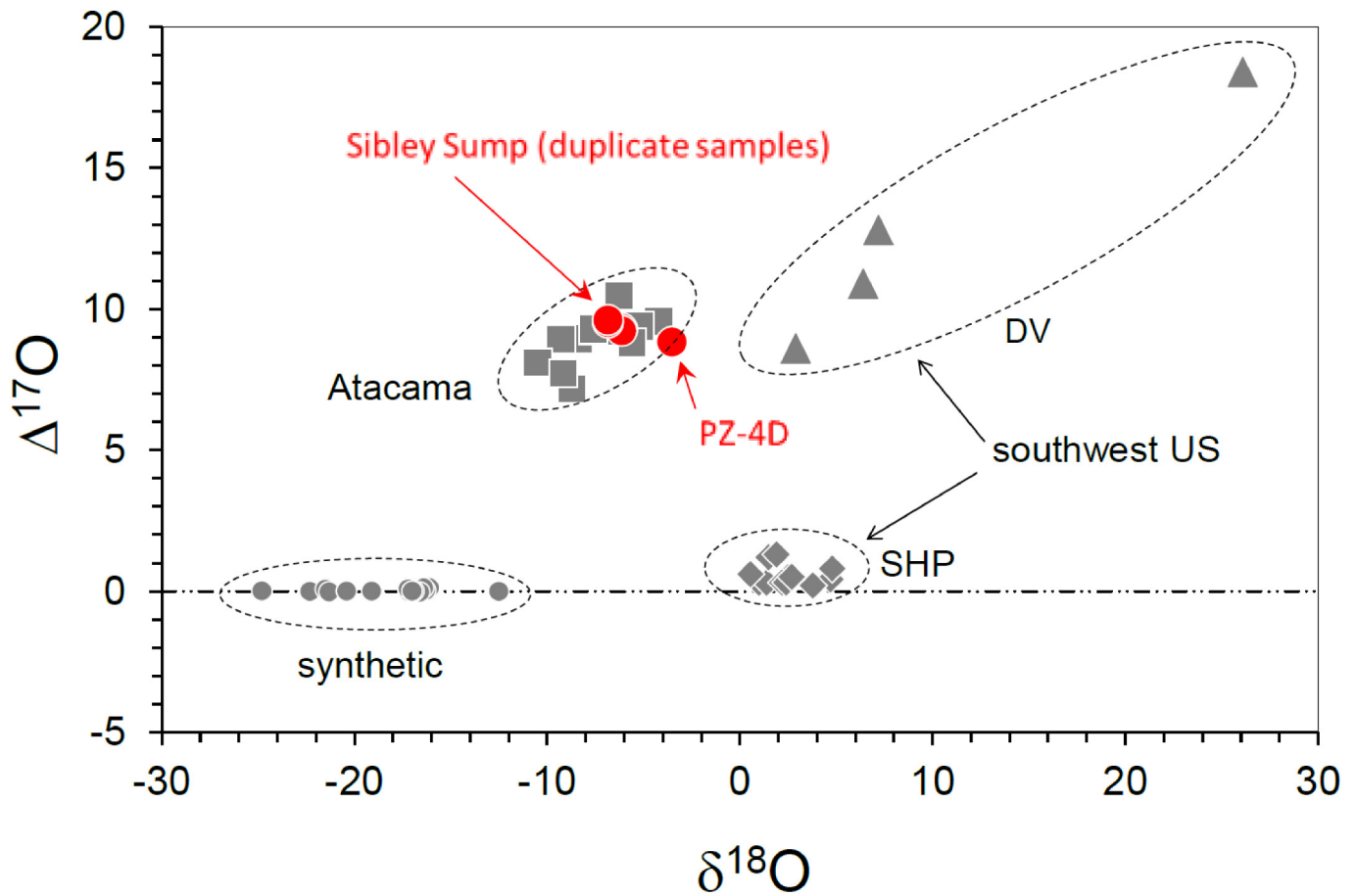
12420 Milestone Center Drive
 Germantown, MD 20876
 301-820-3000

Figure 4-13
Scatter Plot of δ³⁷Cl versus δ¹⁸O
for the Sibley Sump and PZ-4D
Perchlorate Samples

Spring Valley FUDS
Washington, DC

Original Scale: NA
 Date: 3/26/2015
 Revised: 3/26/2015
 GIS: AER
 PM: BE
 G:\Projects\SpringValley\GISData\Projects\2015\Fig4-13_SpringValley_ScatterPlot_37Cl_18O.mxd

Source: Report, Environmental Isotope Geochemistry Laboratory, Department of Earth and Environmental Sciences, University of Illinois at Chicago, September 19, 2012.



Legend

SHP = Southern High Plains of the
Southwestern United States
DV = Death Valley of the United States



12420 Milestone Center Drive
Germantown, MD 20876
301-820-3000

Original Scale: NA
Date: 3/26/2015
Revised: 3/26/2015
GIS: AER
PM: BE
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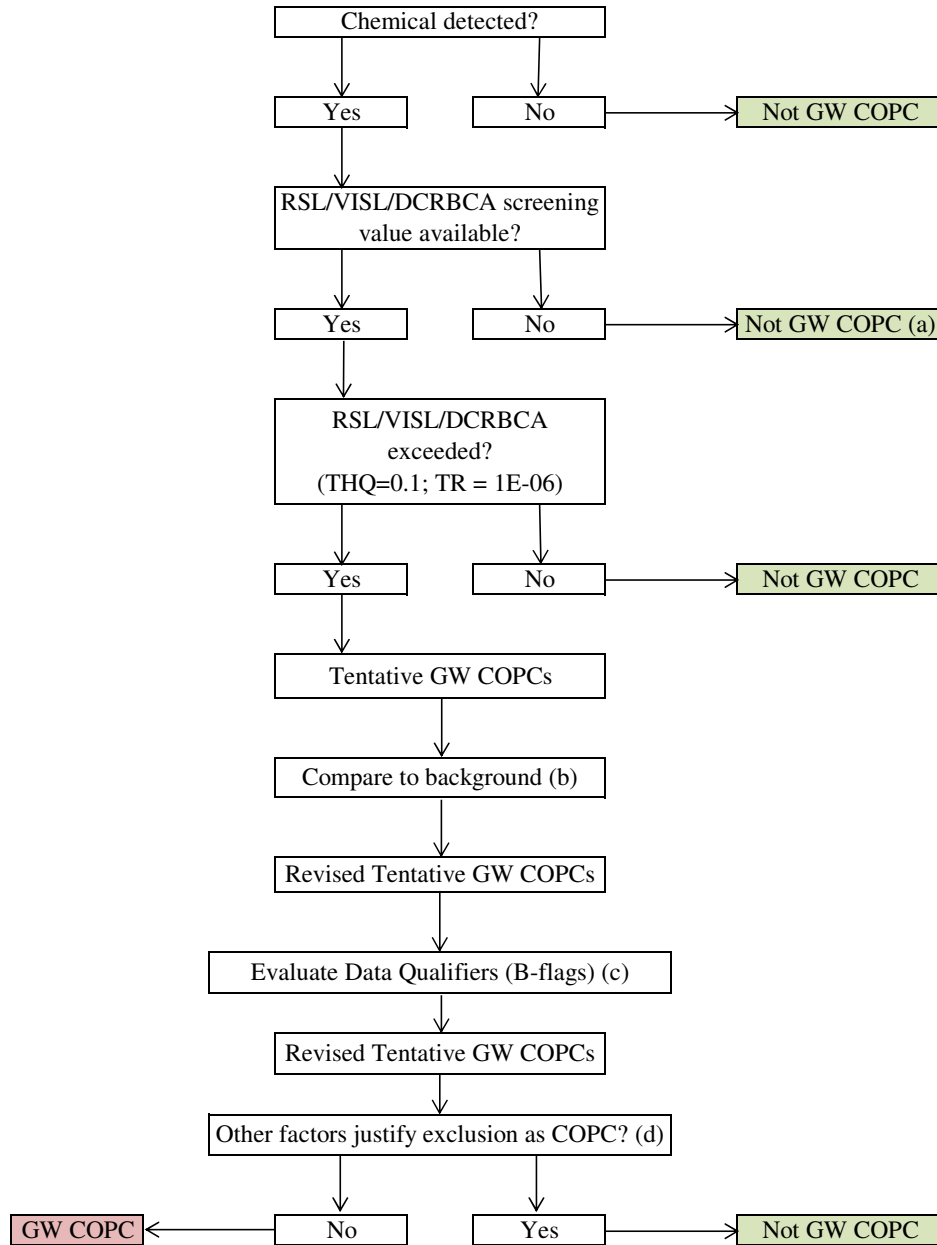
Source: Report, Environmental Isotope Geochemistry Laboratory, Department of Earth and Environmental Sciences, University of Illinois at Chicago, September 19, 2012.

Figure 4-14
Scatter Plot of $\Delta^{17}\text{O}$ versus $\delta^{18}\text{O}$
for the Sibley Sump and PZ-4D
Perchlorate Samples

Spring Valley FUDS
Washington, DC

Figure 5-1

Groundwater COPC Selection Process

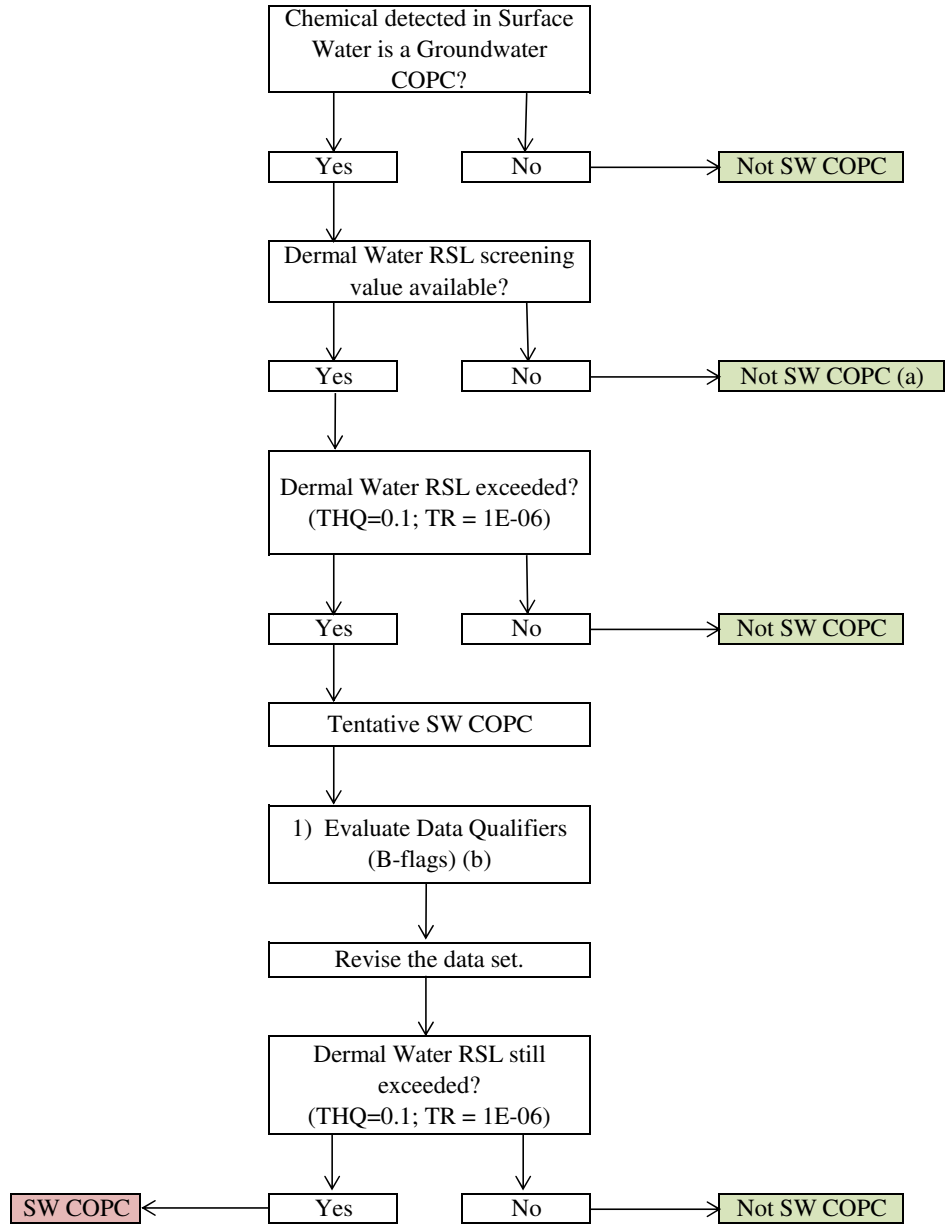


Notes:

- (a) Discuss uncertainties for chemicals lacking toxicity data. For each chemical: Indicate essential nutrient status, compare to background, and discuss in uncertainties section. Essential nutrients without RSLs are calcium, magnesium, phosphorus, potassium, and sodium.
- (b) If all concentrations responsible for exceedance of a screening value were less than the maximum detected concentration in any background well (MW-28, MW-29 or MW-30) then the chemical was eliminated as a tentative COPC
- (c) Data qualifiers will be evaluated to identify false-positive results (e.g., evaluation of B-flags) and false-positives will be eliminated as COPCs and individually discussed if any are eliminated based on this criterion.
- (d) Other factors to be considered include: detection frequencies, whether the RSLs is based on provisional toxicity data (this only applies to zirconium), and persistency across multiple sampling events.

Figure 5-2

Surface Water COPC Selection Process

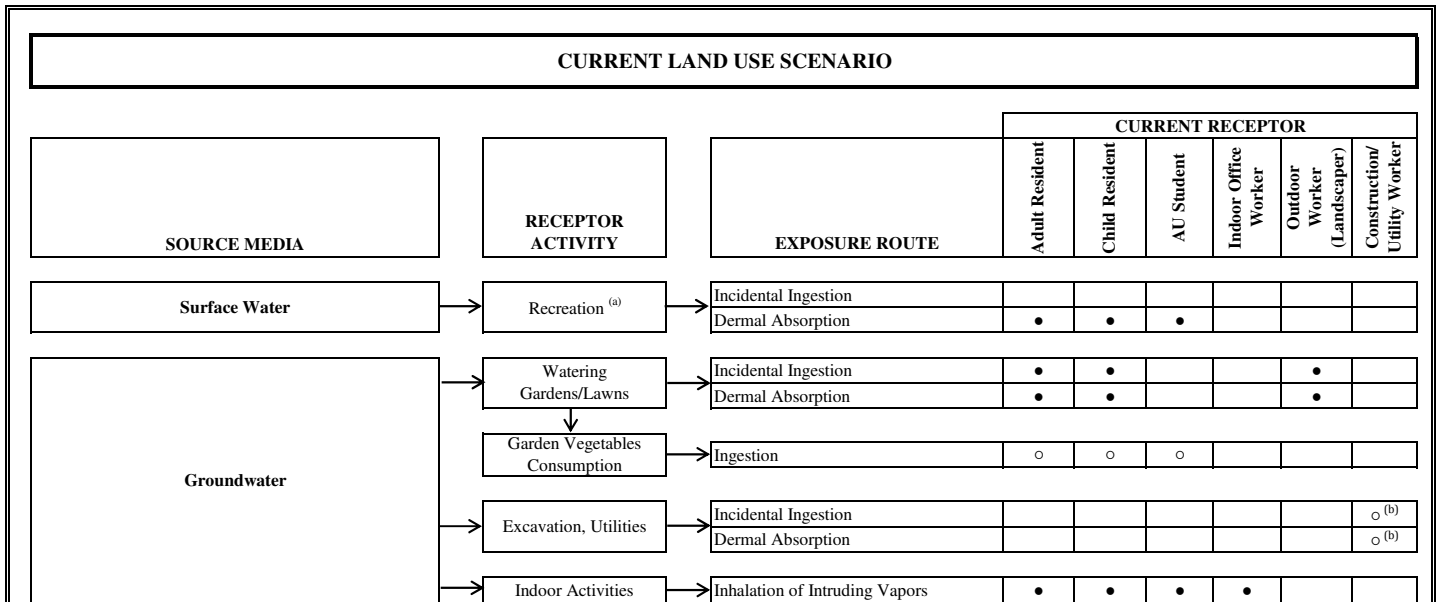


Notes:

(a) Discuss uncertainties for chemicals lacking toxicity data. For each chemical: Indicate essential nutrient status, compare to background, and discuss in uncertainties section. Essential nutrients without RSLs are calcium, magnesium, phosphorus, potassium, and sodium.

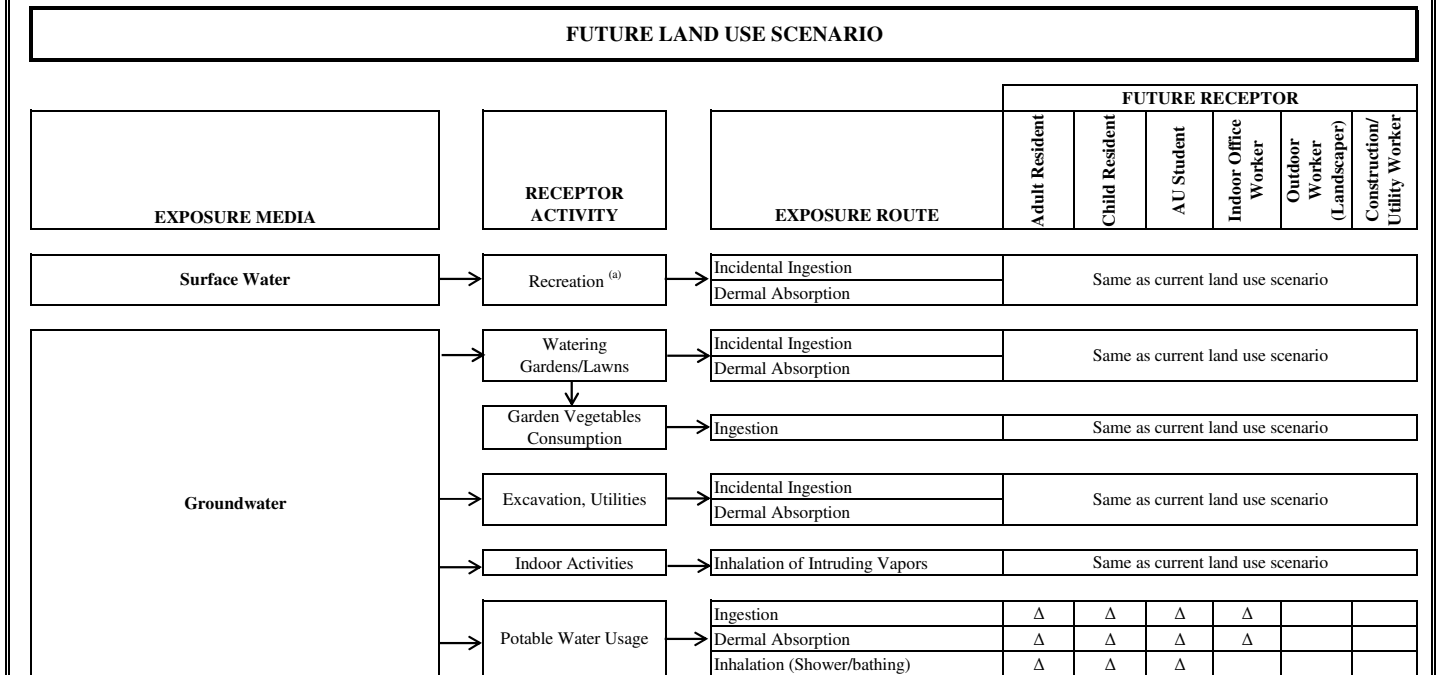
(b) Data qualifiers will be evaluated to identify false-positive results (e.g., evaluation of B-flags) and false-positives will be eliminated as COPCs and individually discussed if any are eliminated based on this criterion.

**Figure 5-3
Human Health Conceptual Site Model
SV FUDS**



(a) Assuming a wading scenario (not full immersion) for recreational activities.

(b) The depth to groundwater generally is much deeper than anticipated excavation depths (10 feet or less) for buildings or utility line work.



(a) Assuming a wading scenario (not full immersion) for recreational activities.

LEGEND

Symbol	Definition
•	Pathway complete and quantified in the risk assessment.
Δ	Pathway assumed to be complete for informational purposes only and, therefore, quantified in the risk assessment.
○	Pathway to be qualitatively evaluated.
	Pathway incomplete

TABLES

Table 1-1
Key Site Investigation Organizations

Organization	Responsibility
GPL Laboratories, LLP (GPL) and Southwest Research Institute	Water samples analysis
Analytical Laboratory Service, Inc. (ALSI)	Water and soil samples analysis
Edgewood Chemical Biological Center (ECBC)	On site screening of samples for chemical agents
Environmental Isotope Geochemistry Laboratory (EIGL)	Perchlorate oxygen isotope analysis
BL Myers Bros. and SGS North America, Inc.	Bedrock borehole drilling and bedrock monitoring construction
CENAB	Overburden drilling and screened monitoring well construction
Charles P. Johnson and Associates (CPJA) and B&R Design Group	Surveying of well and borehole locations.
Bloch Consulting, Inc. and Fine Earth Landscape, Inc.	Landscape appraisal
Traffic Engineering Services (TES)	Permitting and provision of traffic control devices
Hager-Richter Geoscience, Inc.	Bedrock borehole geophysics
Flexible Liner Underground Technologies, LLC (FLUTE)	Bedrock borehole profiling and lining
Insight LLC	Air-knifing to facilitate utilities avoidance
Potomac Environment, Inc. (PEI)	IDW Transportation

Table 1-2
Spring Valley FUDS Groundwater Study Objectives

Phase 1 Study Objectives	
Objective 1:	Determine if it is possible that perchlorate is entering the reservoir from the groundwater. For example, determine the relationship between the groundwater flow system to the east and south of the reservoir and the head within the reservoir to answer the question: Is seepage into or out of the reservoir?
Objective 2:	Determine if Former AUES/Spring Valley FUDS activities have impacted local groundwater quality.
Objective 3:	Determine if Former AUES/Spring Valley FUDS activities have impacted groundwater to the east of the reservoir.
Objective 4:	Determine the relationship between the groundwater flow system to the east and south of the reservoir and the head within the reservoir. For example, to answer the question: Is seepage into or out of the reservoir?
Objective 5:	Determine if perchlorate detections to the south of the reservoir are related to AUES/Spring Valley FUDS activities.
Phase 2 Study Objectives	
Objective 1:	Determine the relationship between the groundwater flow system to the east and south of the reservoir and the head within the reservoir.
Objective 2:	Determine the nature and extent of contamination south of the reservoir.
Objective 3:	Determine if contamination extends south of the AUES / Spring Valley FUDS boundary.
Objective 4:	Determine if perchlorate is introduced into the reservoir by GW at levels that would be a regulatory concern.
Objective 5:	Determine how much of a chemical in GW would need to enter the reservoir to elevate the concentration of that chemical by 1 ppb.
Objective 6:	Conduct further characterization of the Federal property directly east of the reservoir for other chemicals.
Objective 7:	Determine the nature and extent of contamination in groundwater in the Glenbrook Road and Rockwood Parkway area.
Objective 8:	Determine whether the shallow perchlorate plume is continuous between Sibley Hospital and the area of AU / Glenbrook Disposal Areas
Objective 9:	Sample GW discharge areas/surface water as part of GW quality evaluation.
Phase 3 and 4 Studies Objectives	
Objective 1:	Discover the source of the perchlorate plume beneath the AU property.
Objective 2:	Determine how much of the perchlorate plume is discharging locally into East Creek.
Objective 3:	Assess whether a portion of the plume migrates deeper into the bedrock aquifer.
Objective 4:	Find any connection between the AU perchlorate plume and the plume detected in the vicinity of Sibley Hospital.
Objective 5:	Determine whether groundwater and surface water arsenic and perchlorate concentrations change seasonally.
Objective 6:	Assess the potential for human exposure to groundwater and surface water; if potential exists, evaluate the health risks.
Objective 7:	Determine if estimated human health risks indicate a groundwater remediation requirement.
Phase 5 Study Objectives	
Objective 1:	Assess perchlorate and arsenic concentrations in shallow and deep bedrock groundwater in the area between American University (AU) and Sibley Memorial Hospital (Sibley Hospital) via the installation of a new deep bedrock multi-port well (MP-5) roughly between existing wells MP-3 and MP-4.
Objective 2:	Assess whether confirmed shallow groundwater contamination (perchlorate) at the Sibley Sump extends deeper into bedrock at this location, via the installation of a new nested deep bedrock monitoring wells MW-46S and MW-46D (also referred to as MW-46S&D).
Objective 3:	Continue to measure arsenic and perchlorate concentrations in surface water and shallow and deep groundwater at prior established monitoring locations.
Objective 4:	Present all groundwater investigation findings in a Remedial Investigation (RI) report, to also include a Human Health Risk Assessment (HHRA).
Objective 5:	Assess the need for potential groundwater remediation

**Table 3-1
Site Investigation Activities**

Groundwater Monitoring
<ul style="list-style-type: none"> -Select Monitoring Locations. -Secure Well Permits from Maryland for the few monitoring wells in Montgomery County. -Secure Well Permits and Traffic Control Plans as necessary from the District of Columbia for all other wells. -Public outreach to communicate pending field activities. -Conduct land appraisal and utility and MEC avoidance, as necessary. -Well drilling, construction, development and surveying. -Conduct borehole geophysical surveying of boreholes to be completed as multiport wells. -Conduct profiling (using blank liners) of boreholes to be completed as multiport wells. -Removal of blank liners and installation of multiport final liners to complete construction of the multiport wells. -Well water levels measurement, purging and sampling. -Samples analysis, data validation, data interpretation (inferred flow directions and and chemistry). -Discussion of the results with the Partners, scoping of additional investigation activities, and repeat of the above activities as necessary based on the available data. -Conduct perchlorate oxygen isotope analysis on one round of groundwater samples from PZ-4D and Sibley Sump. -IDW Management.
Surface Water Monitoring
<ul style="list-style-type: none"> -Select Monitoring Locations. -Public outreach to communicate pending field activities. -Samples analysis, data validation, data interpretation (inferred flow directions and chemistry). -Discussion of the results with the Partners, scoping of additional investigation activities, and repeat of the above activities as necessary based on the available data.
Soil Boring Program
<ul style="list-style-type: none"> -Coordinate with the Partners to develop a strategy to investigate the possibility of an undefined perchlorate source near PZ-4D. -Conduct surface geophysics to identify geophysical anomalies near PZ-4D (surveys were conducted by third parties). -Finalize temporary soil boring locations. -Conduct land appraisal and utility and MEC avoidance, as necessary. -Install borings and collect soil and groundwater samples. -Screen samples at SV FUDS for chemical agents prior to off-site sample shipment. -Samples analysis, data validation, data interpretation and discussion of all results with the Partners. -IDW Management.

Table 3-2
Monitoring Well and Piezometers Locations and Elevations

Monitoring Location ID Number	Location		Elevation (ft. msl)	
	Northing	Easting	Ground or Top of the Flush Casing	Top of Inner PVC Csg
MW-1	465668.33	1281873.27	174.1	176.11
MW-2	465469.01	1281697.82	180.26	182.3
MW-3	465113.55	1281497.47	164.01	165.74
MW-4	465032.01	1282155.2	217.06	219.23
MW-5	464747.21	1281428.01	167.62	169.38
MW-6	464728.55	1281765.28	196.77	199.4
MW-7	464791.09	1282321.94	240.64	242.67
MW-8	464447.48	1281598.36	165.27	166.99
MW-9	464564.18	1281925.84	176.95	178.57
MW-10	464228.86	1281496.27	168.36	169.85
MW-11	464213.27	1281753.58	192.1	194.55
MW-12	464341.35	1282381.99	240.53	242.78
MW-13	463951.13	1281780.76	167.55	169.1
MW-14	464108.21	1282011.15	176.23	178.46
MW-15	463677.13	1281899.86	168.43	169.9
MW-16	463009.36	1280863.43	202.98	205.36
MW-17	463188.48	1281077.02	191.43	192.98
MW-18	462863.12	1281150.38	216.21	218.99
MW-19	462921.11	1281658.11	222.74	225.7
MW-20	462433.69	1282009.07	240.55	240.33
MW-21	462233.87	1280681.93	153.68	153.42
MW-22	462632.26	1280562.64	160.04	159.85
MW-23	465068.92	1283369.27	259.51	259.26
MW-24	461883.48	1285558.46	319.43	319.25
MW-25	461801.21	1285580.78	323.37	323.09
MW-26	461746.85	1286034.56	350	349.62
MW-27	461728.11	1286229.66	343.58	343.28
MW-28	466597.6351	1284259.371	262.21	261.94
MW-29	467500.42	1287781.82	307.86	307.59
MW-30	467572.42	1290897.36	364.94	364.7
MW-31	463767.82	1281102.69	187.8	190.43
MW-32	462017.08	1279851.99	148.4	148.49
MW-33	461749.61	1280940.35	151.6	151.32
MW-34	Not Installed			
MW-35	462664.34	1283485.69	209.4	209.11
MW-36	462954.1	1284803.68	276	276.01
MW-37	462254.83	1284511.8	254.4	254.22
MW-38	461109.05	1284592.06	312.7	312.2
MW-39	461614.65	1285269.46	322	321.82
MW-40	462621.52	1285954.98	353.3	353.26
MW-41	461966.18	1286305.72	375.65	375.33
MW-42	462013.16	1286143.41	381.05	380.79

Table 3-2
Monitoring Well and Piezometers Locations and Elevations

Monitoring Location ID Number	Location		Elevation (ft. msl)	
	Northing	Easting	Ground or Top of the Flush Casing	Top of Inner PVC Csg
MW-43	462111.85	1286303.66	379.79	379.19
MW-44	461888.98	1285983.21	375.84	375.46
MW-45S	461885.76	1285976.15	375.64	375.43
MW-45D	461885.64	1285976	375.64	375.3
MW-46S	462533.23	1280932.94	189.23	188.77
MW-46D	462533.38	1280932.75	189.23	188.92
PZ-1S	462706.9881	1282136.859	219.6 (a)	219.60
PZ-1D	462706.9621	1282136.776	219.52 (a)	219.52
PZ-2	463250.2681	1281823.55	216.9 (a)	216.90
PZ-3	461659.6415	1286275.121	351.87 (a)	351.87
PZ-4S	461886.8077	1286011.574	375.53 (a)	375.53
PZ-4D	461886.8899	1286011.639	375.54 (a)	375.54
PZ-5	462114.0895	1286266.88	380.53 (a)	380.53
MP-1	MW-44 and MW-45S and MW-45D fulfill the MP-1 technical requirements. MP-1 was not installed.			
MP-2	461809.64	1285576.92	323.21	322.06
MP-3	462254.63	1284518.27	254.44	253.86
MP-4	461380.84	1284713.33	280.87	279.91
MP-5	461895.23	1284084.42	244.28	243.53
Sibley Sump	462395.4	1281101.8	na	na
Hydroelectric Vault	461993.32	1279564.96	na	na

(a) Estimated from inner PVC casing elevation.

'na' = Not applicable

**Table 3-3
Monitoring Wells, Piezometers, Sump, and Vault Comprising the SV FUDS Groundwater Monitoring Network**

Monitoring Location ID Number	Construction Timeframe	Rational (a)	Type (b)	Monitored Zone (c)	Finish Type (c)	Hole Bottom (ft, bgs)	Casing Bottom (ft, bgs)	Open Borehole Length (ft)	Screen Top (ft, ft, bgs)	Screen Bottom (ft, bgs)	Screen length (ft)	Sample Port Top (ft, bgs)	Sample Port Bottom (ft, bgs)	Sample Port Length (ft)		
MW-1	2005 (Spring)	A	2" Screen	DBR	Stickup	33.5	na	na	18.3	33.3	15	na	na	--		
MW-2	2005 (Spring)	A	2" Screen	OB & DBR	Stickup	45	na	na	24.5	44.5	20	na	na	--		
MW-3	2005 (Spring)	A	2" Screen	OB	Stickup	27	na	na	7.8	22.8	15	na	na	--		
MW-4	2005 (Spring)	A	2" Screen	DBR	Stickup	37	na	na	21.8	36.8	15	na	na	--		
MW-5	2005 (Spring)	A	2" Screen	OB	Stickup	27	na	na	11.8	26.8	15	na	na	--		
MW-6	2005 (Spring)	A	4" Open BR BH	CBR	Stickup	64	49.1	14.9	na	na	na	na	na	--		
MW-7	2005 (Spring)	A	2" Screen	DBR	Stickup	49.9	na	na	34.7	49.7	15	na	na	--		
MW-8	2005 (Spring)	A	2" Screen	OB	Stickup	28	na	na	4.8	19.8	15	na	na	--		
MW-9	2005 (Spring)	A	4" Open BR BH	CBR	Stickup	29.2	15	14.2	na	na	na	na	na	--		
MW-10	2005 (Spring)	A	2" Screen	OB	Stickup	32	na	na	12.1	27.1	15	na	na	--		
MW-11	2005 (Spring)	A	4" Open BR BH	CBR	Stickup	53.2	37.5	15.7	na	na	na	na	na	--		
MW-12	2005 (Spring)	A	4" Open BR BH	CBR	Stickup	45.1	30	15.1	na	na	na	na	na	--		
MW-13	2005 (Spring)	A	2" Screen	OB	Stickup	23	na	na	7.8	22.8	15	na	na	--		
MW-14	2005 (Spring)	A	2" Screen	DBR	Stickup	25	na	na	8.8	23.8	15	na	na	--		
MW-15	2005 (Spring)	A	2" Screen	OB & DBR	Stickup	22	na	na	4.8	19.8	15	na	na	--		
MW-16	2005 (Spring)	B	4" Open BR BH	CBR	Stickup	78.7	31.6	47.1	na	na	na	na	na	--		
MW-17	2005 (Spring)	B	4" Open BR BH	CBR	Stickup	58	38	20	na	na	na	na	na	--		
MW-18 (abandoned)	2005 (Spring)	B	4" Open BR BH	CBR	Stickup	45.5	30.5	15	na	na	na	na	na	--		
MW-19 (abandoned)	2005 (Spring)	B	2" Screen	OB & DBR	Stickup	45.2	na	na	29.8	44.8	15	na	na	--		
MW-20 (abandoned)	2005 (Spring)	C	4" Open BR BH	CBR	Flush	51.1	18.7	32.4	na	na	na	na	na	--		
MW-21	2005 (Fall)	D	2" Screen	OB	Flush	25	na	na	9.8	24.8	15	na	na	--		
MW-22	2005 (Spring)	D	2" Screen	OB	Flush	40.3	na	na	25.1	40.1	15	na	na	--		
MW-23	2009 (Fall)	H	2" Screen	DBR	Flush	34.2	na	na	19.2	34.2	15	na	na	--		
MW-24	2005 (Fall)	L	2" Screen	OB & DBR	Flush	25.6	na	na	10.4	25.4	15	na	na	--		
MW-25	2005 (Fall)	L	2" Screen	OB & DBR	Flush	27.4	na	na	12.2	27.2	15	na	na	--		
MW-26	2005 (Spring)	K	2" Screen	DBR	Flush	42	na	na	26.8	41.8	15	na	na	--		
MW-27	2005 (Spring)	K	2" Screen	OB & DBR	Flush	22	na	na	2.3	17.3	15	na	na	--		
MW-28	2005 (Fall)	I	4" Open BR BH	CBR	Flush	31.9	17.2	14.7	na	na	na	na	na	--		
MW-29	2005 (Fall)	I	2" Screen	OB	Flush	25	na	na	9.8	24.8	15	na	na	--		
MW-30	2005 (Fall)	I	4" Open BR BH	CBR	Flush	24.6	20.3	4.3	na	na	na	na	na	--		
MW-31	2006 (Fall)	B	4" Open BR BH	CBR	Stickup	59.1	40	19.1	na	na	na	na	na	--		
MW-32	2006 (Fall)	D	4" Open BR BH	CBR	Flush	85.4	38	47.4	na	na	na	na	na	--		
MW-33	2006 (Fall)	D	2" Screen	OB	Flush	20.5	na	na	5.5	20.5	15	na	na	--		
MW-34									Not Installed							
MW-35	2007 (Spring)	N	2" Screen	DBR	Flush	32	na	na	17	32	15	na	na	--		
MW-36	2007 (Winter)	O	2" Screen	DBR	Flush	20.3	na	na	5	20	15	na	na	--		
MW-37	2006 (Fall)	N	2" Screen	DBR	Flush	20.5	na	na	5.2	20.2	15	na	na	--		
MW-38	2006 (Fall)	M	4" ID OBBH	CBR	Flush	85.4	35	50.4	na	na	na	na	na	--		
MW-39	2006 (Fall)	M	2" Screen	DBR	Flush	44	na	na	27.2	42.2	15	na	na	--		
MW-40	2006 (Fall)	J	2" Screen	DBR	Flush	34.7	na	na	19.7	34.7	15	na	na	--		

**Table 3-3
Monitoring Wells, Piezometers, Sump, and Vault Comprising the SV FUDS Groundwater Monitoring Network**

Monitoring Location ID Number	Construction Timeframe	Rational (a)	Type (b)	Monitored Zone (c)	Finish Type (c)	Hole Bottom (ft, bgs)	Casing Bottom (ft, bgs)	Open Borehole Length (ft)	Screen Top (ft, ft, bgs)	Screen Bottom (ft, bgs)	Screen length (ft)	Sample Port Top (ft, bgs)	Sample Port Bottom (ft, bgs)	Sample Port Length (ft)
MW-41	2009 (Fall)	J	2" Screen	DBR	Flush	52.5	na	na	32	47	15	na	na	--
MW-42	2009 (Fall)	J	2" Screen	DBR	Flush	65	na	na	36.8	51.8	15	na	na	--
MW-43	2009 (Fall)	J	2" Screen	DBR	Flush	36.6	na	na	21.6	36.6	15	na	na	--
MW-44	2012 (Spring)	J	2" Screen	DBR	Flush	100	52	na	80	95	15	na	na	--
MW-45S	2012 (Summer)	J	1" Screen (two)	DBR	Flush	174.5	102	na	119	124	5	na	na	--
MW-45D	2012 (Summer)	J	1" Screen (two)	DBR & CBR	Flush	174.5	102	na	147	152	5	na	na	--
MW-46S	2012 (Summer)	D	2" Screen (two)	CBR	Flush	120.75	52	na	72	92	20	na	na	--
MW-46D	2012 (Summer)	D	2" Screen (two)	CBR	Flush	120.75	52	na	107.5	117.5	10	na	na	--
PZ-1S	2004 (Summer)	F	1" Screen (two)	OB & DBR	Stickup	40.5	na	na	9	19	10	na	na	--
PZ-1D	2004 (Summer)	F	1" Screen (two)	DBR	Stickup	40.5	na	na	30	40	10	na	na	--
PZ-2	2004 (Summer)	F	1" Screen	CBR	Stickup	38.3	na	na	19.1	39.1	20	na	na	--
PZ-3	2004 (Summer)	G	1" Screen	OB & DBR	Flush	28	na	na	8	28	20	na	na	--
PZ-4S	2004 (Summer)	G & J	1" Screen (two)	DBR	Flush	62	na	na	27	47	20	na	na	--
PZ-4D	2004 (Summer)	G & J	1" Screen (two)	DBR	Flush	62	na	na	52	62	10	na	na	--
PZ-5	2004 (Summer)	G	1" Screen	DBR	Flush	38	na	na	18	38	20	na	na	--
MP-1	MW-44 and MW-45S and MW-45D fulfill the MP-1 technical requirements. MP-1 was not installed.													
MP-2-1	2011 (Fall)	L	6" MP Liner	CBR	Flush	201.9	33.5	na	na	na	na	35	39.5	4.5
MP-2-2	2011 (Fall)	L	6" MP Liner	CBR	Flush	201.9	33.5	na	na	na	na	51.5	54	2.5
MP-2-3	2011 (Fall)	L	6" MP Liner	CBR	Flush	201.9	33.5	na	na	na	na	56	71	15
MP-2-4	2011 (Fall)	L	6" MP Liner	CBR	Flush	201.9	33.5	na	na	na	na	73	77	4
MP-2-5	2011 (Fall)	L	6" MP Liner	CBR	Flush	201.9	33.5	na	na	na	na	96	102	6
MP-2-6	2011 (Fall)	L	6" MP Liner	CBR	Flush	201.9	33.5	na	na	na	na	105	114	9
MP-2-7	2011 (Fall)	L	6" MP Liner	CBR	Flush	201.9	33.5	na	na	na	na	123	129	6
MP-2-8	2011 (Fall)	L	6" MP Liner	CBR	Flush	201.9	33.5	na	na	na	na	145	160	15
MP-3-1	2010 (Spring)	N	6" MP Liner	CBR	Flush	187	19.5	na	na	na	na	18	24.7	6.7
MP-3-2	2010 (Spring)	N	6" MP Liner	CBR	Flush	187	19.5	na	na	na	na	27	32.5	5.5
MP-3-3	2010 (Spring)	N	6" MP Liner	CBR	Flush	187	19.5	na	na	na	na	40	49	9
MP-3-4	2010 (Spring)	N	6" MP Liner	CBR	Flush	187	19.5	na	na	na	na	55	60	5
MP-3-5	2010 (Spring)	N	6" MP Liner	CBR	Flush	187	19.5	na	na	na	na	66	74	8
MP-3-6	2010 (Spring)	N	6" MP Liner	CBR	Flush	187	19.5	na	na	na	na	93	100	7
MP-3-7	2010 (Spring)	N	6" MP Liner	CBR	Flush	187	19.5	na	na	na	na	103	109	6
MP-3-8	2010 (Spring)	N	6" MP Liner	CBR	Flush	187	19.5	na	na	na	na	123	128	5
MP-4-1	2011 (Fall)	M	6" MP Liner	CBR	Flush	192.5	41	na	na	na	na	42	49	7
MP-4-2	2011 (Fall)	M	6" MP Liner	CBR	Flush	192.5	41	na	na	na	na	52	57	5
MP-4-3	2011 (Fall)	M	6" MP Liner	CBR	Flush	192.5	41	na	na	na	na	62	69	7
MP-4-4	2011 (Fall)	M	6" MP Liner	CBR	Flush	192.5	41	na	na	na	na	75	85	10
MP-4-5	2011 (Fall)	M	6" MP Liner	CBR	Flush	192.5	41	na	na	na	na	90	100	10
MP-4-6	2011 (Fall)	M	6" MP Liner	CBR	Flush	192.5	41	na	na	na	na	104	114	10
MP-4-7	2011 (Fall)	M	6" MP Liner	CBR	Flush	192.5	41	na	na	na	na	148	158	10
MP-4-8	2011 (Fall)	M	6" MP Liner	CBR	Flush	192.5	41	na	na	na	na	170	176	6
MP-4-9	2011 (Fall)	M	6" MP Liner	CBR	Flush	192.5	41	na	na	na	na	180	191	11
MP-5-1	2014 (Summer)	N	6" MP Liner	CBR	Flush	197.9	38	na	na	na	na	38	45	7
MP-5-2	2014 (Summer)	N	6" MP Liner	CBR	Flush	197.9	38	na	na	na	na	55	68	13

**Table 3-3
Monitoring Wells, Piezometers, Sump, and Vault Comprising the SV FUDS Groundwater Monitoring Network**

Monitoring Location ID Number	Construction Timeframe	Rational (a)	Type (b)	Monitored Zone (c)	Finish Type (c)	Hole Bottom (ft, bgs)	Casing Bottom (ft, bgs)	Open Borehole Length (ft)	Screen Top (ft, ft, bgs)	Screen Bottom (ft, bgs)	Screen length (ft)	Sample Port Top (ft, bgs)	Sample Port Bottom (ft, bgs)	Sample Port Length (ft)
MP-5-3	2014 (Summer)	N	6" MP Liner	CBR	Flush	197.9	38	na	na	na	na	90	108	18
MP-5-4	2014 (Summer)	N	6" MP Liner	CBR	Flush	197.9	38	na	na	na	na	122.5	132.5	10
MP-5-5	2014 (Summer)	N	6" MP Liner	CBR	Flush	197.9	38	na	na	na	na	177.5	182.5	5
Sibley Sump	Pre SV FUDS	E	SS	Bedrock	--	--	--	--	--	--	--	--	--	--
Hydroelectric Vault	Pre SV FUDS	D	HV	shallow Subsurface	--	--	--	--	--	--	--	--	--	--

(a) Rationale:

- A: Assess the vicinity of the munitions debris area in the woods east of Dalecarlia Reservoir and, in general, the area immediately upgradient of the Dalecarlia Reservoir.
- B: Assess the area between Sibley Memorial Hospital and the Dalecarlia Reservoir, based on confirmed groundwater contamination (perchlorate) at the Sibley Sump.
- C: Assess the area immediately upgradient of Sibley Memorial Hospital, based on confirmed groundwater contamination (perchlorate) at the Sibley Sump.
- D: Assess the area down gradient of Sibley Memorial Hospital and beyond the southwestern SV FUDS boundary, based on confirmed groundwater contamination (perchlorate) at the Sibley Sump.
- E: Confirmed location of groundwater perchlorate contamination.
- F: Gather preliminary hydrogeologic data for the area near Sibley Memorial Hospital.
- G: Gather preliminary hydrogeologic data for the area near either the Lot 18 Debris Area or American University's Kreeger Hall / Child Day Care Center area.
- H: Assess the area downgradient of the 52nd Court, NW Recovery Pit.
- I: Assess background.

- J: Assess the areas proximate to and down gradient of American University's Kreeger Hall and Child Day Care Center where one or more of either elevated soil arsenic, perchlorate in groundwater, or geophysical anomalies were confirmed.
- K: Assess the area downgradient of the Lot 18 Debris Area.
- L: Assess the area down gradient of the Glenbrook Road, NW munitions recovery pits.
- M: Assess if confirmed groundwater contamination proximate to the Glenbrook Road, NW munitions recovery pits migrated past/under East Creek toward the south-central SV FUDS boundary along Loughboro Road, NW.
- N: Assess whether confirmed groundwater contamination proximate to the Glenbrook Road, NW munitions recovery pits and American University's Kreeger Hall and Child Day Care Center migrated westward to the area between these locations and Sibley Memorial Hospital.
- O: Assess whether groundwater contamination confirmed proximate to the Glenbrook Road, NW munitions recovery pits and American University's Kreeger Hall and Child Day Care Center had been drawn to the spring-related groundwater discharges along the Spring Valley Park.
- P: Confirm that SV FUDS groundwater contamination did not impact the Dalecarlia Reservoir.

(b) Type:

- 1" Screen = Well constructed with a one-inch diameter screen and riser pipe.
- 1" Screen (two) = Well constructed with two one-inch diameter screens and riser pipes in the same borehole.
- 2" Screen = Well constructed with a two-inch diameter screen and riser pipe.
- 2" Screen (two) = Well constructed with two two-inch diameter screens and riser pipes in the same borehole.
- 4" Open BR BH = Four-Inch Diameter Open Bedrock Borehole.
- 6" MP Liner = Six-inch diameter bedrock borehole lined with a multiport liner.
- SS = A sump in Sibley Memorial Hospital that collects water that seeps into the bottom of an elevator shaft. Based on construction drawings provided by SMH the sump elevation is estimated to be about 164 ft msl.
- HV = A vault into which groundwater from the Dalecarlia Reservoir settling basins underdrain system flows. Washington Aqueduct drawings show that the perforated pipes associated with the under drain vary in elevation from 109.6 to 124.6 ft msl.
- (c) Monitored Zone: "OB" = overburden; "DBR" = decomposed bedrock; "CBR" = competent bedrock.

(d) Finish Type: "Stickup" = Indicates a steel protective casing protrudes above ground surface; "Flush" = Indicates the top of the steel protective casing is flush with the ground surface.

Table 3-4
Surface Water Sampling Locations

Monitoring Location ID Number	Location	
	Northing	Easting
SW-1	461672.25	1286102.60
SW-2	463632.57	1282368.67
SW-3	465621.84	1279446.36
SW-4	460558.74	1280491.76
SW-5	464207.32	1289777.66
SW-6	463251.88	1282028.85
SW-7	465015.76	1282708.55
SW-8	465868.32	1283032.03
SW-9	462913.28	1284709.99
SW-10	463322.84	1284378.44
SW-11	462159.17	1285093.55
SW-12	464739.33	1288246.43
SW-13	459959.90	1285703.35
SW-14	465811.14	1281295.27
SW-15	465636.38	1281708.14
SW-16	464494.22	1281713.20
SW-17	460721.94	1280772.84
SW-18	461411.51	1282866.48
SW-19	465780.02	1284055.22
SW-20	462750.78	1283898.94
SW-21	462201.50	1284495.24
SW-22	460124.15	1287903.05
SW-23	462465.40	1289125.74
SW-24	460602.83	1289250.46
SW-25	460308.00	1289229.00
Reservoir	463825.20	1281458.90

**Table 3-5
Soil Boring Locations and Ground Elevations**

Soil Boring Location ID Number	Location		Ground Elevation (ft, msl)
	Northing	Easting	
SA-1	461915.86	1285791.77	362.3
SA-2	461935.21	1285893.21	372.51
SA-3	461871.19	1285887.42	370.82
SA-4	461956.94	1285953.41	375.41
SA-5	461898.21	1285995.91	376.72
SA-6	461851.38	1285865.79	364.18
SA-7	461944.44	1286041.82	380.54
SA-8	461958.3	1286041.57	380.19
SA-9	461906.3	1286069.26	381.49
SA-10	462006.41	1286108.14	380.76
SA-11	461970.76	1286111.63	380.81
SA-12	461918.46	1286117.82	381.08
SA-13	461881.85	1286168.64	382.28
SA-14	461971.65	1286182.25	380.96
SA-15	461775.25	1285983.15	351.94
SA-16	461962.5	1285771.8	359.05

Table 4-1
Depth to the Boundary Between the Bottom of Saprolite
and the Top of the Underlying Competent Bedrock

Boring ID Number	Monitor Devise Type	Drilling Involved HSA?	HSA Refusal Occurred?	Estimated Depth to the Boundary Between Saprolite and Underlying Competent Bedrock (ft. bgs)		
				Based on HSA Refusal Depth (a)	Based on Bottom of Borehole (b)	Casing (c)
MW-1	2" Screen	YES	no	na	> 33.5	--
MW-2	2" Screen	YES	no	na	> 45	--
MW-3	2" Screen	YES	no	na	> 27	--
MW-4	2" Screen	YES	no	na	> 37	--
MW-5	2" Screen	YES	no	na	> 27	--
MW-6	4" Open BR BH	YES	YES	49	na	--
MW-7	2" Screen	YES	no	na	> 49.9	--
MW-8	2" Screen	YES	no	na	> 28	--
MW-9	4" Open BR BH	YES	YES	15	na	--
MW-10	2" Screen	YES	no	na	> 32	--
MW-11	4" Open BR BH	YES	YES	37.5	na	--
MW-12	4" Open BR BH	YES	YES	30	na	--
MW-13	2" Screen	YES	no	na	> 23	--
MW-14	2" Screen	YES	no	na	> 25	--
MW-15	2" Screen	YES	no	na	> 22	--
MW-16	4" Open BR BH	YES	YES	33	na	--
MW-17	4" Open BR BH	YES	YES	39	na	--
MW-18	4" Open BR BH	YES	YES	30	na	--
MW-19	2" Screen	YES	no	na	> 45.2	--
MW-20	4" Open BR BH	YES	YES	19	na	--
MW-21	2" Screen	YES	no	na	> 25	--
MW-22	2" Screen	YES	no	na	> 40.3	--
MW-23	2" Screen	YES	no	na	> 34.2	--
MW-24	2" Screen	YES	no	na	> 25.6	--
MW-25	2" Screen	YES	no	na	> 27.4	--
MW-26	2" Screen	YES	no	na	> 42	--
MW-27	2" Screen	YES	no	na	> 22	--
MW-28	4" Open BR BH	YES	YES	18	na	--
MW-29	2" Screen	YES	no	na	> 25	--
MW-30	4" Open BR BH	YES	YES	20	na	--
MW-31	4" Open BR BH	YES	YES	41	na	--
MW-32	4" Open BR BH	YES	YES	40	na	--
MW-33	2" Screen	YES	no	na	> 20.5	--
MW-34	Not drilled					
MW-35	2" Screen	YES	no	na	> 32	--
MW-36	2" Screen	YES	no	na	> 20.3	--
MW-37	2" Screen	YES	no	na	> 20.5	--
MW-38	4" Open BR BH	YES	YES	35	na	--
MW-39	2" Screen	YES	no	na	> 44	--
MW-40	2" Screen	YES	no	na	> 34.7	--
MW-41	2" Screen	YES	no	na	> 52.5	--
MW-42	2" Screen	YES	no	na	> 65	--
MW-43	2" Screen	YES	no	na	> 36.6	--
MW-44	2" Screen	no	no	na	na	49
MW-45	2" Screen (two)	no	no	na	na	99

Table 4-1
Depth to the Boundary Between the Bottom of Saprolite
and the Top of the Underlying Competent Bedrock

Boring ID Number	Monitor Device Type	Drilling Involved HSA?	HSA Refusal Occurred?	Estimated Depth to the Boundary Between Saprolite and Underlying Competent Bedrock (ft. bgs)		
				Based on HSA Refusal Depth (a)	Based on Bottom of Borehole (b)	Casing (c)
MW-46	2" Screen (two)	no	no	na	na	47
PZ-1	1" Screen (two)	YES	YES	13	na	--
PZ-2	1" Screen	YES	YES	15.5	na	--
PZ-3	1" Screen	YES	no	na	> 28	--
PZ-4	1" Screen (two)	YES	YES	23.5	na	--
PZ-5	1" Screen	YES	YES	27	na	--
MP-1	Not drilled (See Boring IDs MWs 44 and 45)					
MP-2	6" MP Liner	no	na	na	na	30.5
MP-3	6" MP Liner	YES	YES	19.5	na	--
MP-4	6" MP Liner	no	na	na	na	38
MP-5	6" MP Liner	no	na	na	na	35

(a) HSA refusal occurs when competent bedrock is encountered. The depth where HSA refusal occurs is a good proxy for the depth to the boundary between saprolite and underlying competent bedrock. "na" indicates that HSA drilling was not conducted at this location or, if it was, HSA refusal did not occur.

(b) At locations where HSA refusal did not occur, the boundary between saprolite and underlying competent bedrock is below the bottom of the borehole. "na" indicates that HSA refusal occurred or HSA drilling was not conducted at this location.

(c) Estimated as equal to three feet less than the depth to the bottom of casing.

**Table 4-2
Soil Boring Depths and Bottom Elevations**

Soil Boring Location ID Number	HSA Refusal Occurred?	Boring Bottom	
		Below Ground Surface (ft. bgs)	Elevation (ft. msl)
SA-1	No	45	317.3
SA-2	No	52	320.51
SA-3	No	55	315.82
SA-4	No	54	321.41
SA-5	No	51	325.72
SA-6	No	40	324.18
SA-7	No	55	325.54
SA-8	No	55	325.19
SA-9	No	51	330.49
SA-10	No	54	326.76
SA-11	No	54	326.81
SA-12	No	56	325.08
SA-13	No	52	330.28
SA-14	No	50	330.96
SA-15	No	37	314.94
SA-16	No	37	322.05

Table 4-3
Depths to Groundwater Observed During Borehole Drilling and Prior to Well Construction

Monitoring Location ID Number	Water Levels During Borehole Drilling Timeframe (ft. bgs)							Type (b)	Hole Bottom (ft. bgs)	Casing Bottom (ft. bgs)	Screen Top (ft. bgs)	Screen Bottom (ft. bgs)
	During Drilling	At Completion	After Completion									
			3 Hr	13 Hr	24 Hr	48 Hr	96 Hr					
MW-1	--	19.8	--	--	--	--	--	2" Screen	33.5	na	18.3	33.3
MW-2	--	27.1	--	--	--	--	--	2" Screen	45	na	24.5	44.5
MW-3	16	16.8	--	--	14.7	--	--	2" Screen	27	na	7.8	22.8
MW-4	25.4	--	--	--	--	--	--	2" Screen	37	na	21.8	36.8
MW-5	17	18.3	--	--	18.2	--	--	2" Screen	27	na	11.8	26.8
MW-6	--	--	--	--	--	--	--	4" Open BR BH	64	49.1	na	na
MW-7	39	--	--	--	34.7	--	--	2" Screen	49.9	na	34.7	49.7
MW-8	18.2	20	--	--	11.5	--	--	2" Screen	28	na	4.8	19.8
MW-9	--	--	--	--	7.6	--	--	4" Open BR BH	29.2	15	na	na
MW-10	18	21	--	--	19.4	--	--	2" Screen	32	na	12.1	27.1
MW-11	--	--	--	--	41.9	--	--	4" Open BR BH	53.2	37.5	na	na
MW-12	--	--	--	--	29.9	--	--	4" Open BR BH	45.1	30	na	na
MW-13	13	15	--	--	14.6	--	--	2" Screen	23	na	7.8	22.8
MW-14	20	14	--	--	6.8	--	--	2" Screen	25	na	8.8	23.8
MW-15	16	11.5	--	--	--	13	--	2" Screen	22	na	4.8	19.8
MW-16	--	--	--	--	--	--	69.4	4" Open BR BH	78.7	31.6	na	na
MW-17	--	--	--	--	42.2	--	--	4" Open BR BH	58	38	na	na
MW-18	24.6	24.1	--	--	28.2	--	--	4" Open BR BH	45.5	30.5	na	na
MW-19	36	39.1	--	--	36.4	--	--	2" Screen	45.2	na	29.8	44.8
MW-20	28.1	--	--	--	28.8	--	--	4" Open BR BH	51.1	18.7	na	na
MW-21	--	11.6	--	--	12.8	--	--	2" Screen	25	na	9.8	24.8
MW-22	30.7	30.7	--	--	31.4	--	--	2" Screen	40.3	na	25.1	40.1
MW-23	--	--	--	--	25.5	--	--	2" Screen	34.2	na	19.2	34.2
MW-24	--	16.4	--	--	17.7	--	--	2" Screen	25.6	na	10.4	25.4
MW-25	--	18.4	--	--	--	--	--	2" Screen	27.4	na	12.2	27.2
MW-26	--	--	--	--	19.8	--	--	2" Screen	42	na	26.8	41.8
MW-27	10.8	6.4	--	--	6.4	--	--	2" Screen	22	na	2.3	17.3
MW-28	--	16.5	--	--	13.3	--	--	4" Open BR BH	31.9	17.2	na	na
MW-29	15.4	12.9	--	--	--	--	--	2" Screen	25	na	9.8	24.8
MW-30	--	--	--	--	19.3	--	--	4" Open BR BH	24.6	20.3	na	na
MW-31	--	--	--	--	38.4	--	--	4" Open BR BH	59.1	40	na	na

Table 4-3
Depths to Groundwater Observed During Borehole Drilling and Prior to Well Construction

Monitoring Location ID Number	Water Levels During Borehole Drilling Timeframe (ft. bgs)							Type (b)	Hole Bottom (ft. bgs)	Casing Bottom (ft. bgs)	Screen Top (ft. bgs)	Screen Bottom (ft. bgs)
	During Drilling	At Completion	After Completion									
			3 Hr	13 Hr	24 Hr	48 Hr	96 Hr					
MW-32	80.4	81.4	--	--	--	--	--	4" Open BR BH	85.4	38	na	na
MW-33	13.5	14	--	--	11.3	--	--	2" Screen	20.5	na	5.5	20.5
MW-34	Not Drilled											
MW-35	--	--	--	--	12.4	--	--	2" Screen	32	na	17	32
MW-36	12	12.3	--	--	8.8	--	--	2" Screen	20.3	na	5	20
MW-37	13.9	15.2	--	--	13.2	--	--	2" Screen	20.5	na	5.2	20.2
MW-38	--	--	--	--	36.2	--	--	4" Open BR BH	85.4	35	na	na
MW-39	38	26.6	--	--	22	--	--	2" Screen	44	na	27.2	42.2
MW-40	30.5	32	--	--	20.8	--	--	2" Screen	34.7	na	19.7	34.7
MW-41	--	42.5	--	--	36	--	--	2" Screen	52.5	na	32	47
MW-42	--	--	--	--	41.8	--	--	2" Screen	65	na	36.8	51.8
MW-43	30.8	26.6	--	--	25.7	--	--	2" Screen	36.6	na	21.6	36.6
MW-44	--	38.8	42.1	--	--	--	--	2" Screen	100	52	80	95
MW-45S	--	45.4	--	--	--	--	--	1" Screen	174.5	102	119	124
MW-45D	--	45.4	--	--	--	--	--	1" Screen	174.5	102	147	152
MW-46S	32.8	--	--	110.4	--	--	--	2" Screen	120.75	52	72	92
MW-46D	32.8	--	--	110.4	--	--	--	2" Screen	120.75	52	107.5	117.5
PZ-1S	--	13.1	--	--	--	--	--	1" Screen	40.5	na	9	19
PZ-1D	--	13.1	--	--	--	--	--	1" Screen	40.5	na	30	40
PZ-2	--	19.6	--	--	--	--	--	1" Screen	38.3	na	19.1	39.1
PZ-3	18.2	17.2	--	--	13.1	--	--	1" Screen	28	na	8	28
PZ-4S	--	44	--	--	44.1	--	--	1" Screen	62	na	27	47
PZ-4D	--	44	--	--	44.1	--	--	1" Screen	62	na	52	62
PZ-5	--	30	--	--	29.4	--	--	1" Screen	38	na	18	38

(a) "BR BH" = Bedrock Borehole.

**Table 4-4
Deep Bedrock Borehole Activities**

Borehole	Borehole Activity			Notes
	Down-hole Geophysics	Profiling	Multi-Port Liner Installed	
MP-1	No	No	No	(a)
MP-2	Yes	Yes	Yes	--
MP-3	Yes	Yes	Yes	--
MP-4	Yes	Yes	Yes	--
MP-5	Yes	Yes	Yes	--
MW-44	No	No	No	(a)
MW-45	Yes	No	No	(b)
MW-46	Yes	No	No	(c)

(a) Borehole MP-1 was not completed due borehole caving problems. The partially completed borehole MP-1 was renamed MW-44 which was completed as a monitoring well with a single screened interval to partially fulfill the objectives of MP-1. The borehole conditions did not allow conducting geophysics, profiling or multiport liner installation as was initially planned.

(b) MW-45 was drilled to complement PZ-4S, PZ-4d, and MW-44, and fulfill the technical objectives of MP-1. Geophysics were conducted on MW-45 to help determine the depth intervals for the two screened intervals installed in this borehole.

(c) The activities at borehole MW-46 were conducted as planned..

**Table 4-5
Borehole Geophysical Tests Conducted on the Deep Bedrock Boreholes**

Geophysical Test	Description (a)	Borehole (b)					
		MW-45	MW-46	MP-2	MP-3	MP-4	MP-5
Acoustic Televiwer (ATV)	Acoustic-televiwer logs record a magnetically oriented, photographic image of the acoustic reflectivity of the borehole wall. Televiwer logs indicate the location and strike and dip of fractures and lithologic contacts. Collection of televiwer logs is limited to water- or mud-filled open holes. The ATV tool emits a narrow acoustic beam that rotates 360° and is focused at the borehole wall. A fracture reduces the amplitude of the return signal due to acoustic scattering. The travel time of the acoustic signal is increased where the distance to the borehole wall is increased for any reason, such as by open fractures.	X	X	X	X	X	X
Acoustic Caliper	The travel time of the ATV acoustic signal can be displayed in the form of an acoustic caliper log that shows the cross-sectional dimensions of the borehole.	--	X	X	X	X	X
Three-arm Caliper	A mechanical devise that continuously measures the borehole diameter with changes in depth.	X	--	--	--	--	--
Heat-Pulse Flowmeter	Flowmeter logs record the direction and rate of vertical flow in the borehole. Borehole-flow rates can be calculated from downhole-velocity measurements and borehole diameter recorded by the caliper log. Flowmeter logs can be collected under non-pumping and(or) pumping conditions. Impeller flowmeters are the most widely used but they generally cannot resolve velocities of less than 5 ft/min. Heat-pulse and electromagnetic flowmeters can resolve velocities of less than 0.1 ft/min.	X	X	X	X	X	X

(a) <http://ny.water.usgs.gov/projects/bgag/intro.text.html>

(b) 'X' = Test was conducted.

**Table 4-6
Bedrock Borehole Fracture Frequencies and Orientations**

Boring	Count (a)	Mean Dip Azimuth (b)	Mean Dip Angle (c)	Percent of Fractures (d)
Fracture Rank 1 (e)				
MP-2	45	193	54	15%
MP-3	100	223	51	42%
MP-4	78	214	55	43%
MP-5	69	235	52	47%
MW-45	20	182	46	48%
MW-46	34	224	50	51%
Fracture Rank 2				
MP-2	122	169	46	41%
MP-3	115	249	48	48%
MP-4	89	233	51	49%
MP-5	70	251	47	48%
MW-45	16	176	47	38%
MW-46	33	250	40	49%
Fracture Rank 3				
MP-2	133	172	48	44%
MP-3	18	255	45	8%
MP-4	16	253	53	9%
MP-5	8	296	49	5%
MW-45	6	232	30	14%
MW-46	0	--	--	--
Fracture Rank 4				
MP-2	0	--	--	--
MP-3	5	269	33	2%
MP-4	0	--	--	--
MP-5	0	--	--	--
MW-45	0	--	--	--
MW-46	0	--	--	--

(a) Number of fractures

(b) Compass bearing direction toward which the fracture dips. Zero or 360° = north; 90° = east; 180° = south; 270° = west. Plus or minus 90° from any dip angle azimuth is the fracture strike azimuth.

(c) Angle at which the fracture dips toward the azimuth bearing. A dip of 90° is vertical and 0° is horizontal.

(d) The summed percentages for a particular borhole equals 100 percent. Thus, 15% of the MP-2 fractures are Rank 1, 41% are Rank 2, etc.

(e) Fracture Ranks: Fracture Rank 1 describes minor fractures that are not distinct and may not be continuous around the borehole. Fracture Rank 2 describes intermediate fractures that are distinct and continuous around the borehole with little or no apparent aperture. Fracture Rank 3 describes intermediate fractures that are distinct and continuous around the borehole with some apparent aperture. Fracture Rank 4 describes major fractures that are distinct with continuous apparent aperture around the borehole.

**Table 4-7
Bedrock Borehole Fracture Frequencies Normalized by Borehole Length**

Borehole	Logged Interval			Borehole Bottom (ft. bgs)	Fracture Frequencies (fractures / 10 ft.) (b)				
	Top (ft. bgs)	Bottom (ft. bgs)	Length (ft.)		Rank 1	Rank 2	Rank 3	Rank 4	Total
MP-2	33.5	201.9	168.4	201.9	2.7	7.2	7.9	0.0	17.8
MP-3	19.5	187.0	167.5	187.0	6.0	6.9	1.1	0.3	14.2
MP-4	41	192.5	151.5	192.5	5.1	5.9	1.1	0.0	12.1
MP-5	38	197.9	159.9	197.9	4.3	4.4	0.5	0.0	9.2
MW-45	102	123.0 (a)	21.0	174.5	9.5	7.6	2.9	0.0	20.0
MW-46	52	117.0	65.0	120.8	5.2	5.1	0.0	0.0	10.3

(a) The bottom of the interval logged by OTV and ATV is significantly above the borehole bottom due to borehole diameter narrowing from 6 inches to under 3.5 inches at the bottom of a significant fracture zone in the interval 120.5 to 123.5 ft bgs.

(b) Fracture Ranks:

Fracture Rank 1 describes minor fractures that are not distinct and may not be continuous around the borehole.

Fracture Rank 2 describes intermediate fractures that are distinct and continuous around the borehole with little or no apparent aperture.

Table 4-8
Heat Pulse Flow Meter Results Under Ambient and Pumping Conditions

MP-2 (Bottom of csg. = 33.5 ft. bgs)				
Depth (ft. bgs)	HPFM			
	Ambient		Pumping	
	In & Up	Out	In & Up	Out
csg. to 37		X	X	
45 to 37		X		
49 to 53		X		
72 to 77		X		
105 to 112	X		X	
126	X		X	
148 to 154	X		X	

MP-3 (Bottom of csg. = 19.5 ft. bgs)				
Depth (ft. bgs)	HPFM			
	Ambient		Pumping	
	In & Up	Out	In & Up	Out
19 to 24		X	X	
27 to 33	X			
94 to 97	X		X	
183 to 184			X	

MP-4 (Bottom of csg. = 41 ft. bgs)				
Depth (ft. bgs)	HPFM			
	Ambient		Pumping	
	In & Up	Out	In & Up	Out
47 to 48			X	
52 to 583			X	
72 to 81		X	X	
171 to 176	X		X	

MP-5 (Bottom of csg. = 38 ft. bgs)				
Depth (ft. bgs)	HPFM			
	Ambient		Pumping	
	In & Up	Out	In & Up	Out
csg. to 40		X	X	
54 to 66	X		X	
90 to 107	X		X	
178 to 182	X		X	

MW-45 (Bottom of csg. = 102 ft. bgs)				
Depth (ft. bgs)	HPFM			
	Ambient		Pumping	
	In & Up	Out	In & Up	Out
103 to 107			X	
121 to 123			X	

MW-46 (Bottom of csg. = 52 ft. bgs)				
Depth (ft. bgs)	HPFM			
	Ambient		Injection (a)	
	In & Up	Out	In & Up	Out
csg. to 61				X
84 to 94				X
112 to 117	X			

(a) Insufficient water was in the borehole after drilling to support HPFM pumping (due to very low well yield); therefore water was added to the well bore to support HPFM.

**Table 4-9
Slug Test Results**

Monitoring Location ID Number	Location	Material	Aquifer Model	Solution	K (ft/day) (a)	Diameter (in)		Hole Bottom (ft. bgs)	Casing Bottom (ft. bgs)	Screen Interval (ft. bgs)	Screen Length (ft.)	Screen Length (cm)
						Borehole	Screen					
MW-44	AU Kreeger Hall	Fractured rock	Fractured	Barker-Black	8.0E-02	10	4	100	52	80 to 95	15	457.2
MW-45S	AU Kreeger Hall	Fractured rock	Fractured	Barker-Black	1.2E-02	6	1	174.5	102	119 to 124	5	152.4
MW-45D	AU Kreeger Hall	Fractured rock	Fractured	Barker-Black	2.6E-03	6	1	174.5	102	147 to 152	5	152.4
PZ-4S	AU Kreeger Hall	Highly fractured and weathered rock	Unconfined	Bouwer-Rice	8.4E+00	3.5	1	62	na	27 to 47	20	609.6
PZ-4D	AU Kreeger Hall	Rock	Fractured	Barker-Black	5.4E-01	3.5	1	62	na	52 to 62	10	304.8
MW-21	SMH	Overburden	Unconfined	Bouwer-Rice	1.3E+00	11 5/8	2	25	na	9.8 to 25	15	457.2
MW-22	SMH	Overburden	Unconfined	Bouwer-Rice	2.1E-01	11 5/8	2	40.3	na	25 to 40	15	457.2
MW-46S	SMH	Fractured rock	Fractured	Barker-Black	1.3E-02	8	2	120.75	52	72 to 92	20	609.6
MW-46D	SMH	Fractured rock	Fractured	Barker-Black	2.0E-02	8	2	120.75	52	108 to 118	10	304.8

(a) As reported in Appendix G.

Table 4-10
Estimated Groundwater Flow Velocities

Monitoring Well	Location	Aquifer Model	Porosity (n)	dh/dl (a)	K (ft/day)	Groundwater Flow Velocity (ft./day)
MW-44	AU Kreeger Hall	Fractured	0.025	0.038	8.00E-02	1.22E-01
MW-45S	AU Kreeger Hall	Fractured	0.025	0.038	1.20E-02	1.82E-02
MW-45D	AU Kreeger Hall	Fractured	0.025	0.038	2.60E-03	3.95E-03
PZ-4S	AU Kreeger Hall	Unconfined	0.25	0.038	8.40E+00	1.28E+00
PZ-4D	AU Kreeger Hall	Fractured	0.025	0.038	5.40E-01	8.21E-01
MW-21	SMH	Unconfined	0.25	0.038	1.30E+00	1.98E-01
MW-22	SMH	Unconfined	0.25	0.038	2.10E-01	3.19E-02
MW-46S	SMH	Fractured	0.025	0.038	1.30E-02	1.98E-02
MW-46D	SMH	Fractured	0.025	0.038	2.00E-02	3.04E-02

(a) Feb-Sept 2012 GW Contour map: The head difference between AU and Sibley is about 240 feet and the distance is 6,330 feet.

**Table 4-11
Groundwater Analytical Scope and Detected Chemical Classes**

Groundwater Location ID ⁽¹⁾	Number of Sampling Events	Spring Valley QAPP Chemical Classes Analyzed ⁽²⁾							
		Chemical Agents	Explosives	Metals	SVOCs	SVOC Target TICs	VOCs	VOC Target TICs	Miscellaneous, Including Perchlorate
MW-25	11	X	X	X	X	X	X	X	X
MW-26	8	X	X	X	X	X	X	X	X
MW-27	8	X	X	X	X	X	X	X	X
MW-28	3	X	X	X	X	X	X	X	X
MW-29	3	X	X	X	X	X	X	X	X
MW-30	3	X	X	X	X	X	X	X	X
MW-31	1	X	X	X	X	X	X	X	X
MW-32	9	X	X	X	X	X	X	X	X
MW-33	2	X	X	X	X	X	X	X	X
MW-35	2	X	X	X	X	X	X	X	X
MW-36	2	X	X	X	X	X	X	X	X
MW-37	7	X	X	X	X	X	X	X	X
MW-38	6	X	X	X	X	X	X	X	X
MW-39	9	X	X	X	X	X	X	X	X
MW-40	2	X	X	X	X	X	X	X	X
MW-41	2								X (ClO ₄ only)
MW-42	2								X (ClO ₄ only)
MW-43	9			X (As only)					X (ClO ₄ only)
MW-44	7			X (As only)					X (ClO ₄ only)
MW-45D	6			X (As only)					X (ClO ₄ only)
MW-45S	6			X (As only)					X (ClO ₄ only)
MW-46D	1			X (As only)					X (ClO ₄ only)
MW-46S	1			X (As only)					X (ClO ₄ only)
PZ-1D	10	X	X	X	X	X	X	X	X
PZ-1S	10	X	X	X	X	X	X	X	X
PZ-2	3			X (As only)					X (ClO ₄ , Br, Cl only)
PZ-3	10			X (As only)					X (ClO ₄ , Br, Cl only)
PZ-4D	12			X (Asonly)					X (ClO ₄ , Br, Cl)

**Table 4-11
Groundwater Analytical Scope and Detected Chemical Classes**

Groundwater Location ID ⁽¹⁾	Number of Sampling Events	Spring Valley QAPP Chemical Classes Analyzed ⁽²⁾							
		Chemical Agents	Explosives	Metals	SVOCs	SVOC Target TICs	VOCs	VOC Target TICs	Miscellaneous, Including Perchlorate
PZ-4S	12			X (As only)					X (ClO ₄ , Br, Cl only)
PZ-5	2			X (As only)					X (ClO ₄ , Br, Cl only)
Sibley Sump	14			X (As only)					X (ClO ₄ , Br, Cl)
Hydroelectric Vault	4			X (As only)					X (ClO ₄ , Br, Cl only)

Notes:

(1) MW: monitoring well. MP: multi-port monitoring well. PZ: Piezometer.

(2) Chemical classes are defined below:

Chemical Agents: CVAA/CVAO, mustard, ricin

Explosives: explosive compounds analyzed using SW-846 8330B and picric acid (HPLC/UV)

SVOCs and SVOC TICs: Semi-volatile organic compounds (SVOCs) and SVOC Tentatively Identified Target Compounds (TICs) as per Tables 1 and 3 of the Spring Valley Groundwater Study QAPP .

VOCs and VOC TICs: Volatile organic compounds (VOCs) and VOC Tentatively Identified Target Compounds (TICs) as per Tables 1 and 4 of the Spring Valley Groundwater Study QAPP .

Other: Perchlorate, 1,4-oxathiane, acetic acid, bromide and chloride, ethanol, iodate, iodide

= Chemical class not analyzed.

x = Chemical class analyzed. If specific chemicals are listed in parentheses, this indicates that only these chemicals were analyzed, not all chemicals in the chemical class. Also, at least one chemical was detected.

= No chemical from the chemical class was detected.

Table 4-12
SV FUDS Parameters Detected in Groundwater

Detected Groundwater Chemical (1)	EU1	EU1	EU1	EU1	EU1	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3	EU3			
	MW-21	MW-22	MW-46	MW-46S	SIBLEY SUMP	MP2	MW-24	MW-25	MW-44	MW-45	MW-45S	PZ-4D	PZ-4S	MP3	MP4	MP-5	MW-1	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	MW-8	MW-9	MW-10	MW-11	MW-12	MW-13	MW-14	MW-15	MW-16	MW-17	MW-18	MW-19	MW-20	MW-23	MW-26	MW-27		
Explosives																																									
HMX							X																																		
Metals																																									
Aluminum	X																	X	X	X				X														X		X	
Antimony							X	X										X						X																X	
Arsenic	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Barium	X	X					X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Beryllium								X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Cadmium	X							X									X	X				X																X		X	
Chromium																	X		X				X																	X	X
Cobalt	X	X					X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Copper	X	X					X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Lead	X	X					X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Manganese	X	X					X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Mercury							X	X									X								X															X	
Nickel	X	X					X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Selenium	X																																								X
Silver								X									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Strontium	X	X					X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Tellurium	X	X					X	X									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Thallium																	X						X																	X	
Tin																	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Titanium	X	X					X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Vanadium	X						X	X									X		X				X																	X	
Zinc	X	X					X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Zirconium	X							X									X		X				X			X														X	
SVOCs																																									
2-Nitrophenol																																									X
Benzoic Acid		X														X		X					X			X	X	X									X		X		
Bis(2-Ethylhexyl)Phthalate	X	X					X	X									X		X			X			X															X	
Caprolactam																																									X
Di-N-Butyl Phthalate								X									X																								
Phenyl Isocyanate																																									
VOCs																																									
Chloroform								X																																X	
Dibromochloromethane																																									
Diphenyl Ether (Phenylether)																																									
Ethylbenzene																	X																								
Methylene Chloride							X	X									X						X																		
Tetrachloroethylene (PCE)		X															X		X				X			X															
Toluene																							X																		
Trichlorofluoromethane																																									X
Xylenes (Total)																	X																								
Other																																									
1,4-Oxathiane								X																X																	
Acetic Acid							X	X									X		X				X		X																
Bromide	X	X			X		X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Chloride	X	X			X		X	X				X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Iodate	X	X					X	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Iodide								X									X						X	X																X	
Perchlorate	X	X		X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

Notes:
X = Detection; SVOC = Semi-volatile organic compound; VOC = volatile organic compound
(1) If no chemicals from a chemical parameters class were not detected then the chemical parameter class is not presented here.

Table 4-13
Summary of Volatile Organic Compounds Detected in Groundwater

CHEMICAL CLASS / ANALYTE DETECTIONS	Groundwater Exposure Point (1)	Minimum Concentration (Qualifier) (2)				Maximum Concentration (Qualifier) (2)				Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)				Potential ARAR/TBC		
		Value	LF	VF	RC	Value	LF	VF	RC			Detected	Analyzed	Percent	Value	LF	VF	RC	MCL (ug/L)	AL (ug/L)	DWHA (ug/L)
Volatile Organic Compounds																					
Chloroform	EU 1	nd				nd				ug/l		0	3	0%	11				80	--	--
	EU 2	15				15				ug/l	MW-25	1	5	20%	11						
	EU 3	8.8	J	B	x	8.8	J	B	x	ug/l	MW-27	1	32	3%	11						
Dibromochloromethane	EU 1	nd				nd				ug/l		0	3	0%	nd				80	--	--
	EU 2	nd				nd				ug/l		0	5	0%	nd						
	EU 3	11				11				ug/l	MW-33	1	32	3%	nd						
Diphenyl Ether (Phenylether)	EU 1	nd				nd				ug/l		0	3	0%	nd				--	--	--
	EU 2	nd				nd				ug/l		0	5	0%	nd						
	EU 3	31		J	r	31		J	r	ug/l	PZ-1S	1	32	3%	nd						
Ethylbenzene	EU 1	nd				nd				ug/l		0	3	0%	nd				700	--	--
	EU 2	nd				nd				ug/l		0	5	0%	nd						
	EU 3	2.5	JB	B	z	2.5	JB	B	z	ug/l	MW-3	1	32	3%	nd						
Methylene Chloride	EU 1	nd				nd				ug/l		0	3	0%	1.6	JB	B	z	5	--	--
	EU 2	1.6	JB	B	z	1.7	JB	B	z	ug/l	MW-24	2	5	40%	1.6	JB	B	z			
	EU 3	7.5	JB	B	z	7.6	JB			ug/l	MW-8	2	32	6%	1.6	JB	B	z			
Tetrachloroethylene (PCE)	EU 1	1.2	J			1.2	J			ug/l	MW-22	1	3	33%	nd				5	--	--
	EU 2	nd				nd				ug/l		0	5	0%	nd						
	EU 3	4	J	B	z	14	B	B	z	ug/l	PZ-1S	11	32	34%	nd						
Toluene	EU 1	nd				nd				ug/l		0	3	0%	4.8	J			1000	--	--
	EU 2	nd				nd				ug/l		0	5	0%	4.8	J					
	EU 3	1				1				ug/l	MP4-8	2	34	6%	4.8	J					
Trichlorofluoromethane	EU 1	nd				nd				ug/l		0	3	0%	nd				--	--	--
	EU 2	nd				nd				ug/l		0	5	0%	nd						
	EU 3	1.9	J			1.9	J			ug/l	MW-27	1	32	3%	nd						
Xylenes (Total)	EU 1	nd				nd				ug/l		0	3	0%	nd				10000	--	--
	EU 2	nd				nd				ug/l		0	5	0%	nd						
	EU 3	4.9	JB	B	z	4.9	JB	B	z	ug/l	MW-3	1	32	3%	nd						

NOTES:

(1) EU1: Sibley Sump, MWs 21, 22, and 46; EU2: MP-2, MWs 24, 25, 44, 45, and PZ-4; and EU3: All other locations not in EU1 or EU2

(2) 'LF': Lab Flag (J: value is less than the reporting limit but greater than the method detection limit, B: method blank contamination). 'VF': Validation Flag (B: blank contamination; J: analyte is present but the reported value may not be accurate or precise). 'RC': Validation Reason Code (r: linearity failure in initial calibration, x: field blank contamination, z: method blank or holding blank contamination).

(3) Maximum concentration detected at MW-28, MW-29, or MW-30.

**Table 4-14
Summary of Semivolatile Organic Compounds Detected in Groundwater**

CHEMICAL CLASS / ANALYTE DETECTIONS	Groundwater Exposure Point	Minimum Concentration (Qualifier) (2)			Maximum Concentration (Qualifier) (2)			Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)			Potential ARAR/TBC					
		Value	LF	VF	RC	Value	LF			VF	RC	Detected	Analyzed	Percent	Value	LF	VF	RC	MCL	AL	DWHA
																			(ug/L)	(ug/L)	(ug/L)
Semi Volatile Organic Compounds																					
2-Nitrophenol	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	5	J			5	J				ug/l	MW-11	1	31	3%	nd					
Benzoic Acid	EU 1	1.5	J	B	x	1.5	J	B	x	ug/l	MW-22	1	2	50%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	1	J	B	x	4.9	J	B	x	ug/l	MW-11	9	31	29%	nd				--		
Bis(2-Ethylhexyl)Phthalate	EU 1	1.4	J			3.1	J			ug/l	MW-21	2	2	100%	4.6	J					
	EU 2	1.4	J			6.5	J			ug/l	MW-25	3	5	60%	4.6	J			6		
	EU 3	1.2	J	K	s	8.3	J	K	s	ug/l	MW-3	14	31	45%	4.6	J			--		
Caprolactam	EU 1	nd				nd				ug/l		0	2	0%	100						
	EU 2	nd				nd				ug/l		0	5	0%	100				--		
	EU 3	nd				nd				ug/l		0	31	0%	100				--		
Di-N-Butyl Phthalate	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	1.1	J			1.3	J			ug/l	MW-25	1	5	20%	nd				--		
	EU 3	2	J	K	s	2	J	K	s	ug/l	MW-3	1	31	3%	nd				--		
Phenyl Isocyanate	EU 1	nd				nd				ug/l		0	1	0%	nd						
	EU 2	nd				nd				ug/l		0	3	0%	nd				--		
	EU 3	4.9	J	J	1	4.9	J	J	1	ug/l	PZ-1D	1	19	5%	nd				--		

NOTES:

(1) EU1: Sibley Sump, MWs 21, 22, and 46; EU2: MP-2, MWs 24, 25, 44, 45, and PZ-4; and EU3: All other locations not in EU1 or EU2

(2) 'LF': Lab Flag (J: value is less than the reporting limit but greater than the method detection limit). 'VF': Validation Flag (B: blank contamination, J: analyte is present but the reported value may not be accurate or precise, K: analyte present but reported value may be biased high and actual value is expected to be lower). 'RC': Validation Reason Code (1: laboratory control sample recovery failure, s: surrogate failure, x: field blank contamination).

(3) Maximum concentration detected at MW-28, MW-29, or MW-30.

**Table 4-15
Summary of Explosives Compounds Detected in Groundwater**

CHEMICAL CLASS / ANALYTE DETECTIONS	Groundwater Exposure Point	Minimum Concentration (Qualifier) (2)			Maximum Concentration (Qualifier) (2)			Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)			Potential ARAR/TBC					
		Value	LF	VF	RC	Value	LF			VF	RC	Detected	Analyzed	Percent	Value	LF	VF	RC	MCL	AL	DWHA
																			(ug/L)	(ug/L)	(ug/L)
Explosives																					
HMX	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	0.16	J	J	1	0.16	J	J	1	ug/l	MW-24	1	5	20%	nd			--	--	--	
	EU 3	nd				nd				ug/l		0	30	0%	nd						

NOTES:

(1) EU1: Sibley Sump, MWs 21, 22, and 46; EU2: MP-2, MWs 24, 25, 44, 45, and PZ-4; and EU3: All other locations not in EU1 or EU2

(2) 'LF': Lab Flag (J: value is less than the reporting limit but greater than the method detection limit). 'VF': Validation Flag (J: analyte is present but the reported value may not be accurate or precise).

'RC': Validation Reason Code (1: laboratory control sample recovery failure).

(3) Maximum concentration detected at MW-28, MW-29, or MW-30.

**Table 4-16
Summary of Metals Detected in Groundwater**

CHEMICAL CLASS / ANALYTE DETECTIONS	Groundwater Exposure Point	Minimum Concentration (Qualifier) (2)					Maximum Concentration (Qualifier) (2)					Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)				Potential ARAR/TBC		
		Value	LF	VF	RC	Value	LF	VF	RC	Detected	Analyzed			Percent	Value	LF	VF	RC	MCL	AL	DWHA		
																			(ug/L)	(ug/L)	(ug/L)		
Metals																							
Aluminum	EU 1	23.9	J	B	x	23.9	J	B	x	ug/l	MW-21	1	2	50%	nd								
	EU 2	nd				nd				ug/l		0	5	0%	nd								
	EU 3	2.6	J			1720	J	g		ug/l	MW-32	24	41	59%	nd								
Antimony	EU 1	nd				nd				ug/l		0	2	0%	0.32	J	B	o					
	EU 2	0.18	J			0.21	J	B	o	ug/l	MW-24	3	5	60%	0.32	J	B	o					
	EU 3	0.1	J			0.61	J			ug/l	MW-33	6	41	15%	0.32	J	B	o					
Arsenic	EU 1	0.078	J			5		K	m	ug/l	SIBLEY SUMP	13	32	41%	1.2	J							
	EU 2	0.15	J			18				ug/l	MP2-3	100	112	89%	1.2	J							
	EU 3	0.091	J			7.3				ug/l	MW-8	64	231	28%	1.2	J							
Barium	EU 1	36.4	J			54.3	J			ug/l	MW-21	2	2	100%	204								
	EU 2	71.2	J			137	J			ug/l	MW-25(FD-3)	5	5	100%	204								
	EU 3	13.7	J			452				ug/l	MW-38	41	41	100%	204								
Beryllium	EU 1	nd				nd				ug/l		0	2	0%	0.048	J							
	EU 2	0.13	J	B	o	0.13	J	B	o	ug/l	MW-25	1	5	20%	0.048	J							
	EU 3	0.029	J			1				ug/l	PZ-1S	21	41	51%	0.048	J							
Cadmium	EU 1	0.14	J			0.14	J			ug/l	MW-21	1	2	50%	2.3	J							
	EU 2	0.086	J			0.1	J			ug/l	MW-25	2	5	40%	2.3	J							
	EU 3	0.06	J			1.7	J			ug/l	MW-38	20	41	49%	2.3	J							
Chromium	EU 1	nd				nd				ug/l		0	2	0%	3.4	J	L	p					
	EU 2	nd				nd				ug/l		0	5	0%	3.4	J	L	p					
	EU 3	0.34	J	B	o	7.8	J			ug/l	MW-32	12	41	29%	3.4	J	L	p					
Cobalt	EU 1	0.69	J			2.1	J			ug/l	MW-22	2	2	100%	1.9	J	B	o					
	EU 2	0.34	J	B	o	2.5	J			ug/l	MW-25	4	5	80%	1.9	J	B	o					
	EU 3	0.14	J	B	o	159				ug/l	MW-33	35	41	85%	1.9	J	B	o					
Copper	EU 1	1.9	J	B	x	1.9	J	B	x	ug/l	MW-21	2	2	100%	13.2	J							
	EU 2	1.7	J	B	p	15.2	J	B	x	ug/l	MW-25(FD-3)	4	5	80%	13.2	J							
	EU 3	0.45	J			12.5	J	B	x	ug/l	MW-38	34	41	83%	13.2	J							
Lead	EU 1	0.42	J			0.86	J	B	x	ug/l	MW-22	2	2	100%	1	J							
	EU 2	0.24	J			0.45	J			ug/l	MW-25	3	5	60%	1	J							
	EU 3	0.15	J			5.4	J			ug/l	MW-32	32	40	80%	1	J							
Manganese	EU 1	22.2				59.5				ug/l	MW-22	2	2	100%	553								
	EU 2	6	J			946				ug/l	MW-25	5	5	100%	553								
	EU 3	0.77	J			14400	D			ug/l	MW-33	41	41	100%	553								
Mercury	EU 1	nd				nd				ug/l		0	2	0%	nd								
	EU 2	0.035	J	L	o	0.052	J	B	o	ug/l	MW-24	2	5	40%	nd								
	EU 3	0.021	J	L	o	0.16	J			ug/l	MW-14(FD-2)	8	41	20%	nd								
Nickel	EU 1	3.2	J			10.5	J			ug/l	MW-21	2	2	100%	31.8	J							
	EU 2	1	J			3.2	J	B	p	ug/l	MW-25	5	5	100%	31.8	J							
	EU 3	0.69	J			34.8	J			ug/l	MW-33	39	41	95%	31.8	J							

**Table 4-16
Summary of Metals Detected in Groundwater**

CHEMICAL CLASS / ANALYTE DETECTIONS	Groundwater Exposure Point	Minimum Concentration (Qualifier) (2)				Maximum Concentration (Qualifier) (2)				Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)				Potential ARAR/TBC		
		Value	LF	VF	RC	Value	LF	VF	RC			Detected	Analyzed	Percent	Value	LF	VF	RC	MCL	AL	DWHA
																			(ug/L)	(ug/L)	(ug/L)
Selenium	EU 1	2.9	J			2.9	J			ug/l	MW-21	1	2	50%	nd				50	--	--
	EU 2	nd				nd				ug/l		0	5	0%	nd						
	EU 3	2.5	J			3.9	J			ug/l	MW-19	2	38	5%	nd						
Silver	EU 1	nd				nd				ug/l		0	2	0%	0.017	J	B	o	--	--	--
	EU 2	0.072	J	B	o	0.078	J	B	o	ug/l	MW-25	1	5	20%	0.017	J	B	o			
	EU 3	0.016	J	B	o	4.7	J			ug/l	MW-38	23	41	56%	0.017	J	B	o			
Strontium	EU 1	144				625	N	L	m	ug/l	MW-21	2	2	100%	202				--	--	--
	EU 2	158				278				ug/l	MW-25	5	5	100%	202						
	EU 3	37.2				2240	N	L	m	ug/l	PZ-1D	41	41	100%	202						
Tellurium	EU 1	0.38	J			0.68	J			ug/l	MW-21	2	2	100%	2.3	J			--	--	--
	EU 2	0.76	J			1.2	J			ug/l	MW-25	3	5	60%	2.3	J					
	EU 3	0.3	J			5.6	J			ug/l	MW-38	24	41	59%	2.3	J					
Thallium	EU 1	nd				nd				ug/l		0	2	0%	nd				2	--	--
	EU 2	nd				nd				ug/l		0	5	0%	nd						
	EU 3	0.13	J	B	o	0.65	J			ug/l	MW-19	5	41	12%	nd						
Tin	EU 1	nd				nd				ug/l		0	2	0%	nd				--	--	--
	EU 2	nd				nd				ug/l		0	5	0%	nd						
	EU 3	nd				9				ug/l	MW-32	12	41	29%	nd						
Titanium	EU 1	2.1	J	B	x	3.6	J	J	g	ug/l	MW-21	2	2	100%	4.7	J			--	--	--
	EU 2	0.77	J	B	o	3.4	J	J	g	ug/l	MW-25	5	5	100%	4.7	J					
	EU 3	0.7	J	B	o	94.3		J	g	ug/l	MW-32	38	41	93%	4.7	J					
Vanadium	EU 1	3.9	J	B	o	3.9	J	B	o	ug/l	MW-21	1	2	50%	nd				--	--	--
	EU 2	1.3	J	B	o	3.6	J	B	o	ug/l	MW-24	3	5	60%	nd						
	EU 3	0.8	J	B	o	9.9	J	B	o	ug/l	MW-32	21	41	51%	nd						
Zinc	EU 1	8.3	J	B	p	11.8	J	B	x	ug/l	MW-21	2	2	100%	36.3	J			--	--	--
	EU 2	2.2	J			11.5	J	B	x	ug/l	MW-25	4	5	80%	36.3	J					
	EU 3	2.9	J	B	x	36.2	J	B	p	ug/l	MW-20(FD-1)	36	41	88%	36.3	J					
Zirconium	EU 1	3.2	J	B	o	3.2	J	B	o	ug/l	MW-21	1	2	50%	nd				--	--	--
	EU 2	3.2	J	B	o	3.2	J	B	o	ug/l	MW-25	1	5	20%	nd						
	EU 3	0.12	J			6.9	J	B	o	ug/l	MW-32	16	41	39%	nd						

NOTES:

(1) EU1: Sibley Sump, MWs 21, 22, and 46; EU2: MP-2, MWs 24, 25, 44, 45, and PZ-4; and EU3: All other locations not in EU1 or EU2

(2) 'LF': Lab Flag (J: value is less than the reporting limit but greater than the method detection limit). 'VF': Validation Flag (B: blank contamination, L: analyte present but reported value may be biased low and actual value is expected to be higher). 'RC': Validation Reason Code (g: laboratory duplicate imprecision, m: MS/MSD recovery failure, o: calibration blank contamination, p: preparation blank contamination for inorganics, x: field blank contamination).

(3) Maximum concentration detected at MW-28, MW-29, or MW-30.

**Table 4-17
Summary of Other Compounds (including Perchlorate) Detected in Groundwater**

CHEMICAL CLASS / ANALYTE DETECTIONS	Groundwater Exposure Point	Minimum Concentration (Qualifier) (2)				Maximum Concentration (Qualifier) (2)				Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)				Potential ARAR/TBC		
		Value	LF	VF	RC	Value	LF	VF	RC			Detected	Analyzed	Percent	Value	LF	VF	RC	MCL	AL	DWHA
																			(ug/L)	(ug/L)	(ug/L)
Other Chemicals, Including Perchlorate																					
1,4-Oxathiane	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	0.52				0.52				ug/l	MW-25(FD-3)	1	5	20%	nd				--		
	EU 3	nd				nd				ug/l		0	29	0%	nd				--		
Acetic Acid	EU 1	nd				nd				ug/l		0	2	0%	12000		J	h			
	EU 2	190				4400		J	h	ug/l	MW-24	3	5	60%	12000		J	h	--		
	EU 3	86				1500				ug/l	MW-3	14	30	47%	12000		J	h	--		
Bromide	EU 1	62	J			2200				ug/l	SIBLEY SUMP	7	9	78%	440						
	EU 2	110		K	m	980				ug/l	PZ-4D	12	12	100%	440				--		
	EU 3	0.096	J			2600				ug/l	MW-19	60	82	73%	440				--		
Chloride	EU 1	10000				601000				ug/l	SIBLEY SUMP	10	10	100%	220000						
	EU 2	83000				400000				ug/l	PZ-4S	13	13	100%	220000				--		
	EU 3	3400				1E+06				ug/l	MW-33	81	81	100%	220000				--		
Iodate	EU 1	520				740	J	B	x	ug/l	MW-22	2	2	100%	500		J	h			
	EU 2	600				1800				ug/l	MW-24	4	5	80%	500		J	h	--		
	EU 3	250	J	B	x	1800				ug/l	MW-15	23	32	72%	500		J	h	--		
Iodide	EU 1	nd				nd				ug/l		0	2	0%	3800		J	h			
	EU 2	2300		J	h	2300		J	h	ug/l	MW-25	1	5	20%	3800		J	h	--		
	EU 3	2.6		L	m	3100		J	h	ug/l	MW-7	9	32	28%	3800		J	h	--		
Perchlorate	EU 1	3.43				48		J	c	ug/l	MW-21	37	38	97%	0.986		J	c			
	EU 2	0.221	J	J		146				ug/l	PZ-4S	105	113	93%	0.986		J	c	--		
	EU 3	0.0926	J	J	c	10.6				ug/l	MW-19(confirm)	139	248	56%	0.986		J	c	15		

NOTES:

(1) EU1: Sibley Sump, MWs 21, 22, and 46; EU2: MP-2, MWs 24, 25, 44, 45, and PZ-4; and EU3: All other locations not in EU1 or EU2

(2) 'LF': Lab Flag (J: value is less than the reporting limit but greater than the method detection limit). 'VF': Validation Flag (B: blank contamination, J: analyte is present but the reported value may not be accurate or precise, K: analyte present but reported value may be biased high and actual value is expected to be lower, L: analyte present but reported value may be biased low and actual value is expected to be higher). 'RC': Validation Reason Code (c: calibration failure, h: holding time violation, x: field blank contamination).

(3) Maximum concentration detected at MW-28, MW-29, or MW-30.

Table 4-18
Summary of Non-Target Tentatively Identified Compounds Detected in Groundwater

CHEMICAL CLASS / ANALYTE DETECTIONS	Groundwater Exposure Point	Minimum Concentration (Qualifier) (2)				Maximum Concentration (Qualifier) (2)				Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)			Potential ARAR/TBC			
		Value	LF	VF	RC	Value	LF	VF	RC			Detected	Analyzed	Percent	Value	LF	VF	RC	MCL	AL	DWHA
																			(ug/L)	(ug/L)	(ug/L)
Non-Target TICS (Tentatively Identified Compounds)																					
13-Tetradecen-1-ol acetate (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	3.18	JN	NJ	t	6.79	JN	NJ	t	ug/l	MW-31	2	31	6%	nd				--		
1-Docosene (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	4.18	JN	NJ	t	6.71	JN	NJ	t	ug/l	MW-10(FD-1)	2	31	6%	nd				--		
1-Eicosanol (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	6.09	JN	NJ	t	6.09	JN	NJ	t	ug/l	MW-10	1	31	3%	nd				--		
1-Hexacosanol (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	4.09	JN	NJ	t	4.09	JN	NJ	t	ug/l	MW-40	1	31	3%	nd				--		
2-Chloro-2-Butane (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	3.64	JN	NJ	t	3.64	JN	NJ	t	ug/l	MW-8	1	31	3%	nd				--		
3-Methyl-3-Buten-2-One (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	5.33		NJ	t	5.33		NJ	t	ug/l	MW-8	1	31	3%	nd				--		
3-Penten-2-OL (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	7.95	JN	NJ	t	7.95	JN	NJ	t	ug/l	MW-8(FD-4)	1	31	3%	nd				--		
3-Penten-2-one, 4-methyl- (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	4.4	JN	NJ	t	4.4	JN	NJ	t	ug/l	MW-37	1	31	3%	nd				--		
Acetic acid, octadecyl ester (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	6.19	JN	NJ	t	6.19	JN	NJ	t	ug/l	MW-8	1	31	3%	nd				--		
Benzenesulfonamide, N,4- dimethyl- (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	20	JN	NJ	t	20	JN	NJ	t	ug/l	MW-3	1	31	3%	nd				--		
Hexanoic acid, 2-ethyl- (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	10	JN	NJ	t	10	JN	NJ	t	ug/l	MW-25	1	5	20%	nd				--		
	EU 3	190	JN	NJ	t	190	JN	NJ	t	ug/l	MW-36	1	31	3%	nd				--		
Methane, dichloronitro- (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	nd						
	EU 2	nd				nd				ug/l		0	5	0%	nd				--		
	EU 3	4.3	JN	NJ	t	4.3	JN	NJ	t	ug/l	MW-40	1	31	3%	nd				--		

**Table 4-18
Summary of Non-Target Tentatively Identified Compounds Detected in Groundwater**

CHEMICAL CLASS / ANALYTE DETECTIONS	Groundwater Exposure Point	Minimum Concentration (Qualifier) (2)				Maximum Concentration (Qualifier) (2)				Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)				Potential ARAR/TBC		
		Value	LF	VF	RC	Value	LF	VF	RC			Detected	Analyzed	Percent	Value	LF	VF	RC	MCL	AL	DWHA
																			(ug/L)	(ug/L)	(ug/L)
N-Hexadecanoic Acid (SVOC)	EU 1	nd				nd				ug/l		0	2	0%	5.61	JN	NJ	t			
	EU 2	4.72	JN	NJ	t	4.72	JN	NJ	t	ug/l	MW-24	1	5	20%	5.61	JN	NJ	t	--	--	--
	EU 3	2.35	JN	NJ	t	9.83	JN	NJ	t	ug/l	MW-8	3	31	10%	5.61	JN	NJ	t			

NOTES:

(1) EU1: Sibley Sump, MWs 21, 22, and 46; EU2: MP-2, MWs 24, 25, 44, 45, and PZ-4; and EU3: All other locations not in EU1 or EU2

(2) 'LF': Lab Flag (J: value is less than the reporting limit but greater than the method detection limit, N: spiked sample recovery not within control limits). 'VF': Validation Flag (J:). 'RC': Validation Reason Code (t: tentatively identified compound).

(3) Maximum concentration detected at MW-28, MW-29, or MW-30.

**Table 4-19
Surface Water Analytical Scope and Detected Chemical Classes**

Surface Water Location ID	Number of Sampling Events	Spring Valley QAPP Chemical Classes Analyzed ⁽¹⁾							
		Chemical Agents	Explosives	Metals	SVOCs	SVOC Target TICs	VOCs	VOC Target TICs	Miscellaneous, including Perchlorate
SW-1	9	X	X	X	X	X	X	X	X
SW-2	11	X	X	X	X	X	X	X	X
SW-3	7			X					X (ClO4, Br, Cl only)
SW-4	3			X (As only)					X (ClO4, Br, Cl only)
SW-5	3			X					X (ClO4, Br, Cl only)
SW-6	10			X (As only)					X (ClO4, Br, Cl only)
SW-7	2			X (As only)					X (ClO4, Br, Cl only)
SW-8	3			X (As only)					X (ClO4, Br, Cl only)
SW-9	7			X (As only)					X (ClO4, Br, Cl only)
SW-10	3			X (As only)					X (ClO4, Br, Cl only)
SW-11	10			X					X
SW-12	2			X (As only)					X (ClO4, Br, Cl only)
SW-13	2			X (As only)					X (ClO4, Br, Cl only)
SW-14	3			X (As only)					X (ClO4, Br, Cl only)
SW-15	3			X					X (ClO4, Br, Cl only)
SW-16	10			X					X (ClO4, Br, Cl only)
SW-17	10			X (As only)					X (ClO4, Br, Cl only)
SW-18	7			X (As only)					X (ClO4, Br, Cl only)
SW-19	2			X (As only)					X (ClO4, Br, Cl only)
SW-20	6			X (As only)					X (ClO4, Br, Cl only)
SW-21	11			X					X
SW-22	3			X					X (ClO4, Br, Cl only)
SW-23	2			X (As only)					X (ClO4, Br, Cl only)
SW-24	3			X (As only)					X (ClO4, Br, Cl only)
SW-25	7			X (As only)					X (ClO4 only)
LOT 18 DRAIN PIPE	7			X (As only)					X (ClO4 only)
RESERVOIR	4	X	X	X	X	X	X	X	X

Notes:

(1) Chemical classes are defined below:

Chemical Agents: CVAA/CVAO, mustard, ricin

Explosives: explosive compounds analyzed using SW-846 8330B and picric acid (HPLC/UV)

SVOCs and SVOC TICs: Semi-volatile organic compounds (SVOCs) and SVOC Tentatively Identified Target Compounds (TICs) as per Tables 1 and 3 of the Spring Valley Groundwater Study QAPP .

VOCs and VOC TICs: Volatile organic compounds (VOCs) and VOC Tentatively Identified Target Compounds (TICs) as per Tables 1 and 4 of the Spring Valley Groundwater Study QAPP .

Other: Perchlorate, 1,4-oxathiane, acetic acid, bromide and chloride, ethanol, iodate, iodide

= Chemical class not analyzed.

x = Chemical class analyzed. If specific chemicals are listed in parentheses, this indicates that only these chemicals were analyzed, not all chemicals in the chemical class. Also, at least one chemical was detected.

= No chemical from the chemical class was detected.

Table 4-20
SV FUDS Parameters Detected in Surface Water

Detected Surface Water Chemical (1)	EU1	EU1	EU1	EU1	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	EU2	Back Ground
	SW-1	SW-11	SW-21	LOT 18 DRAIN PIPE	SW-2	SW-4	SW-5	SW-6	SW-7	SW-8	SW-9	SW-10	SW-12	SW-13	SW-14	SW-15	SW-16	SW-17	SW-18	SW-19	SW-20	SW-22	SW-23	SW-24	SW-25	RESER- VOIR	SW-3
Metals																											
Aluminum	X	X	X		X		X									X	X									X	X
Antimony	X	X	X		X		X										X										
**Arsenic	X	X	X	X	X	X	X	X		X				X	X	X	X	X	X		X	X	X		X	X	X
Barium	X	X	X		X		X									X	X									X	X
Beryllium	X						X																				
Cadmium	X		X		X		X										X										
**Cobalt	X				X		X																			X	
Copper	X	X	X		X		X									X	X									X	X
Lead	X	X	X		X		X									X	X										X
**Manganese	X	X	X		X		X									X	X									X	X
Nickel	X	X	X		X		X									X	X										X
Silver		X	X		X		X									X	X										
**Strontium	X	X	X		X		X									X	X										X
Tellurium	X				X																						X
Titanium	X	X	X		X		X									X	X										X
Vanadium			X													X	X										X
Zinc	X	X	X		X		X																				X
Zirconium					X																						
SemiVolatile Organic Compounds																											
4-Methylphenol	X																										
Benzoic Acid	X				X																						X
Bis(2-Ethylhexyl)Phthalate					X																						
Di-N-Butyl Phthalate					X																						
Volatile Organic Compounds																											
Acetone	X																										
Miscellaneous, including Perchlorate																											
Bromide	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chloride	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Iodate	X				X																						X
Iodide	X																										
**Perchlorate	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Notes:

X = Detection; Misc = Miscellaneous; SVOC = Semi-volatile organic compound; VOC = volatile organic compound

** = Groundwater COPC for at least on GW EU

⁽¹⁾ If no chemicals from a chemical parameter class were detected, then the chemical parameter class is not presented here.

**Table 4-21
Summary Volatile Organic Compounds Detected in Surface Water**

CHEMICAL CLASS / ANALYTE DETECTIONS	Surface Water Exposure Point (1)	Minimum Concentration (Qualifier) (2)				Maximum Concentration (Qualifier) (2)				Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (2, 3)				Potential ARAR/TBC		
		Value	LF	VF	RC	Value	LF	VF	RC			Detected	Analyzed	Percent	Value	LF	VF	RC	MCL	AL	DWHA
																			(ug/L)	(ug/L)	(ug/L)
Volatile Organic Compounds																					
Acetone	EU 1	9.6	J			9.6	J			ug/l	SW-1	1	2	50%	na				--	--	--
	EU 2	nd				nd				ug/l		0	2	0%	na						

NOTES:

- (1) EU1: Lot 18 Drain, SW-1, SW-11, and SW-21; EU2: All other locations not in EU1.
- (2) LF: Lab Flag (J: value is less than the reporting limit but greater than the method detection limit).
- (3) Maximum concentration detected at SW-3, representative of Potomac River water.

Table 4-22
Summary Semivolatile Organic Compounds Detected in Surface Water

CHEMICAL CLASS / ANALYTE DETECTIONS	Surface Water Exposure Point (1)	Minimum Concentration (Qualifier) (1)				Maximum Concentration (Qualifier) (1)				Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)				Potential ARAR/TBC		
		Value	LF	VF	RC	Value	LF	VF	RC			Detected	Analyzed	Percent	Value	LF	VF	RC	MCL	AL	DWHA
																			(ug/L)	(ug/L)	(ug/L)
SemiVolatile Organic Compounds																					
4-Methylphenol	EU 1	2.6	J			2.6	J			ug/l	SW-1	1	2	50%	na				--	--	--
	EU 2	nd				nd				ug/l		0	2	0%	na						
Benzoic Acid	EU 1	11		B	x	11		B	x	ug/l	SW-1	1	2	50%	na				--	--	--
	EU 2	2	J	B	x	5.3	J	B	x	ug/l	SW-2	2	2	100%	na						
Bis(2-Ethylhexyl)Phthalate	EU 1	1.4	J			10	J			ug/l	SW-1	1	2	50%	na				6	--	--
	EU 2	3.6	J			3.6	J			ug/l	SW-2	1	2	50%	na						
Di-N-Butyl Phthalate	EU 1	nd				nd				ug/l		0	2	0%	na				--	--	--
	EU 2	3	J			3	J			ug/l	SW-2	1	2	50%	na						

NOTES:

(1) EU1: Lot 18 Drain, SW-1, SW-11, and SW-21; EU2: All other locations not in EU1.

(2) 'LF': Lab Flag (J: value is less than the reporting limit but greater than the method detection limit); 'VF': Validation Flag (B: blank contamination); 'RC': Validation Reason Code (x: field blank contamination)

(3) Maximum concentration detected at SW-3, representative of Potomac River water.

**Table 4-23
Summary Metals Detected in Surface Water**

CHEMICAL CLASS / ANALYTE DETECTIONS	Surface Water Exposure Point (1)	Minimum Concentration (Qualifier) (1)				Maximum Concentration (Qualifier) (1)				Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)				Potential ARAR/TBC		
		Value	LF	VF	RC	Value	LF	VF	RC			Detected	Analyzed	Percent	Value	LF	VF	RC	MCL	AL	DWHA
																			(ug/L)	(ug/L)	(ug/L)
Metals																					
Aluminum	EU 1	17.4	J	B	o	63.3	J	B	z	ug/l	SW-1(FD-5)	3	4	75%	13.9	J	B	o	--	--	--
	EU 2	6.3	J	B	o	303				ug/l	SW-2	7	8	88%	13.9	J	B	o			
Antimony	EU 1	0.12	J			0.4	J			ug/l	SW-1	4	4	100%	nd				6	--	--
	EU 2	0.1	J			2	J			ug/l	SW-2	4	8	50%	nd						
Arsenic	EU 1	0.26	J			3	J			ug/l	SW-1	30	39	77%	1.6	J	L	o	10	--	--
	EU 2	0.11	J			2.1	J			ug/l	SW-2	40	93	43%	1.6	J	L	o			
Barium	EU 1	89.8	J			121	J			ug/l	SW-1	4	4	100%	32.1	J			2000	--	--
	EU 2	32.1	J			125	J			ug/l	SW-22	8	8	100%	32.1	J					
Beryllium	EU 1	0.087	J	B	o	0.092	J	B	o	ug/l	SW-1	1	4	25%	nd				4	--	--
	EU 2	0.067	J	B	o	0.13	J	B	o	ug/l	SW-5	2	8	25%	nd						
Cadmium	EU 1	0.046	J			0.27	J	B	o	ug/l	SW-1	3	4	75%	nd				5	--	--
	EU 2	0.072	J			0.077	J			ug/l	SW-16	3	8	38%	nd						
Cobalt	EU 1	0.87	J	B	o	4.9	J			ug/l	SW-1	2	4	50%	nd				--	--	--
	EU 2	0.35	J	B	o	1.8	J			ug/l	SW-2	4	8	50%	nd						
Copper	EU 1	1.9	J	B	p	4.8	J			ug/l	SW-1	4	4	100%	3.3	J	B	x	1300	1300	--
	EU 2	3.3	J	B	x	49.7				ug/l	SW-2	8	8	100%	3.3	J	B	x			
Lead	EU 1	0.19	J			0.7	J	B	x	ug/l	SW-21	4	4	100%	nd				--	15	--
	EU 2	0.13	J			2.2	J			ug/l	SW-2	6	8	75%	nd						
Manganese	EU 1	5.6	J			949				ug/l	SW-1	4	4	100%	18.7				--	--	--
	EU 2	9.4	J			271				ug/l	SW-22	8	8	100%	18.7						
Nickel	EU 1	2	J			180				ug/l	SW-1	4	4	100%	1	J			--	--	--
	EU 2	1	J			6.9	J			ug/l	SW-5	8	8	100%	1	J					
Silver	EU 1	0.052	J	B	o	0.089	J	B	o	ug/l	SW-21	2	4	50%	nd				--	--	--
	EU 2	0.065	J			0.27	J			ug/l	SW-2	6	8	75%	nd						
Strontium	EU 1	35				314				ug/l	SW-1	4	4	100%	144				--	--	--
	EU 2	144				367				ug/l	SW-16	8	8	100%	144						
Tellurium	EU 1	1.2	J			1.2	J			ug/l	SW-1	1	4	25%	nd				--	--	--
	EU 2	0.45	J			0.49	J			ug/l	RESERVOIR	2	8	25%	nd						
Titanium	EU 1	1.2	J	B	o	2.8	J	B	x	ug/l	SW-1	4	4	100%	0.41	J	B	o	--	--	--
	EU 2	0.41	J	B	o	15.3				ug/l	SW-2	8	8	100%	0.41	J	B	o			
Vanadium	EU 1	1.6	J	B	o	2.7	J	B	o	ug/l	SW-21	2	4	50%	1.7	J	B	o	--	--	--
	EU 2	0.93	J	B	o	3	J	B	o	ug/l	SW-22	4	8	50%	1.7	J	B	o			
Zinc	EU 1	2.5	J			45.4	J			ug/l	SW-1	4	4	100%	nd				--	--	--
	EU 2	3.9	J			48.6	J			ug/l	SW-5	4	8	50%	nd						
Zirconium	EU 1	nd				nd				ug/l		0	4	0%	nd				--	--	--
	EU 2	1.8	J	B	o	1.8	J	B	o	ug/l	SW-2	1	8	13%	nd						

NOTES:

(1) EU1: Lot 18 Drain, SW-1, SW-11, and SW-21; EU2: All other locations not in EU1.

(2) 'LF': Lab Flag (J: value is less than the reporting limit but greater than the method detection limit); 'VF': Validation Flag (B: blank contamination, L: analyte present but reported value may be biased low and actual value is expected to be higher); 'RC': Validation Reason Code (h: holding time violation, m: MS/MSD recovery failure, o: calibration blank contamination, p: preparation blank contamination for inorganics, x: field blank contamination, z: method blank or holding blank contamination).

(3) Maximum concentration detected at SW-3, representative of Potomac River water.

**Table 4-24
Summary of Other Compounds (including Perchlorate) Detected in Surface Water**

CHEMICAL CLASS / ANALYTE DETECTIONS	Surface Water Exposure Point (1)	Minimum Concentration (Qualifier) (1)				Maximum Concentration (Qualifier) (1)				Units	Location of Maximum Concentration	Detection Frequency			Background Concentration (Qualifier) (3)				Potential ARAR/TBC		
		Value	LF	VF	RC	Value	LF	VF	RC			Detected	Analyzed	Percent	Value	LF	VF	RC	MCL	AL	DWHA
																			(ug/L)	(ug/L)	(ug/L)
Other Chemicals, Including Perchlorate																					
Bromide	EU 1	0.14				1600				ug/l	SW-1	9	9	100%	84	J			--	--	--
	EU 2	74	J			820				ug/l	SW-6	32	44	73%	84	J			--	--	--
Chloride	EU 1	120000				270000				ug/l	SW-1	8	8	100%	50000				--	--	--
	EU 2	14000				1100000				ug/l	SW-9	44	44	100%	50000				--	--	--
Iodate	EU 1	820	J	B	x	820	J	B	x	ug/l	SW-1	2	2	100%	na				--	--	--
	EU 2	860	J	B	x	1100		B	x	ug/l	RESERVOIR	2	2	100%	na				--	--	--
Iodide	EU 1	24				27		J	h	ug/l	SW-1	2	2	100%	na				--	--	--
	EU 2	nd				nd				ug/l		0	2	0%	na				--	--	--
Perchlorate	EU 1	0.664				9.94				ug/l	SW-11	38	38	100%	0.742		J	c	--	--	15
	EU 2	0.21	J	L	m	3.13		J	c	ug/l	SW-6	91	101	90%	0.742		J	c	--	--	15

NOTES:

(1) EU1: Lot 18 Drain, SW-1, SW-11, and SW-21; EU2: All other locations not in EU1.

(2) LF: Lab Flag (J: value is less than the reporting limit but greater than the method detection limit); VF: Validation Flag (B: blank contamination); RC: Validation Reason Code (c: calibration failure, h: holding time violation, m: MS/MSD recovery failure, x: field blank contamination).

(3) Maximum concentration detected at SW-3, representative of Potomac River water.

**Table 4-25
Arsenic and Perchlorate Groundwater Seasonality Test Results**

Location ID	Seasonality Indicated Confidence Interval %	
	95	97.5
Perchlorate		
Sibley Sump	NO	NO
MW-21	NO	NO
MW-22	NO	NO
MW-24	NO	NO
MW-25	NO	NO
PZ-4D	NO	NO
Arsenic		
MW-24	NO	NO
MW-25	NO	NO
PZ-4D	NO	NO

Table 4-26
Arsenic and Perchlorate Groundwater Concentration Trends

Exposure Unit	Well	Arsenic	Perchlorate
EU1	MW-21	NC	Decrease
EU1	MW-22	NC	Increase
EU1	Sibley Sump	NC	Decrease
EU2	MP2-1	none	Decrease
EU2	MP2-2	none	Decrease
EU2	MP2-3	none	none
EU2	MP2-4	Decrease	none
EU2	MP2-5	none	none
EU2	MP2-6	none	Decrease
EU2	MP2-7	Decrease	Decrease
EU2	MP2-8	none	Decrease
EU2	MP2-All	Decrease	Decrease
EU2	MW-24	none	Decrease
EU2	MW-25	none	none
EU2	MW-44	none	Increase
EU2	MW-45D	NC	none
EU2	MW-45S	NC	none
EU2	PZ-4D	Increase	none
EU2	PZ-4S	none	Decrease

Notes:

NC = not calculated due to historically very low concentrations

none = insufficient evidence to identify a trend.

Decrease = Decreasing trend

Increase = Increasing trend

**Table 4-27
Soil Borings**

Boring ID	Approximate Depth to 1918 Surface (ft, bgs)	Soil Sample Interval Selected for Analysis (ft, bgs)	Total Boring Depth (ft, bgs)
SA-1	17	16 to 18	43
SA-2	15	14 to 16	50
SA-3	15	14 to 16	55
SA-4	17	16 to 18	54
SA-5	17	16 to 18	51
SA-6	17	16 to 18	40
SA-7	15	14 to 16	55
SA-8	15	14 to 16	55
SA-9	17	17.5 to 19.5	51
SA-10	17	16 to 18	54
SA-11	14	15 to 17	54
SA-12	14	15 to 17	54
SA-13	15	14 to 16	50
SA-14	11	10 to 12	50
SA-15	17	16 to 18	33
SA-16	17	14 to 16	37

Table 4-28
Soil Analytical Results

Sample ID	Date	Sample Interval (ft bgs)	Perchlorate (µg/kg)	Qualifier
SA-1	7/26/2011	16 to 18	ND (2.4)	U
SA-2	7/27/2011	14 to 16	ND (2.6)	U
SA-3	7/25/2011	14 to 16	ND (2.7)	U
SA-4	7/21/2011	16 to 18	ND (2.3)	U
SA-5	7/12/2011	16 to 18	2	J
SA-5 Dup	7/12/2011	16 to 18	ND (0.70)	U
SA-6	7/27/2011	16 to 18	ND (2.5)	U
SA-7	7/21/2011	14 to 16	ND (2.4)	U
SA-8	7/20/2011	14 to 16	ND (2.3)	U
SA-9	7/14/2011	17.5 to 19.5	ND (0.75)	U
SA-10	7/19/2011	16 to 18	ND (2.7)	U
SA-11	7/16/2011	15 to 17	ND (3.0)	U
SA-12	7/15/2011	15 to 17	ND (0.88)	U
SA-13	7/19/2011	14 to 16	5.2	J
SA-14	7/18/2011	10 to 12	ND (2.5)	U
SA-15	7/20/2011	16 to 18	ND (2.3)	U
SA-15 Dup	7/20/2011	16 to 18	2.8	J
SA-16	7/25/2011	14 to 16	ND (2.3)	U

ND = Not Detected

Dup = Duplicate sample

U = The analyte was not detected above the method detection limit


J = The analyte was detected between the method detection limit and the reporting limit. It is also used to indicate an estimated value for tentatively identified compounds in mass spectrometry where a 1:1 response is assumed.

**Table 4-29
Groundwater Analytical Results**

Sample ID	Date	Sample Type	Sample Depth	Perchlorate (µg/l)	Qualifier
			(ft bgs)		
SA-1	7/26/2011	OB	43	4.3	
SA-2	7/27/2011	OB	50	4.1	
SA-3	7/25/2011	OB	55	12	
SA-4	7/22/2011	TW	55	3.8	
SA-5	7/13/2011	OB	51	11	
SA-5 Dup	7/13/2011	OB	51	12	
SA-6	7/28/2011	OB	40	3	
SA-7	7/22/2011	OB	55	22	
SA-8	7/20/2011	TW	55	7.5	
SA-9	7/15/2011	TW	51	1.4	
SA-10	7/19/2011	OB	54	0.65	
SA-11	7/18/2011	OB	54	2.1	
SA-12	7/15/2011	OB	54	2	
SA-13	7/20/2011	OB	50	0.93	
SA-14	7/18/2011	OB	50	0.76	
SA-15	7/20/2011	OB	33	16	
SA-16	7/25/2011	OB	37	2.5	
MW-41	7/28/2011	PW	33	1.1	J
MW-42	7/28/2011	PW	43	1.6	J
PZ-4S	7/28/2011	PW	44	18	
PZ-4D	7/28/2011	PW	45	9.8	

J = The analyte was detected between the method detection limit and the reporting limit. It is also used to indicate an estimated value for tentatively identified compounds in mass spectrometry where a 1:1 response is assumed.

OB = Open borehole; Dup = Duplicate; TW = Temporary well; PW = Permanent well or piezometer

 Shading indicates exceedance of the DWHA screening value of 15 µg/l.

**Table 5-1
SV FUDS Parameters Detected in Groundwater and Without Screening Levels**

Chemical	Concentration (ug/l)									EU Detection Frequency					
	Minimum				Maximum				Background Max			Detected	Analyzed	Percent	
	Value	LF	VF	RC	Value	LF	VF	RC	Value	LF	VF				RC
Groundwater EU1															
Acetic Acid	nd				nd				12,000		J	h	0	2	0%
Bromide	62	J			2200				440				7	9	78%
Chloride	10,000				601,000				220,000				9	10	90%
Diphenyl ether	nd				nd				nd				0	3	0%
Iodate	520				520				500		J	h	1	2	50%
Iodide	nd				nd				3,800		J	h	0	2	0%
1,4-oxathiane	nd				nd				nd				0	2	0%
2-Nitrophenol	nd				nd				nd				0	2	0%
Phenyl Isocyanate	nd				nd				nd				0	1	0%
Tellurium	0.38	J			0.68	J			2.3	J			2	2	100%
Titanium	3.6	J	J	g	3.6	J	J	g	4.7	J			1	2	50%
Groundwater EU2															
Acetic Acid	190				4,400		J	h	12,000		J	h	3	5	60%
Bromide	110		K	m	980				440				12	12	100%
Chloride	83,000				400,000				220,000				13	13	100%
Diphenyl ether	nd				nd				nd				0	5	0%
Iodate	600				1,800				500		J	h	4	5	80%
Iodide	2,300		J	h	2,300		J	h	3,800		J	h	1	5	20%
1,4-oxathiane	1				1				nd				1	5	20%
2-Nitrophenol	nd				nd				nd				0	5	0%
Phenyl Isocyanate	nd				nd				nd				0	3	0%
Tellurium	0.76	J			1.2	J			2.3	J			3	5	60%
Titanium	3.4	J	J	g	3.4	J	J	g	4.7	J			1	5	20%
Groundwater EU3															
Acetic Acid	86				1,500				12,000		J	h	14	30	47%
Bromide	0.096	J			2,600				440				60	82	73%
Chloride	3,400				1,100,000				220,000				70	81	86%
Diphenyl ether	31		J	r	31		J	r	nd				1	32	3%
Iodate	500				1,800				500		J	h	12	32	38%
Iodide	2.6		L	m	3,100		J	h	3,800		J	h	8	32	25%
1,4-oxathiane	nd				nd				nd				0	29	0%
2-Nitrophenol	5	J			5	J			nd				1	31	3%
Phenyl Isocyanate	4.9	J	J	l	4.9	J	J	l	nd				1	19	5%
Tellurium	0.3	J			5.6	J			2.3	J			24	41	59%
Titanium	1.1	J			94.3		J	g	4.7	J			17	41	41%

Notes:

LF = Lab Flag; VF = Validation Flag; RC = Reason Code. Code definitions are in the appendices.

EU1 = Groundwater Exposure Unit 1; EU2 = Groundwater Exposure Unit 2; EU3 =Groundwater Exposure Unit 3.

nd = not detected.

Table 5-2
Groundwater Sampling Locations where SV FUDS Parameters without RSL Screening Values were Detected at Concentrations Above Background (1)

Location	Groundwater Exposure Unit	Parameter							
		Bromide	Chloride	Diphenyl ether	Iodate	Iodide	1,4-Oxathiane	Tellurium	Titanium
MW-21	EU1	X	--	--	X	--	--	--	--
Sibley Sump		X	X	--	--	--	--	--	--
MW-24	EU2	--	--	--	X	--	--	--	--
MW-25		--	--	--	X	--	X	--	--
PZ-4S		--	X	--	--	--	--	--	--
PZ-4D		X	X	--	--	--	--	--	--
MW-3	EU3	--	--	--	X	--	--	--	--
MW-5		--	--	--	X	--	--	--	--
MW-8		X	--	--	X	--	--	--	--
MW-15		--	--	--	X	X	--	--	--
MW-17		X	--	--	--	--	--	--	--
MW-18		X	--	--	--	--	--	--	--
MW-19		X	X	--	--	--	--	--	--
MW-20		X	--	--	--	--	--	--	--
MW-32		--	--	--	--	--	--	--	X
MW-33		--	X	--	X	--	--	--	--
MW-36		--	--	--	--	--	--	X	--
MW-37		--	--	--	X	--	--	--	X
MW-38		X	X	--	--	--	--	X	--
MW-39		--	--	--	--	--	--	X	--
PZ-1S		--	--	X	--	--	--	--	--
PZ-1D		X	X	--	--	--	--	X	X

Note:

X = The chemical was detected at this location at a concentration exceeding the maximum detected concentration in a background sample.

'--' Not analyzed or not detected at a concentration exceeding the maximum concentration detected in a background sample.

(1) Background is represented by SW-3 which is the location where Potomac River water enters the Dalcaria Reservoir.

**Table 5-3
SV FUDS Parameters Detected in Surface Water and Without Screening Levels**

Chemical	Concentration (ug/l)												EU Detection Frequency		
	Minimum				Maximum				Background Max (a)				Detected	Analyzed	Percent
	Value	LF	VF	RC	Value	LF	VF	RC	Value	LF	VF	RC			
Surface Water EU1															
Tellurium	1.2	J			1.2	J			nd				1	4	25%
Titanium	2	J			2.4	J			nd				2	4	50%
Bromide	0.14				1600				84	J			9	9	100%
Chloride	120000				270000				50000				8	8	100%
Iodate	820				820				nd				1	2	50%
Iodide	24				27		J	h	nd				2	2	100%
Surface Water EU2															
Tellurium	0.45	J			0.5	J			nd				2	8	25%
Titanium	1.7	J			15.3				nd				2	8	25%
Bromide	74	J			820				84	J			32	44	73%
Chloride	14000				1100000				50000				42	44	95%

Notes:

LF = Lab Flag; VF = Validation Flag; RC = Reason Code. Code definitions are in the appendices.

EU1 = Groundwater Exposure Unit 1; EU2 = Groundwater Exposure Unit 2; EU3 =Groundwater Exposure Unit 3.

nd = not detected.

(a) Represented by location SW-3.

Table 5-4
Surface Water Sampling Locations where SV FUDS Parameters without RSL Screening Values were Detected

Location	Surface Water Exposure Unit	Parameter					
		Bromide	Chloride	Iodate (a)	Iodide (a)	Tellurium	Titanium
SW-1	EU1	X	X	X	X	X	X
SW-11		X	X	--	--	--	--
SW-21		X	X	--	--	--	X
SW-2	EU2	X	X	--	--	X	X
SW-4		X	X	--	--	--	--
SW-5		X	X	--	--	--	X
SW-6		X	X	--	--	--	--
SW-7		X	X	--	--	--	--
SW-8		X	X	--	--	--	--
SW-9		X	X	--	--	--	--
SW-10		X	X	--	--	--	--
SW-12		X	X	--	--	--	--
SW-13		X	X	--	--	--	--
SW-14		X	X	--	--	--	--
SW-15		X	X	--	--	--	--
SW-16		X	X	--	--	--	--
SW-17		X	X	--	--	--	--
SW-18		X	X	--	--	--	--
SW-19		X	X	--	--	--	--
SW-20		X	X	--	--	--	--
SW-22		X	X	--	--	--	--
SW-23		X	X	--	--	--	--
SW-24		X	X	--	--	--	--
Reservoir			--	--	--	--	X

Note:

(a) No SW-3 sample was analyzed for this chemical.

'X' = The chemical was detected at this location at a concentration exceeding the maximum detected concentration in a background sample.

'--' Not analyzed or not detected at a concentration exceeding the maximum concentration detected in background sample SW-3.

Table 5-5

Exposure Scenario and Exposure Pathway Matrix for
Onsite Receptors at Spring Valley FUDS

EXPOSURE MEDIA/ EXPOSURE PATHWAYS	Adult Resident	Child Resident	AU Student	Indoor Office Worker	Outdoor Worker (Landscaper)	Construction/ Utility Worker
Current/Future Surface Water						
Incidental Ingestion						
Dermal Absorption	•	•	•			
Current/Future Groundwater (Watering Scenario)						
Incidental Ingestion	•	•			•	○
Dermal Absorption	•	•			•	○
Ingestion of Garden Vegetables (1)	○	○	○			
Inhalation of Vapors in Indoor Air	X	X	X	X		
Future Groundwater (Potable Use Scenario)						
Ingestion	•	•	•	•		
Dermal Absorption	•	•	•	•		
Inhalation of Vapors while Showering/Bathing	X	X	X			
Inhalation of Vapors in Indoor Air	X	X	X	X		

Notes:

- = Pathway potentially complete and quantified in the risk assessment.
- = Pathway to be qualitatively evaluated.
- X = No volatile COPCs.

(1) The ingestion of garden vegetables is addressed in the soils investigation/HHRA (USACE, 2015).

Table 5-6

Summary Statistics for the Chemicals of Potential Concern and their Exposure Medium
Spring Valley FUDS

Exposure Media, Exposure Units, and COPCs	Detection Frequency	Units	Summary Statistics						Selected Exposure Point Concentrations (EPCs)		
			Minimum Detection	Maximum Detection	Max Sample Location	Arithmetic Mean	95% UCL ⁽¹⁾	UCL ⁽¹⁾ Description	RME and CT EPC	Selected EPC ⁽¹⁾ Description	Rationale for EPC Selection
Groundwater - EU1											
Arsenic	12/13	µg/L	0.078	4.5	SIBLEY SUMP	1.778	2.582	95% UCL - N	2.582	95% UCL - N	KM(t) and bootstrap UCL in close agreement; selected higher UCL. Also sample size was < 15.
Cobalt	2/2	µg/L	0.69	2.1	MW-22	1.395	NC	NC	2.1	Max	Lower of Max and UCL (EPA, 1989)
Perchlorate	13/13	µg/L	3.43	25	MW-22	12.92	16.06	95% UCL - N	16.06	95% UCL - N	Recommended ProUCL value; UCL lower than Max.
Groundwater - EU2											
Arsenic	23/26	µg/L	0.15	16.8	MW-24	4.336	6.574	95% UCL - G	6.574	95% UCL - G	Adjusted Gamma KM UCL selected (sample size ≥ 15 and k star ≤ 1).
Cobalt	3/4	µg/L	0.5	2.5	MW-25	1.273	2.733	95% UCL - N	2.5	Max	Lower of Max and UCL (EPA, 1989)
Manganese	5/5	µg/L	6	946	MW-25	258.3	629	95% UCL - N	629	95% UCL - N	Recommended ProUCL value; UCL lower than Max.
Perchlorate	22/26	µg/L	0.221	54.3	MW-45D	17.6	55.84	99% UCL - NP	54.3	Max	Lower of Max and UCL (EPA, 1989)
Groundwater - EU3											
Arsenic	19/25	µg/L	0.09	5.2	MW-8	0.972	2.808	97.5% UCL - N	2.808	97.5% UCL - N	Recommended ProUCL value; UCL lower than Max.
Cobalt	16/22	µg/L	0.23	159	MW-33	12.52	87.84	99% UCL - N	87.84	99% UCL - N	Recommended ProUCL value; UCL lower than Max.
Manganese	25/25	µg/L	3.3	14400	MW-33	1737	4855	95% UCL - NP	4855	95% UCL - NP	Recommended ProUCL value; UCL lower than Max.
Strontium	23/23	µg/L	99.1	2240	PZ-1D	507.8	749.3	95% UCL - L	749.3	95% UCL - L	Recommended ProUCL value; UCL lower than Max.
Perchlorate	16/25	µg/L	0.41	3.27	PZ-3	1.223	1.518	95% UCL - N	1.518	95% UCL - N	KM(t) and bootstrap UCL in close agreement; selected higher UCL.
Surface Water - EU1											
Manganese	4/4	µg/L	5.6	949	SW-1	268.1	805.2	95% UCL - N	805.2	95% UCL - N	Recommended ProUCL value; UCL lower than Max.

Table 5-6

**Summary Statistics for the Chemicals of Potential Concern and their Exposure Medium
Spring Valley FUDS**

Notes:

CT = Central Tendency; COPC = Chemical of Potential Concern; EPC = Exposure Point Concentration; EU = Exposure Unit; KM = Kaplan-Meier; NA = not applicable; NC = not calculated; RME = Reasonable Maximum Exposure; UCL = Upper Confidence Limit; µg/L = micrograms per liter

(1) EPA's ProUCL 5.0. was used to calculate the 95% UCLs; the mode of "with non-detects" was used. Results are provided in Appendix T.

Statistics Definitions:

95% UCL-G = 95% UCL of Gamma data
95% UCL-L = 95% UCL of Lognormal data
95% UCL-N = 95% UCL of Normal data
95% UCL-NP = 95% UCL of Nonparametric data
97.5% UCL-N = 97.5% UCL of Normal data
99% UCL-N = 99% UCL of Normal data
Max = Maximum Detection

Data Distribution Definitions:

G = Gamma
L = Lognormal
N = Normal
NP = Nonparametric

Table 5-7

**Reasonable Maximum Exposure (RME) Cancer Risk Results
for the Spring Valley FUDS Human Health Risk Assessment**

Scenario	Current		Future
	Groundwater (Watering)	Surface Water (Recreational)	Groundwater (Potable Use)
EU1			
Lifetime Resident	2E-07	0E+00	5E-05
AU Student	NA	0E+00	7E-06
Indoor Office Worker	NA	NA	4E-06
Outdoor Worker (Landscape)	1E-07	NA	NA
EU2			
Lifetime Resident	4E-07	NA	1E-04
AU Student	NA	NA	2E-05
Indoor Office Worker	NA	NA	1E-05
Outdoor Worker (Landscape)	2E-07	NA	NA
EU3			
Lifetime Resident	2E-07	NA	5E-05
AU Student	NA	NA	8E-06
Indoor Office Worker	NA	NA	4E-06
Outdoor Worker (Landscape)	1E-07	NA	NA

Notes:

NA = not applicable

Shading indicates results greater than/equal to the cancer risk threshold of 1E-04.

Table 5-8

**Central Tendency (CT) Cancer Risk Results
for the Spring Valley FUDS Human Health Risk Assessment**

Scenario	Current		Future
	Groundwater (Watering)	Surface Water (Recreational)	Groundwater (Potable Use)
EU1			
Lifetime Resident	7E-08	0E+00	1E-05
AU Student	NA	0E+00	3E-06
Indoor Office Worker	NA	NA	6E-07
Outdoor Worker (Landscaper)	2E-08	NA	NA
EU2			
Lifetime Resident	2E-07	NA	4E-05
AU Student	NA	NA	9E-06
Indoor Office Worker	NA	NA	2E-06
Outdoor Worker (Landscaper)	5E-08	NA	NA
EU3			
Lifetime Resident	8E-08	NA	1E-05
AU Student	NA	NA	3E-06
Indoor Office Worker	NA	NA	7E-07
Outdoor Worker (Landscaper)	2E-08	NA	NA

Notes:

NA = not applicable

Shading indicates results greater than/equal to the cancer risk threshold of 1E-04.

Table 5-9

Reasonable Maximum Exposure (RME) Non-Cancer Hazard Results
for the Spring Valley FUDS Human Health Risk Assessment

Current Scenarios			
Receptors	Non-Cancer Hazard		Target Organ-Specific HI Analysis (Cumulative HI ≥ 1)
	Groundwater (Watering)	Surface Water (Recreational)	
EU1			
Adult Resident	0.002	0.008	No Analysis
Child Resident	0.02	0.02	No Analysis
AU Student	NA	0.007	No Analysis
Outdoor Worker (Landscaper)	0.003	NA	No Analysis
EU2			
Adult Resident	0.01	NA	No Analysis
Child Resident	0.07	NA	No Analysis
AU Student	NA	NA	No Analysis
Outdoor Worker (Landscaper)	0.02	NA	No Analysis
EU3			
Adult Resident	0.06	NA	No Analysis
Child Resident	0.3	NA	No Analysis
AU Student	NA	NA	No Analysis
Outdoor Worker (Landscaper)	0.08	NA	No Analysis

Future Scenarios			
Receptors	Non-Cancer Hazard	Target Organ-Specific HI Analysis (Cumulative HI ≥ 1)	
	Groundwater (Potable Use)	Chemical	Target Organ-Specific HIs
EU1			
Adult Resident	1	Arsenic	Skin and Vasc (0.3)
		Cobalt	Thyroid (0.2)
		Perchlorate	Thyroid (0.7)
Child Resident	2	Arsenic	Skin and Vasc (0.4)
		Cobalt	Thyroid (0.4)
		Perchlorate	Thyroid (1)
AU Student	1	Arsenic	Skin and Vasc (0.3)
		Cobalt	Thyroid (0.02)
		Perchlorate	Thyroid (0.8)
Indoor Office Worker	0.1	No Analysis	
EU2			
Adult Resident	4	Arsenic	Skin and Vasc (0.7)
		Cobalt	Thyroid (0.3)
		Manganese	CNS (0.9)
		Perchlorate	Thyroid (2)
Child Resident	7	Arsenic	Skin and Vasc (1)
		Cobalt	Thyroid (0.4)
		Manganese	CNS (1)
		Perchlorate	Thyroid (4)
AU Student	4	Arsenic	Skin and Vasc (1)
		Cobalt	Thyroid (0.03)
		Manganese	CNS (1)
		Perchlorate	Thyroid (3)
Indoor Office Worker	0.5	No Analysis	

Table 5-9

**Reasonable Maximum Exposure (RME) Non-Cancer Hazard Results
for the Spring Valley FUDS Human Health Risk Assessment**

EU3			
Adult Resident	16	Arsenic	Skin and Vasc (0.3)
		Cobalt	Thyroid (9)
		Manganese	CNS (7)
		Perchlorate	Thyroid (0.07)
		Strontium	Bone (0.04)
Child Resident	26	Arsenic	Skin and Vasc (0.5)
		Cobalt	Thyroid (15)
		Manganese	CNS (11)
		Perchlorate	Thyroid (0.1)
		Strontium	Bone (0.06)
AU Student	9	Arsenic	Skin and Vasc (0.3)
		Cobalt	Thyroid (1)
		Manganese	CNS (8)
		Perchlorate	Thyroid (0.07)
		Strontium	Bone (0.04)
Indoor Office Worker	2	Arsenic	Skin and Vasc (0.03)
		Cobalt	Thyroid (0.8)
		Manganese	CNS (1)
		Perchlorate	Thyroid (0.006)
		Strontium	Bone (0.004)

Notes:

NA = not applicable

Shading indicates cumulative results greater than/equal to the hazard index threshold of 1.

vasc = vascular system; CNS = central nervous system

Table 5-10

Central Tendency (CT) Non-Cancer Hazard Results
for the Spring Valley FUDS Human Health Risk Assessment

Current Scenarios			
Receptors	Non-Cancer Hazard		Target Organ-Specific HI Analysis (Cumulative HI ≥ 1)
	Groundwater (Watering)	Surface Water (Recreational)	
EU1			
Adult Resident	0.0007	0.006	No Analysis
Child Resident	0.008	0.01	No Analysis
AU Student	NA	0.005	No Analysis
Outdoor Worker (Landscape)	0.001	NA	No Analysis
EU2			
Adult Resident	0.005	NA	No Analysis
Child Resident	0.03	NA	No Analysis
AU Student	NA	NA	No Analysis
Outdoor Worker (Landscape)	0.008	NA	No Analysis
EU3			
Adult Resident	0.03	NA	No Analysis
Child Resident	0.2	NA	No Analysis
AU Student	NA	NA	No Analysis
Outdoor Worker (Landscape)	0.04	NA	No Analysis

Future Scenarios			
Receptors	Non-Cancer Hazard	Target Organ-Specific HI Analysis (Cumulative HI ≥ 1)	
	Groundwater (Potable Use)	Chemical	Target Organ-Specific HIs
EU1			
Adult Resident	0.6	No Analysis	
Child Resident	0.9	No Analysis	
AU Student	0.4	No Analysis	
Indoor Office Worker	0.05	No Analysis	
EU2			
Adult Resident	2	Arsenic	Skin and Vasc (0.4)
		Cobalt	Thyroid (0.1)
		Manganese	CNS (0.5)
		Perchlorate	Thyroid (1)
Child Resident	4	Arsenic	Skin and Vasc (0.7)
		Cobalt	Thyroid (0.2)
		Manganese	CNS (0.8)
		Perchlorate	Thyroid (2)
AU Student	2	Arsenic	Skin and Vasc (0.4)
		Cobalt	Thyroid (0.1)
		Manganese	CNS (0.4)
		Perchlorate	Thyroid (1)
Indoor Office Worker	0.3	No Analysis	

Table 5-10

**Central Tendency (CT) Non-Cancer Hazard Results
for the Spring Valley FUDS Human Health Risk Assessment**

EU3			
Adult Resident	8	Arsenic	Skin and Vasc (0.1)
		Cobalt	Thyroid (4)
		Manganese	CNS (4)
		Perchlorate	Thyroid (0.03)
		Strontium	Bone (0.02)
Child Resident	13	Arsenic	Skin and Vasc (0.2)
		Cobalt	Thyroid (7)
		Manganese	CNS (6)
		Perchlorate	Thyroid (0.05)
		Strontium	Bone (0.03)
AU Student	4	Arsenic	Skin and Vasc (0.1)
		Cobalt	Thyroid (0.4)
		Manganese	CNS (3)
		Perchlorate	Thyroid (0.03)
		Strontium	Bone (0.02)
Indoor Office Worker	1	Arsenic	Skin and Vasc (0.01)
		Cobalt	Thyroid (0.4)
		Manganese	CNS (0.9)
		Perchlorate	Thyroid (0.003)
		Strontium	Bone (0.002)

Notes:

NA = not applicable

Shading indicates cumulative results greater than/equal to the hazard index threshold of 1.

vasc = vascular system; CNS = central nervous system

Table 5-11

Cumulative Non-Cancer Hazard and Cancer Risk Results for Future Receptors Who Use Groundwater as Potable Water

Cumulative RME Non-Cancer Hazard and Cancer Risk	Future Receptor				
	Lifetime Resident	Adult Resident	Child Resident	AU Student	Indoor Office Worker
Groundwater EU1					
Cumulative Non-Cancer HI:	(a)	1	2	1	0.1
Cumulative Cancer Risk:	5E-05	(b)	(b)	7E-06	4E-06
Groundwater EU2					
Cumulative Non-Cancer HI:	(a)	4	7	4	0.5
Cumulative Cancer Risk:	1E-04	(b)	(b)	2E-05	1E-05
Groundwater EU3					
Cumulative Non-Cancer HI:	(a)	16	26	9	2
Cumulative Cancer Risk:	5E-05	(b)	(b)	8E-06	4E-06

NOTES:

(a) See Adult Resident and Child Resident.

(b) See Lifetime Resident.

Pink shading: the value exceeds the cumulative non-cancer hazard threshold, or equals or exceeds the cancer risk threshold.

Green shading: the value equals or is below the cumulative non-cancer hazard threshold, or is below the cancer risk threshold.

Thresholds: Noncancer Hazard Index (HI) = 1. Cancer Risk = 1E-04

Table 5-12

**Target Organ Hazard Indices and Cancer Risk Results for Future Receptors
Who Use Groundwater as Potable Water**

Cumulative RME Non-Cancer Hazard and Cancer Risk	Future Receptor				
	Lifetime Resident	Adult Resident	Child Resident	AU Student	Indoor Office Worker
Groundwater EU1					
Cumulative Non-Cancer HI:	(a)	1	2	1	0.1
<i>Skin and Vasc (Arsenic):</i>	(a)	0.3	0.4	0.3	BT
<i>Thyroid (Cobalt):</i>	(a)	0.2	0.4	0.02	BT
<i>Thyroid (Perchlorate):</i>	(a)	0.7	1	0.8	BT
Cumulative Cancer Risk:	5E-05	(b)	(b)	7E-06	4E-06
Groundwater EU2					
Cumulative Non-Cancer HI:	(a)	4	7	4	0.5
<i>Skin and Vasc (Arsenic):</i>	(a)	0.7	1	0.7	BT
<i>Thyroid (Cobalt):</i>	(a)	0.3	0.4	0.03	BT
<i>CNS (Manganese):</i>	(a)	0.9	1	1	BT
<i>Thyroid (Perchlorate):</i>	(a)	2	4	3	BT
Cumulative Cancer Risk:	1E-04	(b)	(b)	2E-05	1E-05
<i>Arsenic:</i>	1E-04	BT	BT	BT	BT
Groundwater EU3					
Cumulative Non-Cancer HI:	(a)	16	26	9	2
<i>Skin and Vasc (Arsenic):</i>	(a)	0.3	0.5	0.3	0.03
<i>Thyroid (Cobalt):</i>	(a)	9	15	1	0.8
<i>CNS (Manganese):</i>	(a)	7	11	8	1
<i>Thyroid (Perchlorate):</i>	(a)	0.07	0.1	0.07	0.006
<i>Bone (Strontium):</i>	(a)	0.04	0.06	0.04	0.004
Cumulative Cancer Risk:	5E-05	(b)	(b)	8E-06	4E-06

NOTES:

(a) See Adult Resident and Child Resident.

(b) See Lifetime Resident.

Pink shading: the target organ value exceeds the non-cancer hazard threshold, or equals or exceeds the cancer risk threshold.

Green shading: the target organ value is equal or below the non-cancer hazard threshold, or is below the cancer risk threshold.

"BT": Cumulative non-cancer hazard or cancer risk is below the thresholds (1.0 and 1E-04, respectively); therefore, the target organ-specific HIs or chemical-specific cancer risks are not provided.

Table 5-13

Target Organ Non-Cancer Hazard and Cancer Risk for Future Receptors Who Use Groundwater as Potable Water, Lines of Evidence Evaluation

Cumulative RME Non-Cancer Hazard and Cancer Risk	Future Receptor				
	Lifetime Resident	Adult Resident	Child Resident	AU Student	Indoor Office Worker
Groundwater EU1					
Cumulative Non-Cancer HI:	(a)	1	2	1	0.1
<i>Skin and Vasc (Arsenic):</i>	(a)	0.2	0.4	0.3	BT
<i>Thyroid (Cobalt):</i>	(a)	0.2	0.4	0.02	BT
<i>Thyroid (Perchlorate):</i>	(a)	0.7	1	0.8	BT
Cumulative Cancer Risk:	5E-05	(b)	(b)	7E-06	4E-06
Groundwater EU2					
Cumulative Non-Cancer HI:	(a)	4	7	4	0.5
<i>Skin and Vasc (Arsenic):</i>	(a)	0.7	1	0.7	BT
<i>Thyroid (Cobalt):</i>	(a)	0.3	0.4	0.03	BT
<i>CNS (Manganese):</i>	(a)	0.9	1 (c)	1 (c)	BT
<i>Thyroid (Perchlorate):</i>	(a)	2	4	3	BT
Cumulative Cancer Risk:	1E-04	(b)	(b)	2E-05	1E-05
<i>Arsenic:</i>	1E-04	BT	BT	BT	BT
Groundwater EU3					
Cumulative Non-Cancer HI:	(a)	16	26	9	2
<i>Skin and Vasc (Arsenic):</i>	(a)	0.3	0.5	0.3	0.03
<i>Thyroid (Cobalt):</i>	(a)	0.4 (d)	0.7 (d)	0.05 (d)	0.04 (d)
<i>CNS (Manganese):</i>	(a)	7 (e)	11 (e)	8 (e)	1 (e)
<i>Thyroid (Perchlorate):</i>	(a)	0.07	0.1	0.07	0.006
<i>Bone (Strontium):</i>	(a)	0.04	0.06	0.04	0.004
Cumulative Cancer Risk:	5E-05	(b)	(b)	8E-06	4E-06

NOTES:

(a) See Adult Resident and Child Resident.

(b) See Lifetime Resident.

(c) Not shaded pink due to background considerations.

(d) Results after excluding the MW-33 data.

(e) Not shaded pink due to natural occurrence considerations and consideration of the locations where the higher manganese concentrations occur in the SV FUDS, as discussed in the report text.

Pink shading: the target organ value exceeds the non-cancer hazard threshold, or equals or exceeds the cancer risk threshold.

Green shading: the target organ value is equal or below the non-cancer hazard threshold, or is below the cancer risk threshold.

"BT": Cumulative non-cancer hazard or cancer risk is below the thresholds (1.0 and 1E-04, respectively); therefore, the target organ non-cancer hazard or cancer risks are not detailed.