REMEDIAL INVESTIGATION REPORT
AREA OF INTEREST 4

Philadelphia Energy Solutions Refining and Marketing LLC
Philadelphia Refining Complex
3144 Passyunk Avenue, Philadelphia, Pennsylvania
Sitewide PADEP Facility ID No. 780190
Area of Interest 4 PADEP Facility ID No. 770318

Stantec

Prepared for:

Philadelphia Refinery Operations, a series of Evergreen Resources Group, LLC

Prepared by:
Stantec Consulting Services Inc.

A Patel
Avani Naik Patel
Geologic Specialist

Andrew D. Klingbeil, P.G.
Pennsylvania Registered Geologist # PG005029

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL
ANDREW DAVID KLINGBEIL
GEOLOGIST
No. PG005029

Reviewed by:

Jennifer Menges
Jennifer Menges
Principal Consultant, LRS

March 24, 2017

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Acronyms

API LDRM	American Petroleum Institute LNAPL Distribution and Recovery Model
ACGIH	American Conference of Governmental Industrial Hygienists
AOI	Area of Interest
ANT	Apparent NAPL Thickness
AST	Aboveground Storage Tank
ASTM	American Society for Testing and Materials
C	Celsius
CAP	Corrective Action Process
CCR	Current Conditions Report
CPT	cone penetration test (CPT)
CRP	Community Relations Plan
cm/s	centimeters per second
cm^3s/g	cubic centimeters second per gram
CO&A	Consent Order and Agreement
COC	Constituent of Concern
DLA	Defense Logistics Agency
DSCP	Defense Supply Center Philadelphia
EDB	1,2-Dibromoethane
EDC	1,2-Dichloroethane
EPA	United States Department of Environmental Protection
Evergreen	Philadelphia Refinery Operations, a series of Evergreen Resource Group, LLC
ft bgs	feet below ground surface
ft/d	feet per day
ft^2/d	square feet per day
ft/ft	feet per foot
GIS	Geographic Information System
gpm	gallons per minute
g/ml	grams per milliliter
HHRA	Human Health Risk Assessment
HQ	Hazard Quotient
IST	Integrated Science & Technology, Inc.
k	hydraulic conductivity
k_h	horizontal hydraulic conductivity
k_v	vertical hydraulic conductivity
LiDAR	Light Detection and Ranging
LNAPL	Light Non-Aqueous Phase Liquid
LCSM	LNAPL Conceptual Site Model
mg/kg	milligrams per kilogram
mg/l	milligrams per liter
µg/l	micrograms per liter
$\mu g/m^3$	micrograms per cubic meter
MOA	Memorandum of Agreement
MSC	Medium Specific Concentration
MTBE	methyl tert butyl ether
NAPL	Non-Aqueous Phase Liquid
NAVD 88	North American Vertical Datum of 1988
NIOSH	National Institute for Occupational Safety and Health
NIR	Notice of Intent to Remediate
NOC	Notice of Contamination
NORR	Notice of Reportable Release
NOWData	National Weather Service Online Weather Data

NRDC	Non-Residential Direct Contact
OSHA	Occupational Safety and Health Administration
PADCNR	Pennsylvania Department of Conservation and Natural Resources
PADEP	Pennsylvania Department of Environmental Protection
PA FBC	Pennsylvania Fish and Boat Commission
PEL	Permissible Exposure Limit
PES	Philadelphia Energy Solutions Refining and Marketing LLC
PID	Photoionization Detector
PNDI	Pennsylvania Natural Diversity Inventory
PNSY	Philadelphia Naval Shipyard
ppm_v	parts per million by volume
PRCFM	Philadelphia Refining Complex Flow Model
PRM	Potomac-Raritan-Magothy aquifer system
Psi	Pounds per square inch
PWD	Philadelphia Water Department
RACR	Remedial Action Completion Report
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit
RIR	Remedial Investigation Report
RSL	Regional Screening Level
SCR	Site Characterization Report
SHS	Statewide Health Standard
SPT	Standard Penetration Test
SSS	Site-Specific Standard
Sunoco	Sunoco Inc. (R&M)
SPMT	Sunoco Partners Marketing and Terminals L.P.
SVIA-NR	Indoor Air Vapor Intrusion Screening Values – Non-Residential
SWMU	Solid Waste Management Unit
1,2,4-TMB	1,2,4-Trimethylbenzene
1,3,5-TMB	1,3,5-Trimethylbenzene
TDS	Total Dissolved Solids
TEL	Tetraethyl lead
TR	Target Risk
TLV	Threshold Limit Value
USGS	United States Geological Survey
VOC	Volatile Organic Compound

1.0 Introduction

This Remedial Investigation Report (RIR) has been prepared for Area of Interest (AOI) 4 (the site), also known as the No. 4 Tank Farm, at the Philadelphia Energy Solutions Refining and Marketing LLC (PES) Philadelphia Refining Complex (Complex). Sunoco Inc. (R&M) transferred the Complex to PES on September 8, 2012. Sunoco retained the remediation liability prior to this date. The remediation liability was transferred to Philadelphia Refinery Operations, a series of Evergreen Resources Group, LLC (Evergreen) on December 30, 2013. The remediation program is currently being performed under a Buyer-Seller Agreement signed by Sunoco, PES, and the Pennsylvania Department of Environmental Protection (PADEP) in September 2012.

Site remediation at the PES Complex is ongoing as part of previously-established programs and the 2012 Buyer-Seller Agreement. The PES Complex has operated, and is planned to continue operating, as an oil refinery, marketing terminal, and producer of petrochemicals.

1.1 DESCRIPTION OF THE COMPLEX

The PES Complex is located along the banks of the Schuylkill River in the City of Philadelphia, Philadelphia County, Pennsylvania (**Figure 1-1**). Portions of the PES Complex occupy both the eastern and western Schuylkill River banks. The PES Complex, which is located on industrial property, covers approximately 1,400 acres of land with access restricted by fencing and security measures. The area surrounding the PES Complex is characterized by a mixture of residential, commercial, and industrial properties. Current operations at the PES Complex consist of the production of fuels and basic petrochemicals for industry.

AOI 4 occupies approximately 106 acres of the PES Complex in the eastern portion of the Point Breeze Refinery South Yard (**Figure 1-2**). Surrounding the AOI are the following properties/features:

- North: AOIs 1 and 2 of the PES Complex, beyond which is located Belmont Terminal and Passyunk Avenue
- East: 26th Street borders the site except for a vacant parcel located at 3606 S 26th Street; on the east side of 26th Street are two non-residential parcels identified as 3401 S 26th Street and 2551 Penrose Avenue; a CSX Transportation (CSX) elevated railroad right-of-way parallels those properties, beyond which is located vacant lands associated with the former Passyunk Homes development
- South: Penrose Avenue borders the site as shown on **Figure 1-2**, beyond which are several non-residential properties including a scrap metal yard at 2600 Penrose Ferry Road and other apparent commercial properties
- West: AOI 3 of the PES Complex, beyond which is located the Schuylkill River and AOIs 5, 6 and 7 of the Girard Point Refinery

1.2 OPERATIONAL HISTORY AND CURRENT USE OF THE COMPLEX

The PES Complex has a long history of petroleum transportation, storage, and processing. The oldest portion of the PES Complex started petroleum related activities in the 1860's, when the Atlantic Refining Company was established as an oil distribution center. In the 1900's, crude oil processing began and full-scale gasoline production was initiated during World War II. In addition to refining crude oil, various chemicals, such as acids and ammonia, were also produced at the PES Complex for a time. The PES Complex has operated continuously as a refining, product distribution, and storage facility. Use of the PES Complex has remained similar following transfer of ownership.

Currently, AOI 4 is comprised of primarily crude oil and gas oil tankage (No. 4 Tank Farm). Infrastructure mainly includes aboveground storage tanks (ASTs) and process equipment required for the blending and storage of gasoline and additives, including numerous aboveground and underground process lines. Use of the No. 4 Tank Farm has altered little over the course of the PES Complex's history with primary changes being various ASTs taken in and out of service. The only occupied building in AOI 4 is the 15 Pump House, located in the north central section of AOI 4 (**Figure 1-2**).

1.3 REGULATORY HISTORY/OVERVIEW

Sunoco and the PADEP entered into a Consent Order & Agreement (CO&A) in December 2003 with respect to the PES Complex. Sunoco's Phase I Remedial Plan (Phase I Plan), dated November 2003, was included as an attachment to the CO&A. In accordance with the CO&A and Phase I Plan, a Current Conditions Report and Comprehensive Remedial Plan (CCR) was prepared by Langan for Sunoco in June 2004. The Phase I Plan and the CCR divided the PES Complex into 11 AOIs, and presented a prioritization of the AOIs based on specific risk factors. The CCR also presented the Phase II remedial approach and schedule to characterize each of the 11 AOIs, and to conduct Phase I and II corrective action activities in accordance with the 2003 CO&A and the Phase I Plan. Since 2003, Sunoco has performed site characterization activities at all 11 AOIs in accordance with the 2003 CO&A. Sunoco has prepared and submitted a corresponding Site Characterization Report (SCR) for each AOI in accordance with the Revised Phase II Corrective Action Activities schedule that was included in the CCR.

In October 2006, Sunoco submitted a notice of intent to remediate (NIR) to the PADEP entering the PES Complex into the Act 2 program. This NIR was later updated and submitted to the PADEP in November 2014 in order to revise the ownership identity to PES and the remediator identity to Evergreen. In November 2011, the PES Complex was formally entered into the PA One Cleanup Program with the United States Environmental Protection Agency (EPA) – Region III and PADEP. In November 2011, Sunoco submitted a Work Plan for Site Wide Approach Under the One Cleanup Program (Work Plan). As previously discussed, characterization and remediation work at the PES Complex is currently being performed under the September 2012 Buyer-Seller Agreement signed by Sunoco, PES, and the PADEP.

The following provides a timeline of major events and submissions for the PES Complex and relevant AOI 4 vicinity:

- 1987

  - Potential source of hydrocarbon vapors within the 26th Street Intercepting Sewer (26th Street Sewer) was investigated. A pilot remedial system was tested and a report was completed (Engineering Enterprises, Inc., 1987).
- 1990
  - According to refinery personnel, the city sewer along 26th Street was cleaned and checked/sealed at connections.
- 1992
  - ENSR completed a Resource Conservation and Recovery Act (RCRA) facility investigation for the Point Breeze Refinery Solid Waste Management Units (SWMUs).
- 1993
  - A CO&A was established with the PADEP for the Point Breeze Refinery.
- 1996
  - Sunoco and the Defense Logistics Agency (DLA) entered into a CO&A with PADEP which required the two entities to collectively perform a series of tasks to address potential impacts to human health and the environment resulting from the presence of light non-aqueous phase liquid (LNAPL) at the former Defense Supply Center Philadelphia (DSCP) site.
- 1997
  - Dames & Moore Group (Dames & Moore) completed an LNAPL delineation to the south and east of the PES Complex and the DSCP facility (Dames & Moore, 1997a).
  - Malcolm Pirnie, Inc. (Malcolm Pirnie) prepared a final response to the LNAPL study prepared by Dames & Moore (Malcolm Pirnie, 1997).
  - Dames & Moore performed a subsurface assessment at the Steen Outdoor Advertising property (Steen) to evaluate the occurrence of free-phase hydrocarbons in the area between the PES Complex and DSCP facility (Dames & Moore, 1997b).
- 1998
  - Integrated Science & Technology, Inc. (IST) prepared a NAPL source study at the DSCP facility.
- 2002
  - Aquaterra Technologies, Inc. (Aquaterra) completed an investigation report for the Pollock Street Sewer (Langan, 2007).
- 2003
  - SECOR completed a RIR for the 26th Street border area.
  - A revised CO&A, which replaced the 1993 CO&A, was established with PADEP for the Point Breeze Refinery, Girard Point Refinery, Point Breeze West Yard, and the Schuylkill River Tank Farm.
- 2004
  - The PADEP and EPA signed an agreement entitled "One Cleanup Program Memorandum of Agreement (MOA or One Cleanup Program)," which clarifies how sites remediated under Pennsylvania's Voluntary Cleanup Program may satisfy RCRA corrective action requirements through characterization and attainment of remediation standards established under the Pennsylvania Land Recycling and Environmental Remediation Standards Act (Act 2).

  - SECOR prepared a progress report for the 26th Street border area of AOI 1.
  - Langan prepared the CCR for the Philadelphia Refining Complex and Belmont Terminal.
- 2005
  - PADEP, EPA, and Sunoco agreed that the One Cleanup Program would benefit the project by merging the remediation obligations under the various programs into one streamlined approach which would be conducted under the existing 2003 CO&A.
  - Langan completed a SCR/RIR for AOI 4 (Langan, 2005).
- 2006
  - Sunoco submitted a NIR to the PADEP for the Philadelphia Refinery including Schuylkill River Tank Farm, thereby entering the PES Complex, with the exception of Belmont Terminal, into the Act 2 program.
- 2009
  - Roux Associates, Inc. (Roux) submitted a Remedial Action Completion Report (RACR) for the former Ryder leasehold located at 3401 South 26th Street that was subsequently approved by the PADEP having demonstrated attainment of selected remediation standards for onsite soil and groundwater (Roux, 2009).
  - AQUI-VER, Inc. (AQUI-VER) prepared a data summary report that provided a comprehensive reporting of results related to LNAPL that included a portion of AOI 4 (AQUI-VER, 2009).
- 2011
  - In June and July, 2011, Aquaterra performed an investigation of the former ARCO property located at 3301-39 South 26th Street that included six soil borings, installation of four monitoring wells, and laboratory analysis of soil and groundwater samples (Aquaterra, 2011).
  - On November 8, 2011, the EPA provided an acknowledgment letter to Sunoco formally accepting the Sunoco Philadelphia Refinery into the One Cleanup Program.
  - Sunoco submitted the Work Plan to document the site-wide remedial approach extending beyond the requirements of the 2003 CO&A (Langan, 2011). PADEP and EPA reviewed and provided input to this report. Sunoco submitted a letter of commitment stating the Philadelphia Refinery would be remediated according to the Work Plan.
- 2012
  - Sunoco transferred the Philadelphia Refinery to PES and the facility was renamed the Philadelphia Refining Complex.
  - Sunoco, PES, and the PADEP signed the Buyer-Seller Agreement which established the environmental remediation and management obligations of Sunoco and PES following the sale of the PES Complex.
- 2013
  - The legacy remediation liability for environmental impacts existing prior to the conveyance of the Complex to PES was transferred from Sunoco to Evergreen.
  - Sunoco submitted a SCR/RIR for AOI 4 (Langan, 2013).
- 2014
  - Evergreen submitted an updated NIR to the PADEP for the PES Complex.
  - Evergreen submitted a NIR to PADEP exclusively for the Belmont Terminal which is a separate property owned by Sunoco Partners Marketing and Terminals L.P. (SPMT).

- 2015
    - Langan, on behalf of Evergreen, submitted a Human Health Risk Assessment (HHRA) Report to establish a site-specific standard (SSS) for lead in soil at the PES Complex, the Belmont Terminal, and the Marcus Hook Industrial Complex (Langan, 2015).
    - The HHRA was approved by the PADEP in a letter dated May 6, 2015 establishing a SSS of 2,240 milligrams per kilogram (mg/kg) for lead in soil.

On May 17, 2016, Evergreen and Stantec met with the PADEP to discuss proposed additional investigation activities at AOI 4. In accordance with the Work Plan for Site Wide Approach, Evergreen is submitting this RIR for AOI 4 to satisfy the requirements of Act 2 as specified in 25 PA Code §250.408. This RIR describes site characterization work conducted following the last submittal to PADEP regarding AOI 4 (SCR/RIR; Langan, 2013). Activities that have been performed in order to complete characterization within AOI 4 include:

- Additional characterization of surface soil (0-2 feet below ground surface [ft bgs] interval) and subsurface soil (2-15 ft bgs) including targeted soil investigations in potential contaminant source areas, such as historic product handling and storage locations, open storage tank incident areas, and known product releases;

- Horizontal and vertical delineation of impacts in soils;

- Installation of deep soil borings/monitoring wells in order to better understand hydrostratigraphy and address data gaps;

- Additional groundwater sampling from all monitoring wells not containing LNAPL;

- Evaluation of onsite and relevant offsite geology and hydrogeology;

- Delineation of LNAPL;

- Evaluation of LNAPL mobility;

- Investigation of the potential vapor intrusion to indoor air pathway at occupied buildings; and

- Qualitative evaluation of the potential fate and transport and future extent of dissolved contaminants, including a quantitative analysis for benzene at the Penrose Avenue site boundary.

As discussed with PADEP during a meeting conducted on September 28, 2015, Evergreen is in the process of developing a site-wide MODFLOW model to perform quantitative fate and transport modeling. Following the approval of this and other RIRs, Evergreen intends to submit a Cleanup Plan, pursuant to 25 PA Code §250.410, which will present remedies chosen to allow attainment of the selected remediation standards in soil and groundwater.

In accordance with Act 2, the required public and municipal notices for this report have been prepared and issued. **Appendix A** includes a copy of the original NIR, the updated NIR, as well as the report notices and their proof of receipt/publication for the PES Complex.

1.4 DSCP FACILITY

The DLA is the federal entity responsible for the former DSCP facility which is located approximately 550 feet to the east of the boundary of AOI 1 of the PES Complex (**Figure 1-2**). According to the NAPL Source Study at DSCP prepared by IST for Sunoco in March 1998, the federal government acquired an 87-acre parcel in 1917 and began construction of the DSCP facility. The function of the facility was to support the United States military by manufacturing, storing, and distributing supplies. Operations at the facility included printing, vehicle and locomotive repair, woolen fabric treatment and cleaning, painting, chemical laboratory operations, fuel dispensing, and fuel storage. Operations were at heightened levels during periods of conflict, including World War I, World War II, the Korean Conflict, the Vietnam Conflict, and Operation Desert Storm (IST, 1998). In 1999, the former DSCP was closed under the 1993 Base Realignment and Closure program, and has been subsequently redeveloped. In 2004, the Quartermaster Plaza shopping center was constructed on the northwestern section of the former DSCP property. South of the former DSCP was the former Passyunk Homes residential property. The residences were razed between 2002 and 2008, and a Philadelphia Housing Authority office and maintenance facility was constructed on the northern portion of the former Passyunk Homes property. The remainder of the property is currently being redeveloped into a residential neighborhood called Siena Place (**Figure 1-2**) (ARCADIS, 2014a).

Early environmental investigations began at the DSCP site in 1988 and centered primarily on historic fuel storage tank areas (IST, 1998). LNAPL was noted to be present in monitoring wells at DSCP (IST, 1998). A significant LNAPL plume has been in existence under the former DSCP property since at least the time of the IST report and has been investigated by teams from multiple interested parties, including Sunoco. In 1996, Sunoco and DLA entered into a CO&A with PADEP which required the two entities to collectively perform a series of tasks to address potential impacts to human health and the environment resulting from the presence of this LNAPL. Under the CO&A, Sunoco installed a sewer ventilation system on the Packer Avenue Sewer (which also serves the 26th Street and Pollock Street Sewers), and managed the design and construction of a LNAPL remediation system with financial contributions from DLA. On December 10, 1999, PADEP issued an Administrative Order which required DLA to address impacts related to the LNAPL plume located beneath the former DSCP property and former Passyunk Homes including assuming responsibility for operation of remediation systems. This Administrative Order presently requires that as much LNAPL be removed as is practicable. Currently, LNAPL is being removed via both fixed skimming and vacuum-enhanced skimming (VES) systems (ARCADIS, 2014a). According to ARCADIS (2017), the two fixed skimming systems commenced operation in March 1999 (one at the former DSCP property and the other at the former Passyunk Homes property), and the VES system became operational in March 2005.

In addition to LNAPL recovery, DLA is currently conducting characterization activities including soil and groundwater investigations at the former DSCP facility. DLA and Evergreen have conducted annual synoptic well gauging events since May 2014 that have included data from within AOI 4 and the immediate vicinity. Data from the three most recent annual gauging events, and available groundwater analytical data from 2007, and 2012 through 2016, were used in this RIR to evaluate groundwater flow paths and potential groundwater impacts in the water table and lower aquifers.

1.5 SELECTION OF CONSTITUENTS OF CONCERN

Lists of the constituents of concern (COCs) in soil and groundwater for AOI 4 are included as **Tables 1-1 and 1-2**. These tables are updated listings of the COCs identified in the Work Plan for Site Wide Approach for the PES Complex under Pennsylvania One Cleanup Program and will be referred to as the Evergreen Petroleum Short List (**Table 1-1**) and Evergreen Comprehensive List (**Table 1-2**).

1.6 SELECTION OF APPLICABLE STANDARDS AND SCREENING LEVELS

The media of concern for AOI 4 include soil and groundwater. The potential vapor intrusion into indoor air exposure pathway was also evaluated. The approach for attaining Act 2 remediation standards for the media of concern is described below. As the current and anticipated future use of the PES Complex is industrial, standards for non-residential properties were chosen for comparison.

1.6.1 Soil

All soil results were screened using a multi-step process as described in this section. Soil sample analytical results were first screened against the PADEP non-residential, used aquifer (total dissolved solids [TDS] less than or equal to 2,500 milligrams per liter [mg/l]) Statewide Health Standard (SHS). The following process was used to select the soil SHS for each COC:

- The highest value of either 100 times the groundwater medium specific concentration (MSC) or the generic value MSC was selected to represent the soil to groundwater numeric value.

- The selected used aquifer, non-residential soil to groundwater numeric value was then compared to the non-residential direct contact (NRDC) MSC (0-2 feet or 2-15 feet bgs, as applicable).

- The more stringent of the soil to groundwater numeric value and the direct contact value was selected as the SHS for initial comparison of soil sample results.

The SHS value is usually driven by the soil-to-groundwater MSC, and the soil-to-groundwater pathway will be addressed in the groundwater investigation presented in this RIR (**Section 4**) and through subsequent remedial measures which will be further described in future Act 2 deliverables. In order to further evaluate the risk posed by the concentrations of COCs which were detected above their respective SHS, the next step in the screening process is to compare all of the soil analytical results to the non-residential direct contact MSCs. Soil sample locations that will require further pathway evaluation or require a remedial measure in order to attain a standard under Act 2 were identified through comparison to the non-residential direct contact MSCs.

An exception to this soil screening process exists for lead. On February 24, 2015, Evergreen submitted a HHRA Report to PADEP which presented the development of a risk-based SSS for lead in soil (Langan, 2015). In a letter dated May 6, 2015, PADEP approved the report, and a non-residential direct contact site-specific numerical standard for lead of 2,240 mg/kg was established. This SSS is used in place of the default 0-2 ft bgs direct contact MSC for lead.

1.6.2 Groundwater

Groundwater sample analytical results were screened against the PADEP MSCs for non-residential properties overlying used aquifers with TDS less than or equal to 2,500 mg/l (SHS). Where constituent concentrations are above the SHS, Evergreen has evaluated application of the site-specific remediation standard using the pathway elimination option.

1.6.3 Potential Vapor Intrusion into Indoor Air

Indoor and ambient air sample results collected in AOI 4 were screened against the EPA Region 3 Regional Screening Levels (RSL) for Industrial Air Target Risk (TR)=1E-5, Target Hazard Quotient (THQ)=0.1 (updated May 2016; EPA-RSL, TR=1E-5). The EPA RSLs are used as the threshold values to determine if additional controls will be necessary to address vapor intrusion, and any such controls will be presented in the Cleanup Plan. The non-residential PADEP Indoor Air Site Specific Standard Vapor Intrusion Screening Values (SVIA-NR SHS), the non-residential PADEP Indoor Air Statewide Health Standard Vapor Intrusion Screening (SVIA-NR SSS), the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PEL); the National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limits (REL) and the American Conference of Governmental Industrial Hygenists (ACGIH) Threshold Limit Values (TLV) are also provided for reference.

2.0 ENVIRONMENTAL SETTING

This section summarizes the geologic framework and general hydrogeologic properties of sedimentary deposits and bedrock underlying the south Philadelphia area, with emphasis near the PES Complex. A brief discussion of historical and present-day topography and hydrology is also included. This section provides a regional context from which sedimentary deposits observed beneath AOI 4 (discussed in **Section 5**) can be classified and characterized for the purposes of this RIR. Much of the information presented in this section was summarized during conceptualization of a site geologic model that is being used in the development of a numerical groundwater flow (MODFLOW) model.

In general, the groundwater resources and stratigraphic framework of the PES Complex area have been well-documented through a variety of data sources, including previous groundwater resource investigations dating back to the early 1900's, state and federal geologic mapping projects, groundwater modeling studies, and consultant site characterization and remedial investigation reports. Those data sources are summarized herein. In large part, available well and test boring logs from previous onsite and local subsurface investigations were the most valuable resource in evaluating the local subsurface stratigraphy. As such, subsurface information from approximately 750 well and test boring logs was considered in the evaluation of regional conditions. A database of stratigraphic "picks" on interpreted vertical lithologic unit boundaries (and, where possible, geologic formations) was also developed and includes identified records of boreholes completed to bedrock at and near the PES Complex. For the most part, these records include "deep" wells drilled at the PES Complex, the former DSCP property, and within the properties that exist between those two sites (e.g., CSX, former ARCO, and Steen properties). The purpose of developing a "picks" database was to begin archiving geologic interpretations of individual borehole lithologies to bedrock, so that stratigraphic profiles could be developed for use in this and future Act 2 submissions, and so the Schreffler lithologic model (Schreffler, 2001) being used as a basis for MODFLOW modeling could be refined and updated for site-specific use at the PES Complex. It is Evergreen's intention to update the site-specific geologic model as additional subsurface information is collected through remedial investigation activities under Act 2.

Three stratigraphic profiles are presented in this RIR to support evaluation of the lithologic character, geographic extent, and thickness of each geologic unit identified through correlation to published geologic formations. The first of the stratigraphic profiles is discussed in **Section 2.2.1.2** in support of a regional framework discussion. The two remaining profiles, developed specifically to support AOI 4 geologic and hydrogeologic interpretations, are presented in **Section 5** and utilized an updated version of the "picks" database. Database updates included the addition of subsurface information collected during the installation of new monitoring wells S-218D and S-39D as well as additional interpretations of strata from existing borehole records in the study area (to address data gaps where boreholes completed to bedrock are not available). The structure contour map of the bedrock surface originally presented in the AOI 1 RIR (Stantec, 2016) has also been updated and is used to support the discussion presented herein.

2.1 HYDROLOGY AND TOPOGRAPHY

The PES Complex occupies an area of approximately 2.2 square miles adjacent to the Schuylkill River near its confluence with the Delaware River. This region has a long history of human influence and disturbance, dating back to the early 17th Century when European settlers first arrived. The following sections present a brief discussion of the significant land surface morphologic changes that are apparent when comparing modern environments and topography to that shown on historical maps. These changes are important to note in this RIR when considering natural hydrologic conditions, drainage, and the potential for preferential flow paths in the subsurface that may influence the fate and transport of contaminants.

2.1.1 Historical Topography and Natural Depositional Environments

The Philadelphia City Archives (City of Philadelphia, 2017) and several online archival resources, such as the Greater Philadelphia GeoHistory Network (The Athenaeum of Philadelphia, 2017) and the United States Geological Survey (USGS) National Map Viewer (USGS, 2016), have catalogued and provide free access to copies of historical maps and photographs of Philadelphia. Based on review of many of those maps, it is apparent that much of the land area occupied by the present-day PES Complex was formerly tidal marsh and lowlands that once fringed the Schuylkill River. **Figure 2-1** presents a geo-referenced USGS topographic map from 1898 (20-foot contour interval). The map indicates that several small tributary streams, digitized on-screen and shown as blue lines, formerly dissected that marshland and presumably would have exchanged water with the tidal Schuylkill River on a semi-diurnal basis. Several islands were also present throughout the lowlands, most notably League Island, which are interpreted as erosional remnants of uplands that formed sometime after deposition of the "Trenton gravel" sediments (discussed in detail below).

At that time, relatively higher topography was apparent north and west of the Schuylkill River, near Gibson's Point. South and east of that general area, the Schuylkill River coursed through a distinctive meander around Point Breeze, and appeared to have formed an erosive cut bank along present-day AOI 2 where higher elevations were present (and favoring point bar deposition north of AOI 10). A southwest-northeast trending ridge of higher elevation was also present south of Point Breeze near AOI 4 (**Figure 2-1**), and between those two areas of higher elevation a stream was mapped to have been present. That stream appears to have originated in southern AOI 1 and flowed southwest through AOIs 3, 4, and 7, towards its confluence with the Schuylkill River. Numerous other small streams and ditches draining the lowlands surrounding Hollander Creek were also noted. Additional historic maps indicate that by 1900, an earthen dike had been constructed along the banks of the lower Schuylkill River, and sluices were present at each stream/ditch confluence. Other maps show wooden pilings in places along the Schuylkill River. In general, the construction of containment dikes, sluices, and shoreline hardening would have altered the natural tidal exchange between the Schuylkill River and these historic creeks, thereby limiting the natural accretion of sediment in the marshes that once fringed the river. Moreover, the modifications indicated on these maps would have altered the pre-existing tidal regime and dynamic equilibrium of the Schuylkill River.

2.1.2 Post-Industrialization

Figure 2-1 indicates that by 1898, storage of petroleum near Point Breeze and Gibson Point had already begun. According to City of Philadelphia archives (City of Philadelphia, 2017), much of the remaining tidal marsh and lowland environments nearby were reclaimed and routinely dewatered for farming practices around this same time period (mostly on the west side of the Schuylkill River). Industrialization warranted further land filling activity and shoreline hardening, including bulk-heading and filling of the tributary streams that modified and generally raised the antecedent topography into its present-day configuration. Farms were displaced in favor of industrial and commercial land uses. Although some clusters of residential property and open space have existed or still exist near the PES Complex, most land in south Philadelphia has been used for industrial and commercial purposes for over 100 years (IST, 1998).

Light Detection and Ranging (LiDAR) data obtained from the USGS (USGS, 2010) and topographic contours published in 2007 by the City of Philadelphia indicate that present-day topography is relatively flat near the PES Complex, and land surface elevations generally range from a few feet below the North American Vertical Datum of 1988 (NAVD 88) near Mingo Creek to approximately 30 feet near the eastern boundary of the PES Complex in AOIs 1, 4, and 8 (**Figure 2-2**). Although subtle, the high-resolution LiDAR model displays topographically low areas that based on location, likely correlate to the locations of former stream valleys (e.g., Franklin Delano Roosevelt Park). In addition to raising the land surface, much of the filled areas were either paved and/or rendered relatively impervious (**Figure 2-3**), which may have decreased rates of recharge to the water table and necessitated the construction of numerous sewers to convey stormwater runoff (combined with sewage) to the Schuylkill and Delaware Rivers, or deeper intercepting sewers. This further altered the natural hydrology of the area.

2.2 REGIONAL GEOLOGY AND HYDROGEOLOGIC CONDITIONS

The PES Complex occurs within the up-dip limits of the Atlantic Coastal Plain, generally within two miles of the "Fall Line," where crystalline bedrock of the Appalachian foothills intersects the ground surface (outcrops) (**Figure 2-4**). The Atlantic Coastal Plain is a physiographic province that is defined as having relatively flat topography and as being underlain by a characteristic wedge of unconsolidated sediments that thicken in a southeasterly direction, away from sediment source areas in the Appalachian Mountains. These sediments were deposited atop a sloping bedrock surface in complex fluvial, estuarine, and marginal marine environments along the passive Atlantic margin. Overall, subsidence of the Piedmont land surface in conjunction with cyclical sea-level fluctuations have been the primary controlling mechanisms driving periods of deposition, non-deposition, and erosion in the Atlantic Coastal Plain (Trapp, 1992). In general, the resulting sedimentary record in the vicinity of the PES Complex is complicated, largely incomplete, and under-represented by only Cretaceous and Quaternary deposits, separated by a regional disconformity. A summary of those deposits is presented in succeeding sections.

2.2.1 Coastal Plain Deposits

2.2.1.1 Anthropogenic Fill

For reasons discussed, much of the PES Complex and surrounding area is underlain by historical fill material, which was placed for the purpose of reclaiming lowlands along the banks of the tidal Delaware and Schuylkill Rivers during industrialization. These fill materials are heterogeneous in nature and have been described on borehole logs by others as a mixture of compacted soil and anthropogenic debris, including sand, clay, silt, gravel, cinders, concrete, asphalt, crushed stone, ash, glass, brick fragments, and wood. Apparent fill thickness ranges from a veneer where antecedent topography was highest to greater than 50 feet where it was used as railroad ballast just east of the PES Complex. Within the locations of former stream valleys and marshes (**Figure 2-1**), the historical fill material is generally 20 feet or greater in thickness.

The fill materials may contain isolated lenses of groundwater (perched groundwater) where coarse or granular materials are separated from the underlying water table by low permeability sediments. The fill may also be saturated and/or in hydraulic connection with the water table along the axes of former stream channels, where the water-table appears to intersect the fill, or where the fill was placed on marshland. However, at most locations across the PES Complex, the fill layer occurs above the regional water-table under average hydraulic head conditions.

2.2.1.2 Quaternary Deposits

Quaternary sedimentary deposits are present beneath the PES Complex and are generally representative of geologically-recent cycles of deposition and erosion that occurred within the last 200,000 years. These cycles of sedimentation were the result of a series of glacial and interglacial periods, namely the Illinoian and Wisconsin glaciations, separated by an intervening interglacial period and followed by the present interglacial period through the Holocene (Sevon et al., 1999). Depositional environments through this period were primarily controlled by sea-level and the successive down-cutting and infilling of ancestral river valleys, primarily that of the Schuylkill and Delaware Rivers (Owens and Minard, 1979). Details of the Quaternary deposits present at the PES Complex are described below.

2.2.1.2.1 Recent (Holocene) Alluvium

Predominantly gray, muddy deposits with occasional sandy, gravelly, and organic-rich lenses comprise the most recent alluvium present at the PES Complex. These sediments were deposited in dynamic floodplain, channel, and marsh environments through the Holocene. As noted, the upper surface of alluvium, in most places covered by fill, defines the antecedent topography that pre-dated development under a large portion of the area of the PES Complex. This geologic unit is generally present below an elevation of approximately 20 feet NAVD 88. The alluvium ranges in thickness from a few feet at higher elevations, away from the present Schuylkill and Delaware River estuaries, to approximately 15 feet within the former floodplains of buried tributary streams. However, adjacent to and fringing these major river estuaries, apparent marsh deposits accreted in freshwater environments to as much as 60 feet thick (to elevations as low as approximately -60 feet NAVD 88) as sea-level transgressed and flooded the incised river valleys through the Holocene. **Figure 2-1** provides some estimation of how extensive the tidal marshes once were prior to development, existing generally along the Schuylkill River south of and surrounding Point Breeze. Stratigraphic profile C – C’ demonstrates this interpretation and distribution of the most recent alluvial deposits across the PES Complex (**Figures 2-5** and **2-6**).

Similar to the fill described above, most recent alluvium at the PES Complex has limited water-bearing capacity due to its fine-grained texture. However, heterogeneities within the alluvium may allow for the presence of localized seasonal perched groundwater resulting from the percolation of recharge water. Within former marsh areas along the Schuylkill and Delaware River estuaries, the regional water-table occurs within the Holocene alluvium. At locations distal to the rivers and where the Schuylkill River appears to have eroded older alluvial deposits (e.g., along the western periphery of AOI 2), the Holocene alluvium occurs above the regional water-table and is unsaturated.

2.2.1.2.2 Pleistocene Alluvium ("Trenton Gravel")

Geologically-recent glacial outwash deposits, commonly referred to informally as the "Trenton gravel," have long been recognized in southeastern Pennsylvania along the Delaware River valley. Sevon and Braun (2000) provide a comprehensive map of glacial deposits in Pennsylvania, including the presence of sand and gravel outwash, interpreted as stratified drift, along the present Delaware River. Owens and Minard (1979) published a comprehensive summary of previous research into these deposits and subdivided the "Trenton gravel" into two distinct deposits (the Spring Lake and Van Sciver Lake beds) based on topographical position and lithology at those type sections. Low et al. (2002) indicate that in most places the "Trenton gravel" rests directly atop Cretaceous sediments and is overlain by younger alluvium of Holocene age near the Schuylkill River.

Based on literature review, Stantec interprets the "Trenton gravel" as a heterogeneous, stratified alluvial deposit of primarily sand and gravel, with occasional beds of clay and silt (the Van Sciver Lake beds), that resulted from glacial outwash through the Delaware River valley sometime after the Illinoian glacier receded. At the PES Complex, the "Trenton gravel" is commonly described on boring logs as a brown, reddish-brown or, where stained, black, fine to coarse sand with lenses of gravel. The gravel fraction is often multicolored and comprised of a mixture of sub-angular to sub-rounded, sedimentary and metamorphic rocks derived from the Appalachian Piedmont. The "Trenton gravel" generally ranges in thickness from a few feet up to approximately 30 feet near the PES Complex. It appears to be mostly laterally continuous and its thickness depends on the antecedent Cretaceous topography that it filled and on the degree of erosion from above. Along the Schuylkill River at the George C. Platt and Passyunk Avenue bridges, and in places beneath the Delaware River, Greenman et al. (1961) mapped the "Trenton gravel" to be present beneath thick sections of Holocene alluvium to elevations near -60 feet NAVD 88, and those interpretations have been adopted by Stantec in the geologic model for the PES Complex (**Figures 2-6, 2-7 and 2-8**).

The regional water-table at the PES Complex most often occurs within the "Trenton gravel," and, as a result of its stratigraphic position, this geologic unit comprises a large portion of the unconfined aquifer (along with the Potomac-Raritan-Magothy [PRM] aquifer system upper sand unit and localized areas of saturated alluvium and fill). Published well records indicate that the "Trenton gravel" can be a prolific aquifer (Paulachok, 1991). Nevertheless, due to lateral changes in "Trenton gravel" thickness and to its heterogeneous character, hydraulic properties and groundwater yields can vary widely. Stantec reviewed published data and available onsite aquifer testing data regarding the hydraulic properties of the unconfined aquifer and has summarized that data on **Figures 2-9** and **2-10**. It is noted that although most wells tested at the PES Complex and shown on **Figure 2-9** are predominantly screened through

"Trenton gravel" deposits, some test results may represent the hydraulic properties of other geologic units that locally comprise a portion of the unconfined aquifer, such as the PRM upper sand unit.

Of particular importance to this RIR are unconfined aquifer hydraulic property data resulting from a nearly 7-day groundwater extraction test conducted at recovery well RW-2 at the PES Complex (IST, 1998). During testing, RW-2 was pumped at a constant rate of 225 gallons per minute (gpm). Distance-drawdown data analyzed along transects of observation wells suggested that the area of influence extended approximately 1,680 feet from the pumping well under relatively isotropic conditions. Three of the observation well transects were at least partially in AOI 4. The horizontal hydraulic conductivity (k_h) was estimated to be greater than 400 feet per day (ft/d). More recently, a 24-hour pumping test was conducted at the former DSCP property at monitoring well DSCP-MW-65, a well that appears to be screened across the "Trenton gravel" and underlying sandy Cretaceous deposits (ARCADIS, 2013). Analysis of that data provided in the referenced report supports comparable aquifer properties at that site. However, it is noted that during the test, the "Trenton gravel" was reportedly dewatered and individual aquifer k values could not be calculated/resolved. Other, in-situ, single well instantaneous displacement tests and short-duration pumping tests for remedial system design suggest a lower k_h for the "Trenton gravel," on average, but test results vary widely, from less than 1 ft/d to over 600 ft/d. The observed wide range in k_h values over relatively short distances is consistent with the unconfined aquifer's lithologic heterogeneity which can be attributed in most part to the "Trenton gravel."

2.2.1.3 Cretaceous Deposits

Many studies of the Atlantic Coastal Plain near the PES Complex have identified the presence of Cretaceous age sediments in the subsurface. These are the oldest sedimentary deposits in the area and are configured in a southeasterly-thickening wedge, overlain by the much younger Quaternary deposits described above and underlain by Piedmont crystalline bedrock. Greenman et al. (1961) detailed the age, character, configuration, and hydraulic properties of these deposits in southeastern Pennsylvania. At the time of that publication, the Cretaceous deposits were assigned primarily to the Raritan Formation and noted to represent three distinct, fining-upward cycles of non-marine sedimentation. Similarities to lithologic sequences identified on borehole logs were correlated to previously-identified strata at their type locality in New Jersey, where the deposits are much thicker and more easily distinguished. Other similar, near time-equivalent geologic formations of Cretaceous age were elsewhere identified in Maryland and Delaware (Jordan, 1962), and more recently authors began wholly referring to the Cretaceous deposits in south Philadelphia as the PRM aquifer system.

In south Philadelphia, the PRM aquifer system is subdivided into six geologic units in order of increasing age (Schreffler, 2001):

- upper clay unit,
- upper sand unit,
- middle clay unit,
- middle sand unit,
- lower clay unit, and
- lower sand unit.

Near the PES Complex, it is generally true that these units thin, intercalate, and exhibit gradual facies changes that make separation of individual units difficult. The total thicknesses of PRM deposits at the PES Complex ranges from 0 feet, where Quaternary deposits are present atop bedrock, to more than 100 feet within paleochannels incised into bedrock. Details of the individual units and bedrock configuration based on boring log records and published descriptions are presented below.

2.2.1.3.1 Upper Clay Unit

The upper clay unit is a variegated clay/silt that is sometimes discernible from older clay units of the PRM where sandy and gravelly. In general, it is thin when compared to the other PRM clay units in south Philadelphia, and in places distal to the Delaware River, the upper clay may be entirely absent (Greenman et al., 1961). On the basis of geophysical log signature, others have mapped the upper clay to be at least 0.5 feet thick and up to 30 feet thick at the PES Complex, exhibiting its greatest thickness in northern portions of the area of the PES Complex while pinching out to the south (IST, 1998). At the PES Complex, Stantec has assigned the upper clay to first occurrences of light brown, tan, mauve, yellow, gray, and less-commonly, red sandy, silty clay beneath the Quaternary alluvium. However, overall stratigraphic correlation of the PRM across the PES Complex supports the upper clay unit pinching out or being truncated by younger deposits throughout most of the AOIs (**Figures 2-6, 2-7** and **2-8**).

The upper clay unit by nature acts as a confining or leaky confining bed. Where present, it can create hydraulic separation between the upper sand unit and water-table aquifer.

2.2.1.3.2 Upper Sand Unit

The upper sand unit is a varicolored but predominantly brown to gray sand with varying amounts of gravel, clay, and silt (Greenman et al., 1961). Nearer the PES Complex, it has been described as mostly silty and/or clayey fine to medium sand (IST, 1998). Where the upper clay is absent, the upper sand occurs directly beneath, and is typically discernable from, the overlying coarser, poorly-sorted, and more heterogeneous “Trenton gravel.” Stantec used color and lithologic changes, in addition to subtle changes in drilling conditions including Standard Penetration Test (SPT) blow counts, to make “picks” on upper sand occurrences where the upper clay is absent. In general, the upper sand appears most extensive beneath northern portions of the PES Complex (AOIs 1, 2, 3, 4, and 8) where it subcrops the “Trenton gravel”. The upper sand unit, where present, rarely exceeds 10 to 20 feet in total thickness.

The upper sand unit is an excellent aquifer where its thickness and extent are sufficient (Greenman et al., 1961). Aquifer testing of the upper sand unit in New Jersey has indicated that the aquifer has similar hydraulic properties to the middle and lower sand units where discrete (Navoy and Carleton, 1995). At the PES Complex, Stantec did not identify any existing testing data for wells discretely screened within the upper sand unit from which to infer sole hydraulic properties of that unit. The upper sand is fairly continuous along eastern areas of the PES Complex but generally occurs in pockets nearer the Schuylkill River where the middle clay unit is shallower. The upper sand unit comprises a portion of the unconfined aquifer. Most wells that fully penetrate the unconfined aquifer in northern areas of the PES Complex may intersect and be influenced by the hydraulic properties of the upper sand.

2.2.1.3.3 Middle Clay Unit

Whereas other clay units of the PRM are described as being sandy and gravelly in places, the middle clay unit is generally regarded as being a laterally extensive and uniformly massive confining bed of thick, red and white clay with very little sand (Greenman et al., 1961). Near the PES Complex, others have found the middle clay to be nearly continuous in the subsurface (IST, 1998). Based on boring log review and stratigraphic correlation, Stantec would agree with these previous findings and has mapped the middle clay unit of the PRM to be the most persistent of the clay units at the PES Complex. Thicknesses of the middle clay unit generally range from less than one foot to more than 20 feet. While the middle clay appears to be everywhere present, at least on the eastern side of the Schuylkill River, its characteristically muddy texture can vary and become finely-laminated/bedded and intercalated with muddy sand. West of the Schuylkill River and particularly under areas north of Point Breeze, the middle clay unit (in addition to most if not all of the PRM) appears to have been incised and completely removed by erosion. Downgradient, nearer AOI 9 and the George C. Platt Bridge, some pockets or thin lenses of middle and/or lower clay may be present under a thick section of Quaternary alluvium and upper sand. At other locations beneath the PES Complex, the middle and lower clay units appear to be in direct contact with each other (where the middle sand is absent).

The middle clay unit, in places resting directly on and combining with the lower clay unit, acts as a significant confining bed at the PES Complex. In a regional context, it creates hydraulic separation between the unconfined aquifer and deeper, semi-confined aquifer of the middle and/or lower sand units. However where it appears to be thin and sandy, most notably in the southeastern area of AOI 1, there may be more potential for vertical exchange between groundwater of the deeper aquifer and unconfined aquifer, the direction and magnitude of which would depend upon the vertical hydraulic gradients at the time.

2.2.1.3.4 Middle Sand Unit

The middle sand unit is a light-colored, stratified, fine to coarse sand with occasional gravel and clay that was generally deposited in lenticular masses along the axes of troughs carved into the lower clay unit (Greenman et al., 1961). As such, it is by nature discontinuous in the subsurface. Stantec has mapped the presence of middle sand at the PES Complex based on stratigraphic position and where present, is commonly described on boring logs as brown or orange sand and gravel. In some areas where the lower clay was entirely removed, it may be indistinguishable from and rest unconformably atop the lower sand unit. At those locations, Stantec used subtle changes in sample descriptions, including color, density, and/or texture, of the sequences of sand below the middle clay to infer the contact between those units. The middle sand unit, where discernable from the lower sand, has been observed at thicknesses up to approximately 30 feet beneath the PES Complex and is generally thickest in lenticular or tabular bodies.

Much like the other sand units of the PRM, the middle sand unit can be a prolific aquifer where it is laterally continuous and of sufficient thickness. Aquifer testing of the middle sand in New Jersey has indicated that the aquifer has similar hydraulic properties to the lower sand unit (Navoy and Carleton, 1995). At the PES Complex, Stantec did not identify any wells discretely screened within the middle sand unit from which to infer sole hydraulic properties. Deep refinery wells are screened in the lower sand, or potentially across the lower and middle sand units, where hydraulically connected.

2.2.1.3.5 Lower Clay Unit

Published descriptions of the lower clay unit indicate that it appears very similar to, and is sometimes inseparable from, the middle clay unit where the middle sand is absent. The lower clay is generally tough, red clay but is known from drilling records to contain softer zones of gray clay stratified with fine sand. The lower clay tends to exhibit its greatest thickness along the lateral margins of paleochannels in underlying bedrock, and can be thin to absent along the axes of paleochannels where eroded prior to deposition of the middle sand unit (Greenman et al., 1961). Of the PRM clay units, Stantec has interpreted the lower clay unit to be the least significant at the PES Complex in terms of both its lateral extent and vertical thickness. This is based on stratigraphic correlation and likely the result of erosion prior to deposition of the middle sand. Generally gray and red, commonly sandy clay and muddy sand zones were assigned to the lower clay if observed below and distinguishable from the middle clay. Where present, the lower clay was observed at thicknesses ranging from less than 1 foot to no greater than 10 feet. The lower clay appears to thicken and become more continuous to the south and east of the PES Complex.

Where physically connected, the lower and middle clay units combine to form a significant confining bed at the PES Complex. In a regional context, they create hydraulic separation between the unconfined aquifer and deeper, semi-confined aquifer of the lower sand unit. The lower clay can also create localized areas of hydraulic separation between the lower and middle sands, where discretely present.

2.2.1.3.6 Lower Sand Unit

The lower sand unit is a varicolored but predominantly white to yellow sand with gravel, usually fining upward to a cap of fine to medium sand with occasional yellow and gray clay lenses. As further described below, the lower sand unit is the oldest of the PRM deposits and rests unconformably atop bedrock. The lower sand is generally thickest (up to 87 feet thick) along the axial troughs of paleochannels carved into bedrock by discharge through former positions of the Schuylkill and Delaware Rivers (Greenman et al., 1961). At the PES Complex, Stantec recognizes the lower sand unit to be present as a nearly continuous deposit, with the exception of areas proximal to the Schuylkill River where it appears that the river entirely removed the PRM. Where present, the lower sand unit is observed to range in thickness from approximately 20 feet to a maximum of just over 50 feet, where it fills a bedrock paleochannel beneath a portion of AOI 1. Borehole logs from the PES Complex indicate that the lower sand unit is commonly yellow, white, and pale gray in color and predominantly medium to coarse sand with gravel, or gravel with sand. The lower sand's gravelly texture beneath the refinery has been well documented on drilling logs.

Of the PRM aquifer system and Quaternary deposits present, it can be argued that the lower sand unit was historically the most important groundwater resource in south Philadelphia. **Figures 2-10 and 2-11** summarize hydraulic information available for the lower sand unit (considered the lower aquifer at the PES Complex) based on estimates obtained from well testing at the PES Complex (see **Sections 4.5** and **5.2.3**) and published aquifer testing results. To date, the only known aquifer test data available for the lower aquifer at the PES Complex was collected from wells near the guard basin in AOI 3 in the early 1990s by ENSR. Proximal to the PES Complex at the Philadelphia Naval Shipyard (PNSY), a wealth of historical testing data is available providing estimates of hydraulic properties for the lower sand unit that can be reasonably applied to the lower aquifer at the PES Complex. This data indicates an average k value of approximately 134 ft/d. At the PES Complex, somewhat smaller k_h values have been estimated for the lower aquifer, ranging from approximately 3 to 85 ft/d and may include hydraulic properties of the middle sand and lower clay (where present) (**Figure 2-10**). Across the Delaware River in New Jersey, lower sand unit k_h values are documented to be slightly higher, on average.

2.2.2 Bedrock

Bedrock beneath the Coastal Plain near south Philadelphia has been inferred from surface outcroppings above the "Fall Line," and has been described in the subsurface where penetrated by past drilling activities. Bosbyshell (2008) has mapped schist of the Wissahickon Formation to occur in Philadelphia along the "Fall Line" (**Figure 2-4**). Relatively small bodies of granitic gneiss, resulting from igneous intrusions into the country rock during metamorphism, can also be present. Most boring log records of deep holes drilled at the PES Complex indicate that schist is present beneath the Coastal Plain, in agreement with published maps.

Available data pertaining to the bedrock surface beneath the PES Complex suggests that the surface generally dips to the southeast but contains local complexity. Greenman et al. (1961) recognized the presence of four paleochannels incised into bedrock and attributed those features to previous positions of the Schuylkill River. Two of those channels, referred to as the Schuylkill River and League Island Troughs by those authors, occur beneath parts of the PES Complex and influence the total thickness of the Coastal Plain sedimentary sequence above them (**Figure 2-12**). Through boring log review, Stantec has identified additional detail in the bedrock surface beneath the PES Complex, including two small bedrock paleochannels beneath the eastern portions of AOIs 1 and 4 that appear to be extensions of the League Island Trough, and a few localized bedrock surface highs (pinnacles).

In general, bedrock can store and transmit groundwater primarily through secondary porosity structures (e.g., fractures, joints). Bosbyshell (2008) indicates that the Wissahickon Formation can yield up to 20 gpm to wells in the mapped area above the "Fall Line." Balmer and Davis (1996) indicate that in Delaware County, Pennsylvania, the Wissahickon Formation is the most productive of the consolidated rock aquifers present in that county and can yield anywhere from 0 gpm to 300 gpm to wells (data from 127 wells). However, the wells included in their report were generally located above the "Fall Line" and were not screened below significant accumulations of Coastal Plain sediments. In general, when compared to the permeability and thickness of the Coastal Plain deposits, the water-bearing properties of the Wissahickon Formation beneath the PES Complex are considered de-minimis.

3.0 SOIL INVESTIGATION

The following sections summarize the soil investigation activities performed in AOI 4. Previous investigations are summarized in **Section 3.1**. The remainder of the soil investigation activities described were conducted for this RIR between 2013 and 2016 by Aquaterra, Langan, and Stantec, on behalf of Evergreen. The goal of the investigation was to characterize soil in potential source areas, including historic product handling and storage locations, open storage tank incident areas, and known product releases. In addition to collecting soil samples from borings advanced for the source-targeted soil investigations, soil samples were collected during monitoring well installation activities regardless of whether the area was expected to contain a source of petroleum compounds in soil. In addition, soil sample data collected as a part of PES investigations were evaluated and results included for investigations performed up to the time of this RIR.

All characterization fieldwork was performed in accordance with Evergreen's *Quality Assurance/Quality Control Plan and Field Procedures Manual (***Appendix B**). Soil borings were advanced using a variety of methods including hand auger, backhoe, split spoons in conjunction with hollow stem augers or mud rotary drilling, and split spoons driven using direct push methods. The general strategy for the RI was to characterize soil in the 0-2 ft bgs and greater than 2 ft bgs intervals (unsaturated soil). Generally, subsurface soil samples were collected at the depth exhibiting the highest photoionization detector (PID) response and/or above the water table. Delineation was performed to the highest of the SHS, the NRDC MSCs, and the numeric SSS (for lead). **Table 3-1** summarizes the soil boring rationale for the 2016 investigation activities, and soil boring logs are included in **Appendix C**. All soil analytical results are summarized on **Table 3-2**, which compares the results to the non-residential SHS (as defined in this report, the more stringent of the soil to groundwater numeric value and the direct contact value), and **Table 3-3**, which compares the results to the highest of the SHS, the NRDC MSC, and the numeric SSS (for lead) (Soil Screening Levels). Samples were analyzed for the Evergreen Comprehensive List or the Evergreen Petroleum Short List of compounds, unless a shorter list of analytes was appropriate in a specific situation (i.e. delineation of individual compound exceedences). Analysis of soil samples was conducted by either Pace Analytical Services, Inc., Accutest Laboratories, Eurofins Lancaster Laboratories, ESC Lab Sciences, and the Washington Group Environmental Laboratory. All laboratory analytical reports for investigation work conducted between 2013 and 2016 are included in **Appendix D**.

3.1 SUMMARY OF PREVIOUS SOIL ANALYTICAL RESULTS

As part of the site investigation program conducted in 2005, ten monitoring wells were completed under the supervision of Aquaterra (Langan, 2005). Associated soil sampling results collected as part of these activities are provided in **Tables 3-2** and **3-3**. These samples were collected from the 0-2 ft bgs interval, and analyzed for the Evergreen Petroleum Short List, with the exception of 1,2,4-TMB and 1,3,5-TMB, which were not on the PADEP petroleum short lists at the time. Twenty-two soil borings and fourteen monitoring wells were completed under site characterization activities in 2013 by Aquaterra and Langan, and are summarized in a combined SCR /RIR (Langan, 2013). Shallow (0-2 ft bgs) and deep (>2 ft bgs) samples collected from these locations were analyzed for the Evergreen Petroleum Short List, and the analytical results are presented on **Tables 3-2** and **3-3**.

SHS exceedances were observed in the following soil borings for lead: AOI4-BH-13-86, AOI4-BH-13-99, AOI4-BH-13-101, AOI4-BH-13-102, AOI4-BH-13-103, S-381, and S-408. SHS exceedances were observed in the following soil borings for benzene: AOI4-BH-13-104, S-369, S-373, and S-381. In addition, the SHS for 1,2,4-TMB was exceeded in AOI4-BH-13-104. Concentrations of COCs did not exceed the NRDC MSCs or the lead SSS in any samples, except for the following for lead: AOI4-BH-13-99, AOI4-BH-13-103, and S-381. Delineation of these exceedances were completed as part of RI activities in 2016, and are discussed in later sections.

As AOI 4 is mainly an aboveground storage tank farm, many soil samples have been collected for tank closures and tank related incidents regulated under 25 PA Code Chapter 245, in addition to characterization soil sampling that has been performed as part of the Act 2/One Cleanup program. Although the rationale and results of these soil sampling projects are not discussed in detail in this RIR, as they have been submitted to PADEP under 25 PA Code Chapter 245 reporting, they are relevant to the characterization of AOI 4 under Act 2. The analytical results for these tank related assessments are included on **Tables 3-2** and **3-3**, and the soil sample locations and results are presented on **Figure 3-1**. The investigation of select tank incidents was performed as part of the field effort for this RIR, and those results are discussed in the following sections.

3.2 HISTORIC PRODUCT HANDLING/STORAGE AREAS

Thirteen former ASTs were identified and located within AOI 4 which had been historically closed. Of those thirteen ASTs, nine (PB 185, PB 186, PB 187, PB 188, PB 250, PB 254, PB 255, PB 256, and PB 260) have been confirmed to have been removed prior to 1989 (based on a 1971 as-built acquired from a review of facility records), and therefore, are not subject to 25 PA Code Chapter 245. For six of these tanks (PB 185, PB 186, PB 187, PB 188, PB 250, and PB 260), no additional investigation is required because there is no record of a release, no LNAPL is present in the subsurface in the vicinity of the tank footprint, and/or soil sampling has previously been conducted in the vicinity of the tank footprint. Due to presence or historic presence of LNAPL near ASTs PB 254, PB 255, and PB 256, one characterization soil boring was completed in the former tank footprint of each of these three tank (AOI4-BH-16-015 through AOI4-BH-16-017).

Records could not be identified to confirm that the four remaining ASTs (PB 189, PB 257, PB 258, and PB 820) had been removed prior to 1989. No record of site characterization or closure assessment was found for these former ASTs, and although no active PADEP incident numbers exist, one soil boring was completed within the footprint of each former AST (AOI4-BH-16-018 through AOI4-BH-16-021), biased to areas that exhibited visible signs of petroleum impacts.

Two samples (shallow and deep) were collected from each soil boring listed above, and analyzed for the Evergreen Comprehensive List. Concentrations of COCs did not exceed the SHS, the NRDC MSCs, or the lead SSS, with one exception. Benzene exceeded the SHS of 0.5 mg/kg in AOI4-BH-16-020; however, the concentration was below the NRDC MSC.

3.3 OPEN STORAGE TANK INCIDENTS

Evergreen has addressed all open AOI 4 storage tank incidents for which it is responsible through the 25 PA Code Chapter 245 CAP Program in a separate submittal (Stantec, 2017). Review of past activities indicated that eight incidents (6229, 6227, 35654, 37051, 37107, 38093, 38094, and 45998) did not require any additional characterization work; however, three incidents (45961, 6226 and 45966) required further characterization and delineation. A Site Characterization Report/Remedial Action Completion Report (SCR/RACR) was submitted for these incidents (Stantec, 2017). Open storage tank incidents are summarized on **Table 3-4**.

Soil characterization activities were conducted to further investigate three open storage tank incidents within AOI 4. For borings associated with storage tank incidents that involve releases within tank berms, soil analytical results are presented in this RIR for informational purposes only as they relate to overall AOI 4 soil characterization. These data were presented in a SCR/RACR for the identified open storage tank incidents, and submitted under separate cover to the PADEP in order to satisfy the requirements of 25 PA Code Chapter 245 (Stantec, 2017).

PB 823 (INCIDENT 45961)

According to historical documentation, approximately 630 gallons of hydrocracker gas oil were released to the tank dike area of PB 823 in March 1993, due to a leak near the base of the tank. Clean up was initiated at the time of release identification. No record of site characterization sampling was found; therefore, two soil borings (AOI4-BH-16-001 and AOI4-BH-16-002) were completed in the area of the release. Four soil samples were collected and analyzed for the Evergreen Comprehensive List. None of the samples exceeded the SHS, NRDC MSCs, or the lead SSS.

PB 842 (INCIDENT 6226)

According to the Notice of Reportable Release (NoRR) from October 10, 1996, holes were identified in the tank floor during removal from service of Tank PB 842, which formerly stored crude oil/water. No record of sampling to characterize this suspected release was found; therefore, two soil borings (AOI4-BH-16-003 and AOI4-BH-16-004) were completed in 2016 in the area of the former tank footprint. Two samples were collected from each soil boring and analyzed for the Evergreen Comprehensive List. None of the samples exceeded the SHS, NRDC MSCs, or the lead SSS.

PB 253 (INCIDENT 45966)

Approximately 5,040 gallons of diesel fuel were released to the tank dike area of PB 253 in August 1998 as the result of an overflow during filling. According to the NoRR, the overflow resulted from a high-level alarm failure and immediate corrective action was initiated, including the recovery of oil by vacuum truck. As no record was found for soil characterization at the time of the release, three soil borings (AOI4-BH-16-005, AOI4-BH-16-006, and AOI4-BH-16-007) were completed around the tank. Two samples were collected from each soil boring and analyzed for the Evergreen Petroleum Short List. None of the samples exceeded the SHS, NRDC MSCs or the lead SSS.

3.4 HISTORIC RELEASES

The following section discusses known historic releases that were investigated as part of the AOI 4 characterization activities. As part of the remedial investigation under Act 2, historic releases that could have created sources for hydrocarbons in soil were identified as reasonably practicable. In order to identify areas that would require further investigation, a review of internal facility files and meetings with facility operations staff were conducted in 2014. PADEP also reviewed its records and provided information on historic incidents. Based on information obtained, targeted soil investigations were performed as described below.

15 Pump House

Three different releases of crude oil have occurred historically at the 15 Pump House, based on a review of Sunoco's internal records. Due to multiple releases and known product handling, additional investigation in this area was conducted as part of the RI activities in June 2016. Two characterization soil borings (AOI4-BH-16-013 and AOI4-BH-16-014) were completed to the east and west of the 15 Pump House, biased to areas of visible surficial staining and/or access to the areas. At the time of the investigation activities, PES was conducting repairs on an underground pipeline. This area was avoided during Evergreen's sampling efforts. Concentrations of COCs did not exceed the SHS, NRDC MSC or the SSS for lead in any of the soil samples.

3.5 WELL INSTALLATION

During installation of monitoring wells, S-39D and S-218D, in 2016, shallow and deep soil samples were collected from each well and analyzed for the Evergreen Petroleum Short List. Shallow and deep samples were also collected during the installation of monitoring well, S-416, and analyzed for the Evergreen Comprehensive List. Results are included in **Tables 3-2 and 3-3**. Concentrations of COCs did not exceed the maximum of SHS, NRDC MSCs or the SSS for lead, in any of the soil samples.

3.6 DELINEATION OF DIRECT CONTACT MSC/SSS EXCEEDANCES

In order to characterize the horizontal and vertical extent of identified contamination in AOI 4 soil (up to the time of this RIR), areas exhibiting exceedances of the NRDC MSC and the lead SSS were delineated. These areas and associated investigations are described below.

- The concentration of lead detected in the sample from boring AOI4-BH-13-99 collected at 1.5-2 ft bgs exceeded the SSS. This exceedance is delineated vertically by the deep sample at that location; however, horizontal delineation was required in all directions. Three additional locations (AOI4-BH-16-008 through AOI4-BH-16-010) were completed for horizontal delineation, with one shallow sample (0-2 ft bgs) collected from each location and analyzed for lead only. The SHS for lead was exceeded for two of the three locations (AOI4-BH-16-008 and AOI4-BH-16-009), however all three samples were below the SSS for lead.

- A concentration of lead exceeding the SSS in the shallow soil sample (0-0.5 ft bgs) from boring S-381, is delineated vertically by the deep sample at that location and horizontally to the south, east, and northeast. One additional location (AOI4-BH-16-011) was completed as part of RI activities for horizontal delineation to the northwest. One shallow soil sample (0-2 ft bgs) was collected and analyzed for lead only.

  The concentration in delineation sample AOI4-BH-16-011 was also found to exceed the SSS for lead; therefore, one additional soil boring (AOI4-BH-16-022) was completed to northeast of AOI4-BH-16-011 location, with one shallow soil samples (0-2 ft bgs) collected and analyzed for lead only. The concentration of lead in AOI4-BH-16-22 exceeded the SHS, but was below the SSS.

- The exceedance of the lead SSS for the sample from boring AOI4-BH-13-103 collected at 0-1 ft bgs is delineated vertically by the deep sample at that location and horizontally to the northeast and northwest. One additional location (AOI4-BH-16-012) was completed to the south for horizontal delineation. One shallow soil sample (0-2 ft bgs) was collected and analyzed for lead only. The concentration of lead exceeded the SHS, but was below the SSS.

4.0 GROUNDWATER INVESTIGATION

4.1 HISTORIC GROUNDWATER INVESTIGATIONS

Many groundwater investigations have been conducted within AOI 4 and the surrounding offsite area evaluated in this RIR. From those investigations identified through historical document review, the oldest well logs indicate that the installation of monitoring wells occurred at the PES Complex as early as 1982. Other archived documents indicate that recovery wells were operational in this area as early as the late 1960s. Most of the investigations that span multiple properties appear to have been performed in response to suspected releases of petroleum substances to the subsurface based on the identification of petroleum odors in area sewers, observations of LNAPL in excavations, or operational losses. Previous consulting reports describe the purpose, methodologies, and present the results of historic groundwater sampling events performed in conjunction with the investigations. On behalf of Evergreen, Stantec identified and has collected and included as much of the historical subsurface information as was feasible in this RIR. That data includes well construction details and well logs, summarized on **Table 4-1** and included in **Appendix C,** and available analytical data collected from historic reports for wells located in AOI 4, which includes results dating back to 1985, in **Tables 4-2 and 4-3**.

To characterize historical groundwater conditions beneath AOI 4, groundwater analytical data summarized on the above-referenced tables include comprehensive sampling events conducted in 2005 and 2013 (included in previous SCRs/RIRs) and annual perimeter groundwater sampling events performed by Stantec. In general, groundwater analytical data collected as a part of these historic investigations indicate that concentrations of most constituents on the Evergreen COC lists have historically been detected above the SHS (as defined in this report) in groundwater (a detailed discussion of the aquifers present and relative conditions in each aquifer are discussed in **Sections 5 and 10**).

Review of available documents indicates offsite investigations of groundwater have occurred on up to six adjacent properties (see **Figure 1-2**), including the former DSCP, former Passyunk Homes, former Ryder Truck Rental, CSX, Steen property, and the former ARCO property (subsurface data is included in these RIR data tables, as Evergreen retains the environmental liability for that property). The investigations date back as early as the 1980s and like those performed at the PES Complex, were most often conducted to evaluate subsurface petroleum impacts that may be related to releases(s) from former storage tanks or piping in those areas. Relevant offsite data contained in those reports has been included in this RIR for the fate and transport assessment presented in **Section 10**.

4.2 WELL INSTALLATION ACTIVITIES

This section describes well installation activities that were performed as part of the AOI 4 remedial investigation. Activities are discussed by purpose in order to clarify characterization goals. All fieldwork was performed in accordance with the *Evergreen Field Procedures Manual* (**Appendix B**). Monitoring well locations are shown on **Figure 1-2**. Well logs, including both lithologic and well construction details, are included in **Appendix C**. Well construction details are also summarized on **Table 4-1**. The following sections discuss the well installation strategy/rationale, which is also summarized on **Table 3-1**.

4.2.1 Lower Aquifer Monitoring Well Installations

Two 4-inch polyvinyl chloride (PVC) monitoring wells (S-39D and S-218D) were installed in the lower aquifer in AOI 4 to aid in vertical delineation of dissolved impacts in groundwater and to refine the existing hydrogeologic model for the PES Complex presently under development. The locations for these wells were selected to address data gaps identified in the existing lower aquifer well network. Pilot soil borings performed prior to the well installations were advanced to bedrock in order to evaluate Coastal Plain hydrostratigraphy and identify appropriate well screen intervals. Screen intervals were subsequently selected in the lower aquifer and well screens were installed from 122 to 132 ft bgs for S-39D and from 86 to 96 ft bgs for S-218D.

Prior to the commencement of exploratory drilling, each location was cleared for subsurface utilities to a depth of 8 ft bgs using a backhoe. Utility clearing was performed by H.T. Sweeney & Son, Inc., of Brookhaven, Pennsylvania, under the oversight of Aquaterra. Advancement of soil borings and monitoring well installations were performed in January and February of 2016 by Parratt-Wolff, Inc. (Parratt-Wolff) of Lewisburg, Pennsylvania, under the oversight of Stantec. A combination of hollow stem auger and mud rotary drilling methods was utilized during borehole advancement for each monitoring well installed. Pilot boreholes utilized for subsurface characterization to bedrock were reamed with larger drilling tools to the selected well screen depths to allow for the 4-inch wells to be installed. Both wells were developed by Parratt-Wolff for approximately 4 to 6 hours utilizing several cycles of air lifting and surging. The wells were developed until groundwater produced was relatively free of turbidity. Groundwater and sediment generated during well development was contained in frac tanks. Frac tanks were emptied and cleaned by U.S. Environmental using a vacuum truck and the water was treated at the PES Complex's wastewater treatment plant.

During drilling, surface and subsurface soil samples were collected from the locations for laboratory analysis of the Evergreen Petroleum Short List. Continuous soil sampling was performed using a split spoon sampler. Soils were field screened with a PID, and lithologies were logged by a Stantec geologist. In addition, three Shelby tubes were collected within muddy strata of the apparent PRM aquifer system. The Shelby tube samples and some of the spoon samples were sent to GeoStructures in King of Prussia, Pennsylvania, for analysis of particle size, fraction organic carbon, and permeability. Results of the laboratory testing are discussed in **Section 5** and the laboratory report is included in **Appendix J**.

4.2.2 LNAPL Delineation Monitoring Well Installation

Water-table monitoring well S-416 was installed as a part of the remedial investigation. The well was installed as a replacement for destroyed well MW-4, in order to refine the LNAPL plume limits in the northwest portion of AOI 4. Prior to installation, the S-416 location was cleared for subsurface utilities to a depth of 8 ft bgs. Well installation activities were performed using hollow stem auger methods by Parratt-Wolff, Inc. of Lewisburg, Pennsylvania under the oversight of Aquaterra between June and July 2016. During borehole advancement, surface and subsurface soil samples were collected for laboratory analysis of the Evergreen Comprehensive List. Continuous soil sampling using a split spoon sampler was performed. An Aquaterra field technician screened soil with a PID and logged sample lithologies.

4.2.3 Offsite Monitoring Wells

As part of the AOI 4 characterization strategy discussed with the PADEP, installation of five offsite monitoring wells along the southeastern boundary of AOI 4 was proposed. The purpose of these monitoring wells was to aid in the delineation of AOI 4 groundwater contamination in the unconfined aquifer and to assess the potential for offsite contaminant migration. Negotiations with property owners for the installation of these wells have been unsuccessful to date. A fate and transport assessment has been presented in **Section 10.10** to preliminarily evaluate the potential extent of offsite groundwater contamination that may be related to migration from AOI 4. A more comprehensive groundwater model is under development and will be utilized to refine delineation in this area as described in **Section 10.11**.

4.3 GROUNDWATER SAMPLING EVENTS AND RESULTS

Two recent comprehensive rounds of groundwater sampling were conducted in August 2016 and October 2016 to characterize present conditions. All fieldwork was performed in accordance with the *Evergreen Field Procedures Manual* (**Appendix B**). Monitoring well locations are shown on **Figure 1-2**. The 2016 characterization groundwater samples were analyzed for the Evergreen Comprehensive List, although pre-2016 groundwater data may have included analysis of additional parameters. Groundwater sampling analytical results, including available historical results, are summarized on **Tables 4-2 and 4-3**. Along with conventional/low-flow sampling methodologies, the following wells were also chosen to sample using passive (no purge) sampling methodology: S-39D, S-218D, and S-245. These sample results are identified with "HS" in the sample ID. Sub-LNAPL groundwater samples were collected from the following wells to characterize COC concentrations beneath potential source areas: S-30, S-32, S-103, S-104, S-124, S-220, S-235, S-278, S-279, S-365, S-368, and S-373. These sample results are identified in the tables by an "SL" qualifier.

In summary, nearly all COCs on the Evergreen Comprehensive List were detected in AOI 4 groundwater during the 2016 sampling events. Concentrations of the following twenty compounds were detected in groundwater above the SHS during the 2016 sampling events: 1,2,4-TMB, 1,2-dibromoethane (EDB), 2-methylnaphthalene, anthracene, arsenic, benzene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, bis(2-ethylhexyl)phthalate, chrysene, ethylbenzene, lead, methyl tertiary butyl ether (MTBE), naphthalene, phenanthrene, pyrene, toluene, vanadium, and zinc. AOI 4 hydrostratigraphic units and groundwater sampling results by aquifer are discussed further in **Sections 5** and **10**, respectively.

4.4 WELL GAUGING ACTIVITIES AND GROUNDWATER MONITORING

Stantec presently conducts annual liquid level gauging of existing and accessible wells at the PES Complex (including some offsite wells along 26th Street). The PES Complex-wide annual well gauging event, which is typically conducted during the second quarter of each year, is used to identify the presence of LNAPL and estimate groundwater flow patterns. Liquid level measurements, groundwater elevation maps, and product thickness maps are submitted to PADEP with the Philadelphia Refinery Remediation Program Groundwater Remediation Status Reports for the first half of each year. **Table 4-4** presents liquid level measurements collected from AOI 4 and the surrounding area during the 2014 to 2016 annual gauging events. Groundwater elevation contours from the May 2014, May 2015, and May 2016 annual gauging events are discussed further in **Section 5**. In addition to the annual events, select wells in AOI 4 are gauged quarterly. These data are submitted to PADEP semi-annually in the Groundwater Remediation Status Reports.

For this RIR and general goals related to the overall characterization of groundwater conditions beneath the PES Complex, Stantec deployed several absolute pressure (data) loggers in selected wells in March 2016. Four of those monitoring wells, S-218, S-218D, S-39, and S-39D, are located in AOI 4. The data loggers were deployed on jacketed, braided steel cables and set to continuously record water depth at one to ten minute intervals. A barometric data logger was co-deployed in well S-218 to capture atmospheric pressure data at the same time interval. Data logger downloading and water-level gauging was performed periodically by Stantec throughout the course of monitoring. The S-39 and S-39D data loggers were removed after approximately one week. The S-218 and S-218D data loggers have been collecting near-continuous water depth data since that time. The methodology for logger data reduction and interpretation is presented in **Section 5**.

4.5 AQUIFER TESTING

During March 2016, a Stantec geologist and Parratt-Wolff conducted performance tests and short-duration constant rate pumping tests on wells S-218D and S-39D. The purpose of the testing was to acquire drawdown and recovery data that could be used to estimate lower aquifer properties at the PES Complex. The tests were performed using a three-inch submersible pump set approximately 75 feet below the top of casing on a one-inch discharge line that passed through a ball valve and flow meter (for flow rate adjustment and measurement). Pumped groundwater was conveyed through hoses to frac tanks for later disposal, as discussed above. Two check valves were installed above the pump in the discharge line to prevent backflow and allow for the collection of recovery data. During the tests, pumping rates were adjusted in two steps from approximately 15 to 25 gallons per minute (gpm). The second step was run for approximately 2-4 hours to maximize drawdown prior to capturing the recovery data.

In August 2016, Stantec returned to AOI 4 to perform slug tests on wells S-218D and S-39D. The purpose of the slug testing was to establish lower aquifer hydraulic conductivity estimates to compare to those estimated from the pumping and recovery tests. A pneumatic slug assembly was used to pressurize the well casings and initiate instantaneous water-level displacements from which the recovery data could be evaluated (rising-head tests). Both the pumping and slug tests were performed in general accordance with the *Evergreen Field Procedures Manual* (**Appendix B**). AQTESOLV Version 4.5 Professional was used to fit solutions to the normalized slug test and pumping test drawdown/recovery data. Both wells exhibited overdamped/non-oscillatory responses to the slug tests. Stantec applied either the Hvorslev (1951) or KGS Model (Hyder et al., 1994) to fit the data and estimate hydraulic conductivity. For the pumping tests, analysis of both drawdown and recovery or residual drawdown data was performed by applying the Theis (1935) solution. Results of the aquifer testing are discussed in **Section 5** and the data analyses are presented in **Appendix K**.

5.0 SITE-SPECIFIC HYDROGEOLOGIC CONDITIONS

In **Section 2**, details regarding Stantec's methodology and interpretation of regional geologic conditions were presented. The purpose of this discussion of site-specific conditions is to refine the regional hydrogeologic framework to summarize conditions observed beneath AOI 4, with an emphasis on groundwater occurrence, groundwater flow, and hydraulic head potentials. It is understood that although this RIR is designed to address subsurface conditions beneath AOI 4, PADEP has previously requested that investigations of individual AOIs at the PES Complex look beyond the boundary of the AOI being investigated. Further, PADEP has also requested that synoptic well gauging data collected by DLA for the former DSCP and Passyunk Homes properties be considered in the hydrogeological evaluation of data along adjacent portions of the PES Complex.

In consideration of those requests, Stantec has utilized well gauging and groundwater analytical data from perimeter wells in AOIs 1, 2, and 3 in this investigation of AOI 4. Moreover, available DLA gauging data for the former DSCP, Passyunk Homes, CSX, and/or Steen properties has been utilized herein for the years obtained through collaborative data exchanges. It is noted that wells on the Steen property were not available for two of the three gauging events (May 2014 and May 2015) presented in this report as that property was not accessible to the DLA's consultants. Boring/well logs reviewed for the characterization of AOI 4 are included in **Appendix C**. A well summary table, including construction details for AOI 4 wells where available, and well gauging data utilized in groundwater contouring and evaluation of recent hydraulic head conditions for AOIs 1, 2, 3, and 4, are included in **Tables 4-1** and **4-4**, respectively.

5.1 GEOLOGIC FORMATIONS AND UNITS OBSERVED

On the basis of available lithologic data from boring logs, the principle of stratigraphic position, results of past investigations, review of historical maps, review of archived sediment core samples from select monitoring wells, test drilling in support of this investigation, and attempted correlation of observed lithologies across the study area to a published geologic framework (e.g., Quaternary deposits and the PRM aquifer system), Stantec has interpreted the following stratigraphy in the subsurface beneath AOI 4. A generalized stratigraphic column adopted from Schreffler (2001) is included as **Table 5-1** and discussed further in **Section 5.2** in the context of interpreted hydrostratigraphy.

5.1.1 Anthropogenic Fill

Anthropogenic fill is present beneath the existing land surface at most locations in AOI 4 and has been identified to range in thickness from a thin veneer to a maximum of approximately 10 feet. The anthropogenic fill rarely exceeds a few feet in total thickness. It has been observed that the thickest area of fill generally correlates to and is reflective of the location of a former incised stream valley that once bisected AOI 4, as mentioned in **Section 2.1.1**. Stratigraphic Profile F – F' (**Figure 2-7**) cuts across that former valley and indicates that it was approximately 1,000 to 1,500 feet wide along the north-central to northwestern margin of AOI 4 (thalweg defined by AOI 3 well S-284D log on Profile F). This is the same former stream discussed by Stantec regarding AOI 1 (Stantec, 2016). Historic contoured topography (**Figure 2-1**) suggests that the stream valley was sourced offsite under 26th Street and the CSX Property to the east-northeast (upstream) of the PES Complex, and flowed southwest traversing through AOI 2 near Hartranft Street, AOI 4, AOI 3, and AOI 7 before reaching its confluence with the Schuylkill River. Borehole logs for wells S-284D, S-111, S-367, and S-416 indicate that the fill in this valley and elsewhere in AOI 4 is heterogeneous in nature, as previously described, and is composed of an admixture of sand and gravel, mud, and anthropogenic debris including bricks and construction debris. In places, the fill is saturated and supports a perched water table above finer-grained alluvium. Precipitation percolating through fill in the former stream channel could also create localized groundwater mounding on the water table, where the water table intersects the fill (e.g., at S-284D, present-day water table elevations intersect the base of the filled stream valley and would support groundwater discharge to fill). For this reason, it is important to evaluate the former stream as a preferential flow path (**Section 9.6**).

5.1.2 Recent (Holocene) Alluvium

Recent alluvial deposits that post-date the "Trenton gravel" are nearly everywhere present beneath filled areas or at existing land surface within AOI 4. In general, recent alluvium defines the antecedent topography that preceded industrialization at the PES Complex. In large part, recent alluvium within the study area is fine-grained, brown to brownish gray silt/clay with occasional lenses of sand and gravel that commonly grades with depth to include some sand. In places, decomposing organic material has also been observed in this deposit. Overall recent alluvium thickness has been observed to range from less than one foot to a maximum of approximately 17 feet in AOI 4. Within axial portions of the former stream valley identified in AOI 4, it appears that more-recent stream incision may have completely removed the older alluvial deposits, and may have at one time allowed for ground surface exposure of the underlying "Trenton gravel" deposits (e.g., monitoring well S-284D and S-365 on **Figure 2-7**). Because of its stratigraphic position and fine-grained texture, the recent alluvium is commonly mottled from the slow percolation of recharge from ground surface and generally is present above the seasonal high water table (i.e., does not support local artesian water-table conditions).

5.1.3 "Trenton Gravel"

The "Trenton gravel" is everywhere present beneath AOI 4 and ranges in thickness from approximately 10 to 15 feet. Its predominant lithology appears to be silty, clayey, poorly-sorted sand with gravel, but includes secondary sandy gravel and clay/silt lithologies in lenses. As described PES Complex-wide, the "Trenton gravel" is a heterogeneous unit that is reflective of its depositional environment. In AOI 4, the water table typically occurs in the "Trenton gravel". However, in the context of overall saturated thickness, the unconfined aquifer is mostly comprised of sediments correlated to the PRM upper sand unit, particularly in eastern portions of AOI 4.

5.1.4 Upper Clay Unit

The PRM upper clay unit is interpreted to be present beneath most of AOI 4 and was mapped as the first occurrence of reddish yellow, brown, and brownish yellow clay/silt (commonly sandy and laminated) beneath the "Trenton gravel". The upper clay was distinguished from the underlying middle and/or lower clay units where possible by stratigraphic position, color, consistency, and overall lithologic character. Where interpreted to be present, the upper clay generally ranges in thickness from less than one foot to approximately 5 feet and appears to fill channels cut into the upper sand. **Figure 2-7** supports this interpretation of the upper clay and as mapped, indicates that the upper clay is very thin and could be patchy along 26th Street. In the context of AOI 4 hydrostratigraphy, the upper clay unit is interpreted to be a part of the unconfined aquifer and where present, function as an aquitard limiting groundwater exchange between the "Trenton gravel" and upper sand unit.

5.1.5 Upper Sand Unit

The PRM upper sand unit is interpreted to be present beneath most of AOI 4 and ranges in thickness from approximately 5 to 30 feet. The upper sand unit appears to be thickest along the axial margin of the League Island Bedrock Trough where it forms a terrace near well S-39D. The upper sand unit is generally light gray to pale yellow, fine to medium-grained quartz sand with a trace to little silt, distinctly different from the heterogeneous "Trenton gravel". Muddy sand lenses are observed most often near the top of the unit where they sometimes grade up into the upper clay. In contrast, gravelly beds may be present near the bottom of the unit, generally along the margins of channel cuts into the underlying middle clay unit. The upper sand unit occurs beneath the water table under average conditions. However, in the context of hydrostratigraphy, the upper sand is interpreted to be part of the water-table aquifer beneath AOI 4 due to the discontinuous nature of the intervening upper clay unit aquitard in the area. Beneath the approximate eastern half of AOI 4, upper sand unit deposits comprise a greater portion of the unconfined aquifer than do the Pleistocene deposits (eg. S-39D, the unconfined aquifer is almost entirely composed of upper sand).

5.1.6 Middle Clay Unit

The PRM middle clay unit is mapped in this RIR as a continuous deposit of predominantly medium to high plasticity, gray, red, and white clay/silt beneath AOI 4. Where interpreted from boring logs, the thickness of the middle clay ranges from approximately 5 to 20 feet. Like AOI 1 (Stantec, 2016), the lithology of the interpreted middle clay is noted to vary beneath AOI 4, from red and white 'fat' clays to sandy gray clay and silt with fine sand laminations. Variability in middle clay lithology is plausible in this subcrop area near the "Fall Line," where the PRM aquifer system's "defined" lithologic units experience thinning and facies changes that can alter the primary lithologies from that of their down-dip type section, and make separation of each geologic unit difficult and interpretive. Lignite, noted by Greenman et al. (1961) to be oftentimes present at the base of the middle clay unit, has been observed on select borehole logs and was used in this RIR as a potential stratigraphic marker to help guide correlation of the base of the middle clay beneath AOI 4 (e.g., monitoring wells S-284D and S-218D). The middle clay unit generally represents an aquitard that separates the two mappable hydrostratigraphic units (i.e., the water-table and lower aquifers) beneath most of the PES Complex, but where thin and sandy could support limited recharge to the underlying lower aquifer through vertical leakage (leaky confining bed), depending on head potentials between those aquifers (discussed further in **Section 5.4**).

5.1.7 Middle Sand Unit

The PRM middle sand unit has been mapped in this RIR to be present beneath AOI 4 as a continuous deposit, primarily based on stratigraphic position. The middle sand is generally mapped where brown and reddish yellow, occasionally muddy and gravelly sand is present between the interpreted middle and lower clay units, where those units are distinct, or between the middle clay and lower sand (where the lower clay appears to have been eroded). Thickness generally ranges from approximately 10 to 30 feet. The middle sand pinches out to the east offsite where the middle and lower clays form a vertically continuous stratum (e.g., well PH-85 in **Figure 2-7**). To the west of AOI 4, the middle sand appears to have been truncated by erosion through the Schuylkill River valley, likely during the Pleistocene, and is in direct contact with the "Trenton gravel". In either scenario because of the discontinuous nature of the lower clay unit, the middle sand unit is interpreted to form a portion of the lower aquifer hydrostratigraphic unit.

5.1.8 Lower Clay Unit

The interpretation presented in this RIR suggests that the PRM lower clay unit is absent beneath most of AOI 4. If present, it may exist in small lenses as erosional remnants occupying troughs cut into the top of the lower sand. Where mapped to the east of AOI 4, the lower clay unit appears to be a discrete unit within portions of the League Island Bedrock Trough. The lower clay unit would most likely represent a leaky confining bed (aquitard) within the lower aquifer hydrostratigraphic unit if and where present.

5.1.9 Lower Sand Unit

Of the six published PRM geologic units, the lower sand unit appears to be the thickest and most laterally continuous beneath and near AOI 4. In general, the lower sand coarsens with depth, from a dense fine to medium pale gray, pale yellow, and white (commonly muddy) quartz sand to white and varicolored sandy gravel and gravelly sand. Scattered lenses of clayey sand and gravel within the overall sequence are common. Thickness of the lower sand generally ranges from approximately 25 feet to over 50 feet beneath AOI 4 and the surrounding area evaluated. Maximum thickness is observed beneath eastern AOI 4, where the lower sand unit fills a bedrock trough. Because of its predominantly sandy and gravelly lithology and large geographic extent, the lower sand is interpreted to form a large portion of the lower aquifer hydrostratigraphic unit.

5.1.10 Crystalline Bedrock

Bedrock has been observed beneath AOI 4 and, where encountered, has been described as moderately to highly-weathered mica schist. Where highly-weathered, the saprolite is generally a sandy, micaceous clay/silt. As shown on **Figure 2-12**, bedrock elevations beneath AOI 4 range from a maximum of approximately -70 feet NAVD 88, near the northern AOI 4 boundary, to a minimum of approximately -135 feet NAVD 88 near well S-39D. As refined by subsurface data collected for this AOI 4 investigation, it appears that the larger, more prominent League Island Bedrock Trough may have had extensions defined by smaller valleys oriented west-east that originated beneath AOI 1 and AOI 4 of the PES Complex. The bedrock surface (including saprolite) is interpreted to function as an aquitard representing the lower boundary of the lower aquifer.

5.2 AQUIFER HYDRAULIC PROPERTIES

Two aquifers have been established as mappable units beneath AOI 4 of the PES Complex. In general, these are the water-table (unconfined) and lower (semi-confined) aquifers (**Table 5-1**). For the purposes of this RIR, Stantec identified and has evaluated properties of those aquifers through review of approximately 200 well and soil boring records. The goal of the records review was to identify relatively distinct hydrostratigraphic units from well gauging data and where available, lithologic logs, soil physical properties, and well/aquifer testing data. Hydrostratigraphic units were assigned to wells where possible using the stratigraphic profiles developed for this RIR and nearby, deep boreholes as control points (**Table 4-1**). Overall, approximately 90% of existing monitoring wells used in AOI 4 are screened across the unconfined aquifer and were constructed to intersect the water table. The remaining 10% are screened in the lower aquifer, which may include portions of screened intervals that intersect lithologies correlated to the middle sand, lower clay, and/or lower sand units.

It is noted that where identified based on lithology and stratigraphic position, the PRM upper sand and middle sand geologic units appear to be hydraulically connected to portions of the two mappable aquifers identified above. Because of apparent discontinuities in the upper and lower clay units, they do not appear to represent discrete hydrostratigraphic units in this area. It is also noted that hydraulic head potentials between the unconfined and lower aquifers appear to vary across AOI 4 and the vicinity. These hydrogeologic conditions are discussed further below and are supported by **Figures 5-1** through **5-9**, which show groundwater elevation contours and groundwater monitoring data for both aquifers for calendar years 2014, 2015, and 2016.

5.2.1 Methodology for Evaluation of Hydraulic Data

For the purposes of evaluating present-day hydraulic head, groundwater flow patterns, magnitudes of groundwater flow (groundwater velocities), and any potential variability in those conditions through time for the aquifers identified in this RIR, Stantec reviewed and interpreted 2014, 2015, and 2016 water-levels from annual, site-wide well gauging data within AOI 4 and proximity (as described in **Section 4.4**). The analysis included gauging data from wells at the former DSCP property that are synoptically gauged by the DLA. For wells gauged by Stantec, depth-to-water measurements were collected with an optical oil/water interface probe and reported to the nearest hundredth of a foot. Water-table elevations were calculated using surveyed well top-of-casing elevations and, where necessary due to LNAPL accumulations, corrected using appropriate LNAPL density data (see **Table 4-4** for well gauging data).

It is noted that active remedial systems within the study area were shut down prior to annual well gauging for the 2014 and 2015 events (except for the 3 Separator System in 2015) and the results presented herein are interpreted to represent near-static conditions for those years. During the 2016 annual gauging event, all remediation systems at the PES Complex were operating (apart from historic systems labeled "inactive" on **Figure 1-2**). The integrity of DLA well gauging data for DSCP area wells was assumed to have been evaluated by the DLA, but Stantec also completed spot checking of DLA well gauging data and wells typically excluded by DLA's consultant were also excluded from contouring in this study. Stantec understands that no significant remedial groundwater pumping is presently occurring at the former DSCP property and assumes that those data represent near-static conditions.

After well data evaluation, Golden Software's Surfer® 12 was used to interpolate the well data using block Kriging. Grid residuals were evaluated and the interpolated surfaces were subsequently contoured and imported into a geographic information system (GIS) for display and evaluation. Due to the high well density in areas of AOI 4 and the commonality of groundwater mounding in the subsurface, 2016 water-table elevation and lower sand potentiometric surface datasets were then refined through several iterations of gridding to remove anomalous data, where appropriate. For the unconfined aquifer, anomalous data points include those for wells screened within areas of apparent groundwater mounding where it is unclear whether those water-level elevations represent true water-table mounds under unconfined conditions, or areas of perched groundwater in fill or alluvium not at equilibrium with atmospheric pressure. Only one well was excluded from interpolation of the 2016 lower aquifer dataset. Both "unprocessed" and "processed" surfaces are presented and discussed in this RIR for 2016 unconfined aquifer data (unfiltered and filtered data). Well identifiers representing the filtered 2016 dataset were then used to select consistent 2014 and 2015 datasets, except for wells not gauged in 2016 but used in the AOI 1 RIR. Those wells were added to the queries for consistency between RIRs, pending gauging data availability for each annual event.

In addition to groundwater contouring of annual well gauging data, data logger monitoring data collected as described in **Section 4.4**, were processed and used to create a high-resolution water-level elevation plot for the wells monitored in AOI 4 (**Figure 5-9**). Water depths recorded by the absolute sensors were compensated for variability in atmospheric pressure using a linear correction to the synoptic barometric logger data. Manual depth to water measurements performed with a water-level meter were used to correct the data for sensor drift. Lastly, corrected depths were converted to elevations and plotted through time using the surveyed top of well casing elevations.

5.2.2 Unconfined (Water-Table) Aquifer

Beneath the study area, the unconfined aquifer is primarily composed of saturated portions of the "Trenton gravel" and PRM upper sand unit. Where present in mappable thickness, the unconfined aquifer also includes the intervening PRM upper clay unit and where saturated (mostly to the west of AOI 4), deeper portions of Holocene alluvium and fill. On average, the saturated thickness of the unconfined aquifer beneath AOI 4 is approximately 10 to 35 feet. As a part of this RIR, Stantec mined existing data and has identified estimations of horizontal hydraulic conductivity (k_h) for the AOI 4 unconfined aquifer from 2 in-situ aquifer (slug) tests and one regional pumping test (see **Figure 2-9**). From those tests and as previously discussed in **Section 2.2.1.2.2**, estimated values of unconfined aquifer k_h vary from approximately 12 ft/d to more than 450 ft/d in AOI 4. The wide range of estimated values of k_h is reflective of the heterogeneous nature of the "Trenton gravel" in AOI 4 and in some instances nearby anthropogenic fill (e.g., AOI 3 guard basin wells). Anomalously low values of k_h may be the result of poor well-aquifer hydraulic communication related to inadequate well development, or fouling of the well screen. It is noted that in general, estimated values of unconfined aquifer k_h are higher for pumping tests that were designed to estimate local to regional conditions, where the k_h has been estimated to range from approximately 434 to 452 ft/d beneath northwestern portions of AOI 4 (RW-2 test area of influence). It is noted herein that Stantec is presently evaluating reasonable values of reported unconfined aquifer k_h for AOI 4 and vicinity as a part of PES Complex-wide numerical model calibration and sensitivity analysis.

In addition to estimates of k_h, other estimates of unconfined aquifer properties were identified. Limited estimates of vertical hydraulic conductivity (k_v) are available for the unconfined aquifer near AOI 4. ENSR (1992) evaluated the vertical permeability of unconfined aquifer muddy lithologies near the guard basin in AOI 3 that can be reasonably applied to similar lithologies in AOI 4. Based on Stantec's subsurface interpretation and the consistency of the historical data with depth, muddy lenses within and alluvium overlying the unconfined aquifer may have a vertical permeability of approximately 10^{-8} centimeters per second (cm/s). Recent laboratory testing in AOI 4 (**Appendix J**) and other AOIs of the PES Complex indicates that the effective porosity of granular lithologies in the unconfined aquifer may range from approximately 7 % (well S-412, 12.6-13.4 ft bgs) to 28 % (well S-118DSRTF, 42-44 ft bgs). Within AOI 4, the fraction organic carbon in unconfined aquifer sand and gravel deposits may range from approximately 0.5-2% (well S-218D, 38-40 ft bgs; well S-39D, 26-28 ft bgs).

5.2.2.1 Hydraulic Heads and Groundwater Flow

As shown in **Figure 5-1**, water-table mounds and other anomalies are apparent near AOI 4 and tend to obscure the pattern of overall regional flow within the unconfined aquifer. The most significant, apparent groundwater mound in the study area is located adjacent to AOI 4 along the eastern bank of the guard basin as indicated by wells in parentheses: S-409, S-410, S-18, and S-21. Boring logs indicate that mounding in this area is the result of groundwater perching within significant fill deposits. Other areas of localized groundwater perching are apparent within a filled stream valley in northwestern AOI 4 as previously described in **Section 5.1.1**. In addition, groundwater mounding may also be the result of leaking infrastructure (such as fire suppression lines or sewers). Wells constructed with long but shallow screen intervals may intersect both perched water zones and the underlying water table, and where separated by a finer-grained, unsaturated stratum (e.g., Holocene alluvium) can contain unreliable water levels. Near the Penrose Avenue Remediation System (Penrose System), a groundwater capture zone is apparent surrounding that system's wells (both operational and sentinel wells). Evaluation of the persistence of groundwater mounding and groundwater losses from the unconfined aquifer are important components of this RIR because under these apparent conditions, horizontal hydraulic gradients, vertical flow potential, and groundwater velocities may be exaggerated or underestimated in AOI 4 and thus could influence scenarios of contaminant fate and transport.

Figures 5-2, **5-3**, and **5-4** display 2014 through 2016 water-table elevation contours after analysis and filtering of existing well data, as interpreted by Stantec. With localized areas of apparent groundwater mounding and/or anomalous data removed (including removal of actively pumping remediation wells in 2016 at the Penrose System), contours for all three years indicate that unconfined aquifer groundwater flows in a pattern that generally mirrors the historical topography shown on **Figure 2-1**. As such, a southwest-northeast trending groundwater divide is present in the southern half of AOI 4 beneath higher topography (well S-371 area). Around this divide, groundwater is indicated to flow in a radial pattern. North of that feature, flow appears to be southeast out of higher topography in AOI 2 and converge near the AOI 1/AOI 2 boundary near the location of the former stream. Horizontal hydraulic gradients generally range from approximately 0.001 to 0.004 feet per foot (ft/ft) in AOI 4. In contrast, horizontal hydraulic gradients steepen (up to 0.01 ft/ft) and groundwater flow beneath AOI 1, Steen, and the former DSCP property to the northeast of AOI 4 appears to converge along a depression, centered along the eastern PES Complex boundary at 26th Street (Stantec, 2016). Beneath the former Passyunk Homes site, unconfined aquifer groundwater flows radially from another groundwater divide indicated at that property. Stantec discussed these flow patterns in detail and interpreted that the patterns of unconfined aquifer groundwater flow in that area are dominated by infiltration into the 26th Street Sewer, and potentially areas along the Pollock Street/Packer Avenue Sewer offsite (Stantec, 2016). The contours presented in this RIR indicate that within AOI 4, unconfined aquifer groundwater flow converges along the identified former stream valley that bisects a portion of the area, and in the northeastern corner may be influenced by offsite infiltration into the 26th Street Sewer.

5.2.3 Lower Aquifer

Beneath AOI 4, the lower aquifer is mapped in this RIR to be composed of nearly equal thicknesses of the middle and lower sand units as the lower clay unit appears to be absent in this area. On average, the saturated thickness of the lower aquifer beneath AOI 4 is approximately 50 to 90 feet and is thickest along 26th Street where a deep bedrock trough exists (e.g., S-39D). As noted in **Section 4** and on **Figure 2-11**, Stantec performed slug and pumping tests on lower aquifer deposits in AOI 4 using wells S-218D and S-39D. Well testing indicates that a representative hydraulic conductivity for the lower aquifer in AOI 4 may be approximately 65 to 85 ft/d (**Appendix K**). This encompasses lithologies that include silty sand to well-graded gravelly sand with a trace of silt (see sieve analyses in **Appendix J**). Older slug testing results for wells near the AOI 3 guard basin resulted in lower k_h values for the lower aquifer in that area, ranging from approximately 3 ft/d to 30 ft/d (eg. S-8 and S-22 on **Figure 2-8**). The data analysis appendix of ENSR (1992) was not available for review of test analysis methods; however, the results appear anomalous in the context of other testing and apparent lithologies present. Fraction organic carbon testing data included in **Appendix J** indicates that the AOI 4 lower aquifer deposits may contain approximately 1% organic carbon.

Lower aquifer k_h data can also be reasonably estimated from historical testing performed at the Philadelphia Naval Shipyard and as such has been summarized from offsite areas on **Figure 2-10**. From those tests, values of lower aquifer k_h are estimated to vary from approximately 123 ft/d to 151 ft/d. As noted for the unconfined aquifer, Stantec is presently evaluating potential values of AOI 4 aquifer k_h as a part of PES Complex-wide numerical model calibration and sensitivity analysis. No estimates of k_v are available for lithologies correlated to the lower aquifer beneath AOI 4.

5.2.3.1 Hydraulic Heads and Groundwater Flow

Groundwater flow within the lower aquifer beneath AOI 4 and proximity has been evaluated and contoured utilizing data from up to 20 wells, and the resultant potentiometric surfaces are shown on **Figures 5-5** through **5-7** for synoptic well gauging events conducted in May of 2014, 2015, and 2016. At the locations evaluated, the well gauging data indicates that the lower aquifer has artesian conditions or is at least semi-confined beneath AOI 4. In general, the datasets indicate an overall southerly groundwater flow direction beneath AOI 4 under a hydraulic gradient of approximately 0.0006 ft/ft. Like the pattern of flow in the unconfined aquifer, along the northeastern perimeter of AOI 4 and areas to the east, the lower aquifer potentiometric surface indicates that groundwater flow direction is to the southeast. Offsite beneath the former Passyunk Homes property, flow convergence is indicated in May 2016. Variability in patterns of lower aquifer groundwater flow in the area evaluated may be related to aquifer transmissivities through the referenced bedrock troughs, or as indicated by Stantec (2016) upward leakage into the 26th Street Sewer or offsite unconfined aquifer.

5.3 CLAY UNIT PROPERTIES

5.3.1 Upper Clay Unit

The PRM upper clay unit appears to be of limited thickness and lateral extent beneath AOI 4 and proximity. As such, the upper sand unit is interpreted as being hydraulically continuous with the overlying "Trenton gravel". However, where locally present in significant thickness, the upper clay unit aquitard could maintain hydraulic separation between the two formations/units and lead to localized areas of artesian pressure in the upper sand. Stantec collected one Shelby tube in the apparent upper clay unit at AOI 4 monitoring well location S-218D, and from that permeability test (depth of 30.1 to 30.5 ft bgs) it is estimated that the upper clay unit k_v may be approximately 2.16 x 10^{-7} cm/s (see **Appendix J**). At well S-39D, the upper clay was not encountered in sufficient thickness for Shelby tube sample collection but was observed to be of similar lithology to the upper clay at well S-218D.

5.3.2 Middle Clay Unit

The PRM middle clay unit is generally regarded as a regional confining unit in the study area. As presented in this RIR, the middle clay unit appears to be laterally continuous beneath AOI 4 and creates overall hydraulic separation between the unconfined and lower aquifers. For this RIR, Stantec collected two Shelby tubes in the apparent middle clay unit at AOI 4, one each from monitoring well locations S-218D (59.5 to 59.9 ft bgs) and S-39D (56.0 to 56.3 ft bgs). From those permeability tests it is estimated that the middle clay unit k_v may be approximately 6.0 x 10^{-7} to 7.21 x 10^{-9} cm/s (see **Appendix J**).

Offsite, Stantec is aware that DLA's consultants, the USGS, and others responsible for characterizing and remediating subsurface conditions at the former DSCP property have interpreted that a "breach" in the upper, middle, and/or lower clay units exists across a small area of that site. The interpreted "breach" area, as displayed by ARCADIS (2014a), is generally located beneath the Schuylkill Expressway, to the east of the CSX Property and west of Penrose Avenue. At that location, the current subsurface interpretation includes the lower sand unit mapped in direct hydraulic contact with the overlying "Trenton gravel" (e.g., well log for DSCP-MW-65). Using interpolation (inverse-distance weighted) software, Sloto (2012) modeled that "breach" as an approximately 25-acre area where the middle and lower sand units are hydraulically connected to the unconfined aquifer. The western limit of that "breach" area has not been delineated. However, no such area has been identified beneath AOI 4.

For the purposes of this RIR, Stantec reviewed the lithologic logs for 13 deep wells installed under the oversight of Tetra Tech, Inc. (Tetra Tech) in 2005 and 2007 at the former DSCP Property. Lithologic logs for deep wells DSCP-MW-20D and DSCP-MW-6D were also reviewed (logs for these wells can be found in IST [1998]). Those logs were interpreted and stratigraphic "picks" were made on the apparent formations/units and used in conjunction with well data at the PES Complex to create the stratigraphic profiles presented in this report. Of the well records reviewed, Stantec did not identify any logs exhibiting a complete hydraulic connection between the unconfined and lower aquifers in AOI 4. However, the cross sections developed for this RIR show that to the west of AOI 4 beneath AOIs 6 and 7, the middle clay was incised by erosion through the Schuylkill River valley and has been removed and replaced by Quaternary deposits. North and east of AOI 4 beneath the former Passyunk Homes property, the middle clay unit is interpreted to thin relatively rapidly over a short distance and may have been completely eroded prior to deposition of the upper sand unit near well PH-DW-10 (**Figure 2-8**). In this "breach" area as identified by others, it appears that the aquifers defined at AOI 4 may be hydraulically connected through muddy strata of the apparent middle sand unit.

5.4 AQUIFER CONDITIONS AND HEAD POTENTIALS BETWEEN AQUIFERS

Stantec evaluated the magnitude of vertical hydraulic head potentials for May 2016 between the unconfined and lower aquifers throughout the study area by identifying locations of well pairs in AOI 4 and by utilizing offsite well pair locations previously identified by Sloto (2012) and ARCADIS (2014a) for the former DSCP Property. **Figure 5-8** displays the results of that evaluation. The figure indicates that across most of the study area (including all well pairs in AOI 4), the hydraulic head potential between observed aquifers was positive (downward) in May 2016. However, an area of negative (upward) hydraulic head potential is indicated in southern AOI 1 and along 26th Street as supported by head observations at nested well pairs S-46/S-46D, S-214/S-392D, STEEN-PH-10/STEEN-DW-09, PH-MWS-1/PH-DW-10, EPH-PH-5/PH-DW-3, ARCO-1/ARCO-1D, and S-41/S-264D.

Outside of the area of indicated negative potential, a broad area of nearly equal hydraulic heads is indicated, generally along northeastern AOI 4 (eg., S-119/S-119D) and at the former DSCP Property near the "breach" area identified by others (eg., PH-DW-10/PH-MWS-1). Overall the positive hydraulic head potentials beneath AOI 4 support the existence of two aquifers and the continuity of the middle clay. Water-level monitoring data for AOI 4 well pairs shown on **Figure 5-9** indicate that the head potentials between the aquifers are consistent throughout the year. However, as concluded by Stantec (2016) the offsite pattern of flow potential continues to suggest that the 26th Street Sewer is receiving groundwater from the unconfined aquifer along an area of the sewer, and that groundwater losses are affecting heads in the lower aquifer through upward recharge/vertical leakage to the unconfined aquifer or direct losses to the sewer. The exact nature or cause of these losses is not currently known (i.e., breaks in the sewer, joint separation, construction anomaly, or other). Upward vertical leakage from the lower aquifer to the unconfined aquifer could be occurring in the offsite area to the east of AOI 4 where the middle clay unit may be absent.

6.0 LNAPL INVESTIGATION

To investigate LNAPL in AOI 4, a comprehensive LNAPL Conceptual Site Model (LCSM) was prepared and is included as **Appendix E** of this RIR. In general, the LCSM utilizes a technical approach to evaluate the potential mobility of LNAPL present at the site incorporating multiple lines of evidence, including observations of LNAPL distribution over time, an analysis of apparent NAPL thickness (ANT), physical and chemical laboratory analysis of LNAPL samples, and theoretical estimates of LNAPL mobility supported by field and laboratory measurements to understand whether AOI 4 LNAPL areas are residual (immobile), mobile (recoverable), and/or migrating. As defined in the LCSM, residual LNAPL represents LNAPL that is trapped in soil pores, mobile LNAPL is LNAPL that exceeds residual saturation, and migrating LNAPL is LNAPL that is observed to spread or expand. It is noted that although mobile LNAPL includes migrating LNAPL, not all LNAPL indicated to be mobile is migrating.

The following summarizes findings and conclusions of key elements of the LCSM utilizing data gathered from literature review, historical and recent field investigations, laboratory analyses, and remediation efforts. **Figure 6-1** is provided to support the summary.

- Numerous LNAPL characterization samples collected from the PES Complex by Stantec and others through time have identified the presence of several variably-weathered products and product mixtures in the subsurface at AOI 4. The variation in LNAPL characteristics is indicative of multiple product releases at different times with subsequent co-mingling of plumes. For the purposes of this and other RIRs for the PES Complex, AOI 4 laboratory-characterized LNAPL samples [i.e., qualitative analysis using chemical data of hydrocarbon distributions (gas chromatographic patterns) and comparison to reference product sample data] have been generalized by Stantec into the product groups (see LCSM for a description of the categories) listed below:
    - Light Distillate
    - Mixture of Light and Middle Distillate
    - Middle Distillate
- A mixture of light and middle distillate is the most common product type delineated in the subsurface beneath AOI 4. **Figure 6-1** displays the maximum observed LNAPL thickness for wells gauged during the time period 2013 – 2016 (Present). The maximum observed LNAPL thickness since 2013 was used conservatively (i.e., in some instances the maximum LNAPL thickness was observed in 2013) as a guide for delineation of the 6 general LNAPL plume areas shown. A few select wells that contained measurable LNAPL within this timeframe are not shown as plume areas due to insufficient spatial, temporal, and/or ANT data available to support that interpretation (e.g., well S-369).
- A review of ANT data through time suggests that in general, LNAPL plumes at AOI 4 are not migrating, mainly, because the vertical thickness of LNAPL as observed in AOI 4 monitoring wells has

not been increasing. However in the following wells, increasing trends in ANT have recently been observed indicating that LNAPL in these areas might be migrating:

- S-30 and S-31: located within the influence area of the inactive S-30 Remediation System (S-30 System).
- S-104 and S-368: these wells are located adjacent to the northern (center) AOI 4 border with AOIs 1 and 2 along Hartranft Street.
- S-221, S-240, S-241, and RW-701: these wells are located along or north of the northern leg of the Penrose System.
- S-220: located to the northwest of the Penrose System.

- Review of the aerial extent of apparent LNAPL through monitoring well observations suggests that overall, AOI 4 LNAPL plumes are not migrating because fluid level gauging through time indicates that LNAPL has not been identified in a downgradient portion of the monitoring well network that has historically lacked measurable LNAPL, with one exception: monitoring well S-368 has been gauged six times between 2013 and 2016. LNAPL was not detected until the most recent gauging events at monitoring well S-368, in May and November 2016, when it was observed at a maximum thickness of 2.25 ft. The recent LNAPL observation at well S-368 could also be the result of a new release, and not necessarily migration of existing LNAPL.

- At the Penrose System area along the southern AOI 4 boundary, use of ANT and aerial extent of LNAPL through time cannot completely demonstrate LNAPL delineation at the apparent downgradient boundary (point of compliance) as efforts by Evergreen to install offsite monitoring wells have been unsuccessful due to property access. Operation of the Penrose System wells is meant to mitigate the potential offsite migration of LNAPL in this area. ANT trends support continued operation of the Penrose System.

- Recent (post-2015) product releases are suspected to have occurred in the Penrose System area and may account for the ANT increases observed and discussed in the LCSM. During July/August 2016, product soaked soil was identified at the ground surface around pipes which are associated with Tank 253 but outside the emergency containment dike, located north of well S-241. The area around the lines was excavated and product removed by PES personnel. In addition, there is a product line that is suspected to have leaked which runs north-south along the access road leading to the Penrose system wells, approximately bisecting AOI 4. This line is being excavated and replaced in sections by PES. **Figure 6-1** contains an inset map that comparatively shows the ANT in May 2015 in this area versus the maximum thickness for the time period 2013 – 2016.

- Average LNAPL transmissivity for the Penrose system was calculated using monthly system operational data. Annual averages for the system were calculated to range from 0.5 ft^2/day in 2013 to 4.5 ft^2/day in 2016 with a significant increase in estimated transmissivity occurring in September 2016. The significant increase in Penrose system LNAPL transmissivity in 2016 is likely the result of new product releases in the area south of the system. These estimates are based on average extraction rates for the Penrose system as a whole. LNAPL transmissivity may be higher or lower at individual wells included in or near the system. For AOI 4, LNAPL baildown testing of system wells could be used to facilitate future optimization of the Penrose system.

- In February 2017, Stantec revisited the S-30 System area and collected one LNAPL sample from well S-30 to reevaluate LNAPL occurrence in that area. The sample was characterized as extremely-weathered middle distillate with a very similar density [0.8680 grams per milliliter (g/ml) versus 0.8681 g/ml] to what was collected and characterized as middle distillate in 2004 from that well. Potential mobility and recoverability of LNAPL at this well should be evaluated as a part of Cleanup Plan activities. Evergreen plans to resume operation of the idled remediation system following new equipment installation in 2017.

- A conservative value for the site-specific mobility term was calculated to be 1.92×10^{-4} cm^3s/g which is above the practical limit of mobility.

- The critical pore entry pressure was estimated for wells that had greater than 0.1 feet of apparent LNAPL thickness in 2016. The estimated critical pore entry pressure thickness ranged from 0.38 to 0.70 feet with an average of 0.45 feet. For 18 of the 20 wells evaluated, the observed LNAPL thickness was greater than the critical pore entry pressure indicating that the LNAPL observed at these wells is potentially mobile.

- ASTM suggests that LNAPL seepage velocities less than 1×10^{-6} cm/s are indicative of functionally immobile LNAPL. As a part of this LNAPL CSM, plume velocity calculations were updated for wells with greater than 0.1 feet of ANT in 2016. Model calculated plume velocities ranged from 5.2×10^{-7} cm/s to 2.5×10^{-4} cm/s with an average velocity of 1.3×10^{-4} cm/s, indicating that LNAPL is functionally mobile in some areas of AOI 4.

- The API LDRM model was run for wells with greater than 0.1 feet of ANT in 2016. The LDRM model indicates that LNAPL in 13 of the 20 wells evaluated was within the range of practicable recoverability, five wells are in the transitional range (S-29, S-31, S-278, RW-704, and S-373), and two wells (S-368 and S-104) have estimated LNAPL transmissivity values below the limit of practicable recoverability. LNAPL transmissivity testing completed at these wells could be used to further calibrate the LDRM model and in simulating recovery methods over time.

Site-specific values of LNAPL transmissivity based on groundwater recovery ratios indicate that overall, LNAPL at AOI 4 is below the lower limit of practicable recovery. However, pore entry pressure, mobility modeling, and LDRM evaluations indicate that areas of potentially mobile and practicably recoverable LNAPL are still present at and in some areas adjacent to AOI 4. In general, based upon the multiple lines of evidence presented above, LNAPL observed at AOI 4 appears to be stable or decreasing (not migrating) as a whole. Nonetheless, wells located in three distinct areas of AOI 4 indicate potentially mobile LNAPL: (1) S-30 System area (based on wells S-30 and S-31); (2) Penrose System area (based on S-221, S-240, S-241, and RW-701); and (3) in the vicinity of S-220 (between the S-30 System and Penrose System areas). Increasing ANT trends at S-104 and S-368 indicated potentially mobile LNAPL, however, the estimated plume velocity and/or LNAPL transmissivity indicate that the onsite edge of this plume is functionally immobile and not practically recoverable. In the Penrose System area, the apparent LNAPL mobility may be the result of recent (post-2015) product releases.

The results of this LNAPL mobility assessment may be used to focus additional testing and to facilitate recovery system optimization. As additional site-specific LNAPL data becomes available it may be used to update and calibrate the LNAPL mobility evaluations presented in the AOI 4 LCSM.

7.0 VAPOR INTRUSION

The vapor intrusion pathway in AOI 4 was evaluated for potential receptors of vapors originating from petroleum hydrocarbon source material, in accordance with the PADEP Land Recycling Program Technical Guidance Manual for Vapor Intrusion into Buildings from Groundwater and Soil under Act 2 (VI Guidance) (PADEP, 2017a). In accordance with the VI Guidance, an evaluation of the potential for a complete vapor intrusion pathway is required for each building based on size, construction, and use. Within AOI 4, the 15 Pump House building was identified as the only occupied building requiring further evaluation of the vapor intrusion pathway. An indoor air evaluation was selected as the method to investigate whether a complete pathway for hydrocarbon vapors exists within the 15 pump House, which is an approximately 4,000 square foot, single-story, slab on grade building typically occupied by 2 to 3 operators.

Potential offsite receptors are located greater than 30 feet from onsite sources in soil; therefore, volatilization from soil is not a concern. The proximity distances, established in the VI Guidance, for LNAPL are 30 horizontal feet and 15 vertical feet. As discussed in **Section 6,** LNAPL was not detected in wells at the AOI boundary in recent site-wide gauging events. Volatilization from dissolved-phase impacts are not a concern, as depth to groundwater in this area is greater than five feet, the vertical proximity distance established by the PADEP for dissolved-phase hydrocarbon constituents from any building foundations. The 26th Street and Penrose Avenue Sewers were identified as a potential preferential pathway for vapor intrusion to offsite receptors. These are submerged sewers in known areas of groundwater impacts. A vapor mitigation system is currently in operation to address vapors that could be migrating within the 26th Street Sewer which is connected to the Penrose Sewer. A summary of this remediation system is available in **Section 10.4.3**, and details are presented in **Appendix F**. Operational information regarding the system is currently reported to PADEP on a semi-annual basis as part of the Philadelphia Refining Groundwater Remediation Status Reports, and details regarding the plans to maintain this vapor mitigation system in the future will be included in future Act 2 deliverables. No other potential offsite receptors were identified within the specified proximity distances that warranted further vapor intrusion evaluation within AOI 4.

The following sections summarize the results of the vapor intrusion assessment performed in AOI 4, which was conducted in general accordance with the VI Guidance. The evaluation of indoor air was selected as the preferred investigation approach because indoor air data represent conditions that are as close to the receptor as possible and, therefore, provide the most accurate representation of concentrations at the point of exposure.

7.1 AMBIENT AND INDOOR AIR SAMPLING

Stantec completed an evaluation of VOCs in occupied buildings at the refinery, including in AOI 4 (Stantec, 2013). An initial site visit was conducted in September 2012, which identified the sample locations and specific number of samples to be collected. On October 24, 2012, three air samples were collected to evaluate the vapor intrusion pathway for the 15 Pump House and outdoor air located within AOI 4. Of the three samples collected for the AOI 4 vapor intrusion assessment, two were ambient air, and one was indoor air. Samples named AOI 4 Sample 21 and AOI 4 Sample 20, were collected from outside the 15 Pump House, under the equipment roof at grade and under the equipment roof approximately 8-10 ft below grade, respectively, and one blank was also collected on the day of sampling. The indoor air sample was collected from the breathing zone (3-6 feet above floor/ground level). All samples were collected using Summa© canisters with laboratory-provided regulators set to collect air over one continuous 4-hour period, which was determined to represent VOC concentrations during normal operating conditions at the PES Complex. The samples were packaged by Stantec field personnel and transported by FedEx to Columbia Analytical Services, Inc. under chain-of-custody documentation for analysis of VOCs including naphthalene on the Evergreen Petroleum Short List by EPA method TO-15.

In order to evaluate the potential for volatilization to outdoor air, an additional ambient air sample was collected above a LNAPL plume in 2016. A conservative approach was used to identify potential locations of concern using the vertical proximity distance, presented in the VI Guidance for volatilization to indoor air, of 15 ft for petroleum separate phase liquids. The S-104 area was identified as the only location in AOI 4 to have product at or less than 15 ft bgs. In June 2016, an ambient air sample (AOI4-AA-16-001) was collected at S-104, near the intersection of Hartranft Street and 10th Avenues. The sample was collected by Aquaterra and analyzed by ESC, for analysis of VOCs by EPA method TO-15.

All sample locations are shown on **Figure 7-1**. Air samples were collected in general accordance with the *Evergreen Field Procedures Manual* as presented in **Appendix B**.

7.2 SAMPLE RESULTS

The analytical results of the indoor and ambient air sampling activity conducted in 2012 and 2016 are summarized below. Available analytical results for compounds on the Evergreen Comprehensive List are presented on **Table 7-1** and the laboratory analytical reports are included in **Appendix D**. Sample results were compared to six sets of screening values:

- EPA RSL, TR=1E-5, THQ=0.1
- SVIA-NR SHS
- SVIA-NR SSS
- OSHA PEL
- NIOSH REL
- ACGIH TLV

The VI Guidance establishes the EPA RSLs, TR=1E-5, THQ=0.1 as appropriate screening values when it can be demonstrated that vapor intrusion is the only complete exposure pathway for a receptor. Upon the completion of remediation activities, volatilization to the breathing zone will be the only potentially complete pathway for petroleum impacts in AOI 4. A calculated site specific standard is not being used, except for lead in soil, which is not a potential vapor intrusion concern. Results for 1,3,5-TMB were screened against the SVIA-NR SSS because there is not an established EPA RSL for this compound.

It should be noted that the laboratory reporting limits for 1,2-dibromoethane were above the EPA RSL in the 2012 samples. Options to address these compounds will be presented in the Cleanup Plan.

7.2.1 Ambient Air Results

A combination of several COCs were detected in all three ambient air samples collected within AOI 4. With the exception of 1,2,4-TMB in two samples, concentrations did not exceed the corresponding EPA RSLs. AOI4 Sample 21 and AOI4-AA-16-001 had 1,2,4-TMB concentrations in exceedance of the EPA RSL of 3.1 $\mu g/m^3$.

PADEP operates a network of air toxics monitoring stations that sample for VOCs. Note that several COCs are not included in PADEP's monitoring program. Detailed analytical results by year for each monitoring station are available on-line at Regional ambient air quality in the Philadelphia Refining Complex is best represented by data from the Marcus Hook monitoring station (latitude 39.8178, longitude - 75.4142) (PADEP, 2017b). **Table 7-2** presents the results for the ambient air samples with the air toxics monitoring data for 2012; data from 2016 was not made available at the time of this report. The concentrations of petroleum-related compounds in the outdoor air at the PES Complex were somewhat higher than regional mean background as represented by concentrations reported from PADEP's Marcus Hook monitoring location.

7.2.2 Indoor Air Results

Several COCs were detected in the indoor air sample collected from the 15 Pump House in AOI 4 in 2012. Concentrations of COCs did not exceed the EPA RSLs, with the exception of 1,2,4-TMB, which slightly exceeded the EPA RSL of 3.1 $\mu g/m^3$.

7.3 SUMMARY

The sampling events conducted in 2012 and 2016 represent ambient air and indoor air during the heating season when levels of VOCs inside buildings are expected to be higher than during warmer months.

- Indoor air sample, AOI4 Sample 19, and two of the outdoor air samples (AOI4 Sample 21 and AOI4-AA-16-001) exceeded the EPA RSLs for 1,2,4-TMB of 3.1 $\mu g/m^3$.
- With few exceptions, the concentrations of petroleum hydrocarbon-related VOCs were similar in both ambient and indoor air samples collected in 2012. There are multiple sources of petroleum-related VOCs at the Philadelphia Refining Complex and in the immediate proximity, such as traffic on major highways and other industries.
- PADEP operates a network of air toxics monitoring stations that sample for VOCs. Regional ambient air quality in the Philadelphia area where the PES Complex is located is best represented by data from the Marcus Hook monitoring station. As would be expected, the concentrations of petroleum-related compounds in the outdoor air at the PES Complex were somewhat higher than regional background as represented by concentrations reported from PADEP's Marcus Hook monitoring location.

Stantec plans to conduct an additional round of air sampling pursuant to the VI Guidance. In order to evaluate data trends, a minimum of one indoor air sample and one ambient air sample are planned for the 15 Pump House area, and one ambient air sample may be collected near the vicinity of well S-104. Samples will be collected for an 8-hour period during the heating season to represent the most conservative scenario. Exceedances of any EPA RSLs in air samples will be evaluated in the Cleanup Plan.

8.0 QUALITY ASSURANCE/ QUALITY CONTROL

Methods established by Evergreen to examine data quality are outlined in **Appendix B**, *Quality Assurance/Quality Control Plan and Field Procedures Manual*. All fieldwork conducted as part of the site characterization activities was performed in accordance with the procedures outlined in the *Evergreen Field Procedures Manual*, **Appendix B**. An assessment of analytical data collected as part of this investigation under the *Quality Assurance/Quality Control Plan* is included in **Appendix G**. The following sections describe specific aspects of quality assurance/quality control procedures that pertain to the activities outlined in this report.

8.1 EQUIPMENT DECONTAMINATION

All sampling equipment was either dedicated or decontaminated in accordance with the field sampling procedures to prevent cross-contamination. Prior to sampling, the equipment was decontaminated with successive rinses of detergent, potable water, and distilled water.

8.2 EQUIPMENT CALIBRATION

Air quality monitors used for both air monitoring and soil screening were calibrated prior to use. Both a zero calibration and a span calibration using gases of known concentration as recommended by the manufacturer (i.e. 100 parts per million by volume (ppm_v) isobutylene for the photoionization sensor) were performed.

8.3 SAMPLE PRESERVATION

Samples were placed directly into chemically preserved and/or non-preserved glassware provided by the analytical laboratory, as appropriate. All samples were preserved and shipped at a temperature of approximately 4° Celsius (C) or less by application of ice prior to shipment to the analytical laboratory. This temperature was maintained during shipment by placing ice in zip-top bags above, around, and below the sample containers.

8.4 DOCUMENTATION

Chain-of-custody forms were maintained throughout the sampling program to document sample acquisition, possession, and analysis. Chain-of-custody documentation accompanied all samples from the field to the laboratory. Each sample was assigned a unique identifier that was recorded in the field notes as well as on the chain-of-custody document.

9.0 CONCEPTUAL SITE MODEL

Through comprehensive file review and characterization activities performed as a part of this RIR, Stantec's conceptual understanding of the present conditions identified at AOI 4 and nearby proximity is summarized as follows.

9.1 DESCRIPTION AND SITE USE

- The PES Complex is located along the banks of the Schuylkill River in the City of Philadelphia, Philadelphia County, Pennsylvania (**Figure 1-1**). The PES Complex, which is located on industrial property, covers approximately 1,400 acres of land with access restricted by fencing and security measures. Current operations at the PES Complex consist of the production of fuels and basic petrochemicals for the chemical industry.

- The area surrounding the PES Complex is characterized by a mixture of residential, commercial, and industrial properties, including property formerly occupied by the DSCP discussed in this RIR.

- AOI 4 occupies approximately 106 acres of the PES Complex in the southeast portion of the Point Breeze Refinery South Yard (**Figure 1-2**).

- AOI 4 is comprised of primarily light-end hydrocarbon tankage (Tank Farm No. 4). Infrastructure mainly includes ASTs and process equipment required for the blending and storage of gasoline and additives, included numerous aboveground and underground process lines. Use of the Tank Farm No. 4 has altered little over the course of history at the PES Complex with primary changes being various ASTs taken in and out of service. The only occupied building in AOI 4 is the 15 Pump House, which is located in the northcentral section of AOI 4.

9.2 GEOLOGY AND HYDROGEOLOGY

9.2.1 Geologic Framework

- The PES Complex occurs within the up-dip limits of the Atlantic Coastal Plain, generally within two miles of the "Fall Line" (**Figures 2-1 and 2-2**). Historical maps indicate that AOI 4 topography was generally low-lying prior to industrialization and contained subtle topographic highs surrounded by lowlands and streams. Present-day topography has been significantly altered by humans and in most places is capped by low permeability materials (**Figure 2-3**).

- Published geologic information indicates that the Coastal Plain sedimentary record beneath, and in the vicinity of, AOI 4 is complex, largely incomplete, and under-represented by only Cretaceous and Quaternary deposits, separated by a regional disconformity. Total Coastal Plain thickness above bedrock (predominantly variably weathered mica schist) ranges from approximately 80 to 150 feet near AOI 4 (**Figure 2-12**).

- Beneath AOI 4 and the area evaluated, the following Coastal Plain deposits may be present, in order of increasing depth/age: anthropogenic fill, Quaternary alluvium [including Holocene (recent) and Pleistocene ("Trenton gravel") deposits], and the Cretaceous Potomac-Raritan-Magothy (PRM) aquifer system, including the upper clay, upper sand, middle clay, middle sand, lower clay, and lower sand units. These deposits are identified and described in this RIR based on correlation to published geologic formations/units using lithology and stratigraphic principles (**Figures 2-5** through **2-8**).

- Within the Coastal Plain, thicknesses of fill and each individual geologic formation/unit vary across the PES Complex. Along the northern AOI 4 margin, recent alluvium appears to have been truncated by erosion through a presently-buried stream valley. To the west of AOI 4, the PRM upper clay, upper sand, middle sand, and middle clay are interpreted to have been cut by the ancestral Schuylkill River or laterally "pinch" out (**Figures 2-5** through **2-8**) as they approach the "fall line." Beneath AOI 4, the PRM units appear to follow a similar depositional pattern that mirrors the bedrock surface (a vertical sequence of cut and fill deposits). In large part, the PRM lower clay unit is not present beneath AOI 4. Overall Coastal Plain thickness is greatest along the eastern boundary of AOI 4 and offsite, where a bedrock trough is present (**Figure 2-12**).

- Hydrostratigraphic units (aquifers and aquitards/confining beds) were defined from the geologic units to identify water-bearing strata on a mappable scale applicable to AOI 4 (**Table 5-1**).

9.2.2 Unconfined (Water-Table) Aquifer

- Beneath AOI 4, the unconfined aquifer is primarily composed of saturated portions of unconsolidated materials that are interpreted as the "Trenton gravel" and underlying PRM upper sand unit. The intervening PRM upper clay unit aquitard, where present, is also included in this aquifer.

- On average, the saturated thickness of the unconfined aquifer beneath AOI 4 is approximately 10 to 35 feet.

- Estimated values of unconfined aquifer k_h vary from approximately 12 ft/d to more than 450 ft/d in AOI 4 (**Figure 2-9**). Permeability (k_v) of muddy strata found within the unconfined aquifer may range from approximately 10^{-7} to 10^{-8} cm/s (Trenton gravel and PRM upper clay unit), the fraction organic carbon may range from approximately 0.5% to more than 1.5%; and effective porosity may range from approximately 7% to 28%.

- Numerous groundwater mounds are apparent beneath and near AOI 4 that may be the result of saturated fill areas or leaking underground infrastructure (**Figure 5-1**). Many of the mounds present appear to behave independently of water-table trends and are likely indicative of perched water that is supported by an underlying layer of lower permeability, recent alluvium.

- Recent (2014-2016) patterns of AOI 4 unconfined aquifer groundwater flow appear relatively consistent through time. Near-continuous water-level monitoring data suggest that seasonal variability is limited to approximately 1 foot (2016 data) (**Figure 5-9**). An earth tide and/or river tide signal is superimposed on the unconfined aquifer data on a semidiurnal timescale. The amplitude of the tidal signal is approximately 0.05 feet (well S-218 data).

- Unconfined aquifer groundwater flows radially under a gentle hydraulic gradient (0.001 to 0.004 ft/ft) beneath most of AOI 4 and appears to subtly mirror natural surface topography (see **Figures 5-2** through **5-4**) that creates a southwest-northeast trending groundwater divide. North of that feature, flow appears to be southeast out of higher topography in AOI 2 and converges with northerly flow out of AOI 4 near the AOI 1/AOI 2/AOI 4 boundary along the location of a former stream. The pattern of unconfined aquifer groundwater flow north and east of AOI 4 suggests that infiltration into the 26th Street Sewer, and potentially the Pollock Street/Packer Avenue Sewer, is occurring. Regardless of the cause(s), groundwater convergence along 26th Street influences flow in the northeastern portion of AOI 4.

- Offsite to the east of AOI 4 and 26th Street, unconfined aquifer groundwater flow appears to be further influenced by factors in addition to potential infiltration into the large, deep sewers present. Geologic mapping suggests that these factors may include enhanced vertical groundwater exchange/leakage to/from the lower aquifer where a regional confining unit, the PRM middle clay, is mapped to thin, become sandy (reworked), and in a small area may be missing (eroded) entirely.

- A filled, former stream valley identified to have historically flowed south out of AOI 1 and into AOI4 before turning west, appears to remain an influence on groundwater flow patterns in the unconfined aquifer beneath AOI 4. The buried stream valley appears to contain perched water in places where perching is supported by stratigraphy.

9.2.3 Lower Aquifer

- Beneath AOI 4, the lower aquifer is primarily composed of saturated portions of the PRM lower and middle sand units. The lower clay unit aquitard appears to be largely absent.

- On average, the saturated thickness of the lower aquifer beneath AOI 4 is approximately 50 to 90 feet.

- Lower aquifer k_h is estimated to vary from approximately 65 ft/d to 85 ft/d (**Figure 2-10** and **Appendix K**) where the lithology is silty sand to well-graded gravelly sand with a trace of silt. In vicinity to AOI 4 the k_h may be as high as approximately 123 ft/d to 151 ft/d (**Figure 2-11**). The fraction organic carbon is estimated at approximately 1%.

- Well gauging data indicates that the lower aquifer exhibits artesian conditions and is at least semi-confined beneath AOI 4. Near-continuous monitoring of the lower aquifer potentiometric surface (2016) indicates that seasonal variability is limited to approximately 1 foot (**Figure 5-9**). An earth tide and/or river tide signal is superimposed on the lower aquifer data on a semidiurnal timescale. The amplitude of the tidal signal is approximately 0.3 feet (well S-218D data).

- Lower aquifer groundwater flows to the south beneath most of AOI 4 under a hydraulic gradient of approximately 0.006 ft/ft (see **Figures 5-5** and **5-7**). Within the overall southerly groundwater flow regime present across the study area, the lower aquifer potentiometric surface may appear non-uniform and flow can converge towards an offsite depression along a portion of 26th Street and the former Passyunk Homes property. Along the northeastern perimeter of AOI 4 and areas to the east the lower aquifer potentiometric surface indicates that the groundwater flow direction is to the southeast. Variability in patterns of lower aquifer groundwater flow in the area evaluated may be related to aquifer transmissivities through the referenced bedrock troughs, or as indicated in Stantec (2016) upward leakage into the 26th Street Sewer or offsite unconfined aquifer.

9.2.4 Vertical Head Potentials

- Across most of the study area (including all well pairs in AOI 4), the hydraulic head potential between observed aquifers was positive (downward) in May 2016 (**Figure 5-8**). However, an area of negative (upward) hydraulic head potential is indicated in southern AOI 1 and along 26th Street. A broad zone of nearly equal hydraulic heads is indicated between these areas, generally along northeastern AOI-4 and at the former DSCP Property near the “breach” area identified by others. Overall the positive hydraulic head potentials beneath AOI 4 support the existence of two aquifers and the continuity of the middle clay unit aquitard. Water-level monitoring data for AOI 4 well pairs shown on **Figure 5-11** indicate that the head potentials between the aquifers are consistent throughout the year.

9.3 COMPOUNDS OF CONCERN

9.3.1 Soil

- AOI 4 soil delineations were performed to the highest concentration in soil of the SHS, the NRDC MSC, and the lead SSS for the Evergreen Comprehensive List, unless a shorter list of analytes was appropriate for a specific situation, and as described in **section 3.6** (**Figure 3-1**).

- Lead was identified in AOI 4 surface soil samples at concentrations in excess of the SSS for lead (**Tables 3-2** and **3-3**).

- Where identified in surface soil to exceed the referenced standards, lead has been delineated both horizontally and vertically through characterization activities and review of existing soil sample analytical data. It is noted that Stantec has observed some correlation between the locations of lead exceedances in surface soil and the occurrence of (presumably smelter) slag and cinders in areas of anthropogenic fill.

- No exceedances of the NRDC MSCs for compounds listed on the Evergreen Petroleum Short List were identified in subsurface soil in AOI 4.

9.3.2 Groundwater

- Two comprehensive rounds of characterization groundwater sampling were completed in 2016 as a part of this RIR and groundwater samples were analyzed for the Evergreen Comprehensive List.

- For the unconfined aquifer, concentrations of the following compounds were detected above the SHS in groundwater during the 2016 groundwater sampling events: 1,2,4-TMB, EDB, 2-methylnaphthalene, anthracene, arsenic, benzene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, bis(2-ethylhexyl)phthalate, chrysene, ethylbenzene, MTBE, naphthalene, phenanthrene, pyrene, toluene, vanadium, and zinc. (**Table 4-2**). Prior to 2016, available historical groundwater data shows the following compounds detected above the SHS: 1,2,4-TMB, EDB, arsenic, benzene, benzo(a)pyrene, benzo(b)flouranthene, benzo(g,h,i)perylene, bis(2-ethylhexyl)phthalate, chromium, chrysene, cobalt, ethylbenzene, indeno(1,2,3-c,d)pyrene, lead, MTBE, naphthalene, toluene, and total xylenes.

- For the lower aquifer, concentrations of the following COCs were detected above the SHS in groundwater during the 2016 groundwater sampling events: benzene, MTBE, and lead (**Table 4-3**). Prior to 2016, available historical groundwater data shows the following compounds detected above the SHS: arsenic, cobalt, benzene, and lead.

9.3.3 Indoor/Ambient Air

The sampling events conducted in 2012 and 2016 represent ambient air and indoor air during the heating season when levels of VOCs inside buildings are expected to be higher than during warmer months.

- Indoor air sample, AOI4 Sample 19, and two of the outdoor air samples (AOI4 Sample 21 and AOI4-AA-16-001) exceeded the EPA RSLs for 1,2,4-TMB of 3.1 $\mu g/m^3$.

- With few exceptions, the concentrations of petroleum hydrocarbon-related VOCs were similar in both ambient and indoor air samples collected in 2012. There are multiple sources of petroleum-related VOCs at the PES Complex and in the immediate proximity, such as traffic on major highways and other industries.

- PADEP operates a network of air toxics monitoring stations that sample for VOCs. Regional ambient air quality in the Philadelphia area where the PES Complex is located is best represented by data from the Marcus Hook monitoring station. As would be expected, the concentrations of petroleum-related compounds in the outdoor air at the PES Complex were somewhat higher than regional background as represented by concentrations reported from PADEP's Marcus Hook monitoring location.

9.4 LNAPL DISTRIBUTION AND MOBILITY

- A comprehensive LCSM was prepared and is included as **Appendix E** of this RIR.

- LNAPL samples collected from site monitoring wells through time have identified the presence of several variably-weathered products and mixtures of products refined from crude oil in the subsurface at AOI 4 (**Figure 6-1**).

- Variability in LNAPL characteristics observed at AOI 4 is indicative of multiple product releases at different times with subsequent co-mingling of plumes. Several areas of LNAPL are identified within AOI 4 (**Figure 6-1**).

- A review of apparent LNAPL thickness data and the aerial LNAPL extent through time suggest that overall LNAPL plumes are not migrating. However, LNAPL plumes at the site may be migrating in the following areas: (1) S-30 System area (based on S-30 and S-31); (2) Penrose System (based on S-221, S-240, S-241, and RW-701); (3) in the vicinity of S-220 (between the S-30 System and Penrose System areas); and (4) northern AOI 4 boundary (based on S-104 and S-368).

- The PES Complex remains an active refinery and as such, may be impacted by additional petroleum releases through time. Recent product releases are suspected to have occurred near the Penrose System area and may account for the ANT increases observed and discussed in the LCSM. Observations of LNAPL migration are made difficult for this reason.

- The API LDRM model was run for wells with greater than 0.1 feet of apparent LNAPL thickness in 2016. The LDRM model indicates that LNAPL in 13 of the 20 wells evaluated was within the range of practicable recoverability, five wells are in the transitional range (S-29, S-31, S-278, RW-704, and S-373), and two wells (S-368 and S-104) have estimated LNAPL transmissivity values below the limit of practicable recoverability.

- Estimates of critical pore entry pressure and seepage velocities indicate that LNAPL is functionally mobile at a majority of wells included in the calculations in AOI 4.

- LNAPL observed at AOI 4 appears to be stable or decreasing (not migrating) as a whole and immobile at most locations. LNAPL areas are continually monitored through well gauging. LNAPL recovery is ongoing at the Penrose System, and anticipated in 2017 for the inactive S-30 System once it has been rehabilitated.

9.5 QUALITATIVE FATE AND TRANSPORT OF SELECTED COMPOUNDS

- A soil to groundwater model to evaluate the soil to groundwater pathway was not developed for the qualitative fate and transport assessment presented in this RIR. Rather, a qualitative-level assessment of groundwater data has been completed (**Section 10**).

- Of the COCs identified to be present in groundwater beneath AOI 4, benzene and MTBE were chosen for the qualitative assessment of fate and transport presented in this RIR because of their higher water solubility and potential mobility when compared to other Evergreen List COCs, and/or due to their general persistence in groundwater at the PES Complex. Other COCs identified in groundwater are discussed in the context of benzene and MTBE distributions.

- Comprehensive rounds of groundwater data from three timeframes for AOI 4 and adjacent AOIs 1, 2, and 3 conducted in 2004-2005, 2012- 2013, and 2014-2016 are presented on **Figures 10-1 through 10-6**. Data from offsite wells at the Steen, ARCO, and DSCP properties were incorporated to better characterize dissolved COC plumes across AOI 4 boundaries. Offsite datasets from the 2004-2005 timeframe did not include key wells, therefore, a 2007 dataset was supplemented. Golden Software's Surfer® 13 was used to interpolate the well data using point Kriging. Grid residuals were evaluated and the interpolated surfaces were subsequently contoured and imported into a geographic information system (GIS) for display and evaluation. For co-located wells, the maximum concentration was considered for kriging.

- Historical (2004-2005 and 2012-2013) benzene distribution in the unconfined aquifer beneath AOI 4 shows a continuous plume core of SHS exceedences that generally encompasses the central and western portion of AOI 4 (**Figures 10-1** and **10-2**).

- Recent (2014-2016) benzene concentrations in unconfined aquifer groundwater beneath AOI 4 show three general areas of benzene SHS exceedences: in the northeast corner of AOI 4 generally delineated by wells S-369, S-40, S-119, S-368, and AOI 1 well S-95; in the western and central portion of AOI 4, centered around wells S-415 and S-218 and generally delineated by wells within AOI 4; and in the south-central portion of AOI 4 near the PES Complex boundary, generally delineated by AOI 4 well data (**Figure 10-3**).

- Except for a few isolated occurrences, historical (2004-2005) MTBE concentrations in exceedance of the SHS are limited in time and extent to the Penrose System area (south central AOI 4 in association with the benzene plume) during the recent (2014-2016) timeframe (**Figures 10-4** through **10-6**).

- Recent (2014-2016) distributions of dissolved-phase benzene and MTBE in unconfined aquifer groundwater appear to in-part reflect groundwater movement along current hydraulic head gradients identified at AOI 4. Additional distribution of these substances may have been influenced by the operation of recovery wells (Penrose System area), or have resulted from gradients induced by historical pumping at the site (S-30 System and S-36 Remediation System).

- Recent (2014-2016) distributions of dissolved-phase 1,2,4-TMB, ethylbenzene, and toluene in unconfined aquifer groundwater generally resemble that identified for benzene at AOI 4, and have demonstrated the highest number of exceedances following benzene. The distribution of these substances in groundwater also suggests that they were released in the same areas as benzene and were likely components of the same petroleum hydrocarbon products (e.g., light and/or middle distillate). As such, benzene is used as a qualitative-level proxy for the fate and transport assessment of these substances in this report. Where these substances are present as co-contaminants along the AOI 4 property boundary and may pose potential risk to offsite receptors, they will be further evaluated during quantitative fate and transport model simulations and documented under future Act 2 submission(s).

- MTBE, naphthalene, and bis(2-ethylhexyl)phthalate demonstrated the highest number of exceedances in AOI 4 in recent years (2014- 2016), following benzene, 1,2,4-TMB, ethylbenzene, and toluene. The remaining COCs identified at concentrations above the MSC in unconfined aquifer groundwater during 2014-2016 sampling were generally only observed in a few AOI 4 well samples.

Within AOI 4, no significant spatial distribution of these constituents was observed. Most of these compounds are generally less soluble in groundwater than benzene or MTBE. Where these substances are present as co-contaminants along the AOI 4 property boundary and may pose potential risk to offsite receptors, they will be further evaluated during quantitative fate and transport model simulations and documented under future Act 2 submission(s).

- The most elevated concentrations of benzene and MTBE in unconfined aquifer groundwater generally correlate to locations beneath free-phase LNAPL or presumed areas of residual LNAPL that is trapped within a "smear zone" beneath AOI 4.

- Concentration trends generally support that dissolved benzene and MTBE in groundwater have stabilized onsite, except for observations from a portion of wells in the Penrose System that indicate a stable to increasing trend. Recent product releases have occurred in this area and may be complicating the apparent benzene trend. Recent observations of significant MTBE concentrations in groundwater at the Penrose System where not previously observed may be attributable to a historic, onsite source that may have been mobilized in association with recent (post-2015) pipeline excavations and repair in the area.

- MSC exceedances of lead in unconfined aquifer groundwater over the period of record have been very limited, and show no pattern of spatial distribution. In 2016, lead was only detected in three wells; S-218D, S-39D, and S-97.

- Concentrations of benzene and MTBE in lower aquifer groundwater generally do not indicate the presence of any significant, onsite source areas in that aquifer (**Figure 10-7**).

- The PRM lower sand unit was historically developed and heavily pumped for water supply in southeastern Philadelphia. Published water-level/historical well gauging data and aquifer heads modeled by others indicate that heavy groundwater production from the lower sand in the region, primarily during the late 1940s and early 1950s, significantly lowered heads in that (lower) aquifer. Those relic hydraulic conditions may have been the mechanism responsible for present-day COC distributions observed in AOI 4 aquifer groundwater as the regional lowering of heads may have facilitated the downward migration of contaminants.

- Quantitative fate and transport analysis of selected dissolved-phase COCs in, and potentially across, AOI 4 aquifers, including benzene and MTBE, will be performed utilizing a 3-dimensional, steady-state, numerical groundwater flow (MODFLOW) model presently under development.

9.6 FATE AND TRANSPORT OF BENZENE NEAR THE PENROSE SYSTEM

- A predictive analysis of the potential fate and transport of dissolved benzene in unconfined aquifer groundwater near the Penrose System was performed using QD. The "worst case" analysis utilized conservative and site-specific input parameters to evaluate plume lengths and potential offsite impacts. The analysis indicates that dissolved benzene in unconfined aquifer groundwater near the southern AOI 4 boundary has the potential to migrate and/or have migrated offsite. This is based on recent benzene data and analysis of historical benzene contamination trends, and on the assumptions inherent to the QD model (**Appendix L**).

9.7 POTENTIAL MIGRATION PATHWAYS AND SITE RECEPTORS

- AOI 4 occupies approximately 106 acres in the southeast portion of the Point Breeze Refinery South Yard, and access is restricted by fencing and security measures.

- PES is responsible for overall security and oversight of contractor safety, and PES implements PPE and work plan/permitting protocols that mitigate the potential for worker exposure to impacted soil, groundwater, and/or LNAPL through the direct contact pathway.

- AOI 4 areas with identified surface soil exceedances of the SSS for lead have been delineated and remedies will be addressed in future Act 2 submissions, including a Cleanup Plan.

- Concentrations of Evergreen Petroleum Short List COCs identified through indoor and ambient air sampling were below the EPA RSLs with the exception of 1,2,4-TMB in three samples.

- Infiltration of groundwater into underground utilities has the potential to generate vapors along subsurface corridors, or direct vapor migration into the vadose zone. The 26th Street and Penrose Avenue sewers were identified as potential vapor migration (external preferential) pathways for petroleum hydrocarbon sources identified in AOI 4 because they either do not meet the 30 foot horizontal proximity distance from AOI 4 identified groundwater impacts, or are submerged beneath the water table in areas of potential groundwater impacts (do not meet the vertical separation distance). A vapor mitigation system (Point Breeze Biofilter System) is currently in operation in AOI 1 to remove and treat potential vapors from the 26th Street Sewer.

- Other potential vapor receptors were not identified within the proximity distances specified in the PADEP Technical Guidance Manual (PADEP, 2017) that warranted further vapor intrusion evaluation. This includes the potential offsite benzene plume area predicted by conservative QD modeling.

- Areas of potentially mobile LNAPL may be present in AOI 4 and could impact offsite receptors if they were to migrate beyond the AOI 4 boundary. LNAPL areas are continually monitored through well gauging. Operation of the Penrose System is meant to mitigate the potential offsite migration of LNAPL along that boundary. ANT trends support continued operation of the Penrose System.

- Dissolved-phase Evergreen Petroleum Short List COCs, including benzene and MTBE, are present in unconfined aquifer groundwater at concentrations above their respective MSCs within, and in places directly adjacent to AOI 4.

- 2015 vertical head potentials (**Figure 5-8**) between the unconfined and lower aquifers adjacent to AOI 4 indicate that limited groundwater exchange may occur between those aquifers through leakage or, where the potential for connection or penetration along the 26th Street Sewer exists (**Figure 10-1**), direct connection between the aquifers.

- Surface water bodies that intersect the water table are not present in, or directly adjacent to, AOI 4. According to a 2016 well search, the unconfined aquifer is not utilized for municipal or nearby communal, potable water supply in south Philadelphia (**Appendix N**).

- Selected geologic units of the PRM are utilized for water supply in New Jersey. The potential for migration of dissolved-phase Evergreen Petroleum Short List COCs from AOI 4 into, and along, the lower aquifer will be evaluated through use of a PES Complex-wide, 3-dimensional, steady-state, numerical groundwater flow (MODFLOW) model presently under development and will be presented in a separate Act 2 submission to PADEP.

- The 26th Street Sewer, under normal flow conditions or when not at capacity, captures flow from the shallower Packer Avenue/Pollock Street and Penrose Avenue Sewers through intercepting chambers located near AOI 4. All three sewers are constructed of reinforced concrete. The 26th Street Sewer appears to intercept groundwater from the unconfined, and potentially the lower, aquifer(s) to the northeast of AOI 4, based on water-level data (**Figures 5-2** through **5-4**).

- Dissolved-phase Evergreen Petroleum Short List COCs present in groundwater along the AOI 4 boundary, or present in the Penrose Avenue Sewer and the 26th Street Sewer, have the potential to migrate offsite through preferential flow into, or along, the sewer interceptor at locations identified in this report (**Section 10.4.2**). The 26th Street Sewer conveys wastewater to the City of Philadelphia's Southwest Wastewater Treatment Plant and is maintained by PWD. The potential for offsite migration of dissolved-phase COCs from AOI 4 to the PWD sewer interceptor system will be evaluated through interim remedial actions, including the MODFLOW model under development, and will be discussed in a Cleanup Plan or other future submission to PADEP under Act 2.

10.0 FATE AND TRANSPORT ASSESSMENT

This RIR presents a fate and transport assessment that contains both qualitative and quantitative components. The qualitative portion is presented with the goal of broadly identifying subsurface impacts in AOI 4 and vicinity, and was designed in accordance with a September 30, 2015, meeting during which Evergreen's team of consultants and the PADEP collaboratively decided that individual AOI RIR submissions for the PES Complex would include qualitative assessments of contaminant fate and transport. These assessments were to include an evaluation of plume stability, COC trends, and potential impacts to receptors, including surface water. Findings and conclusions of the AOI specific, qualitative assessments of fate and transport will ultimately be used to construct and refine a calibrated, steady-state MODFLOW and transport model (e.g., MT3DMS model) to comprehensively quantify contaminant fate and transport at the PES Complex, including predictive simulations that will address cumulative mass loading to potential receptors.

The following discussion qualitatively summarizes factors that may influence contaminant fate and transport at AOI 4 of the PES Complex, utilizing qualitative assessments of benzene and MTBE as proxies for future quantitative modeling. Additionally, an analytical groundwater fate and transport model is included to estimate the potential fate and transport of dissolved benzene from a source area near the Penrose Avenue Remediation System (**Section 10.10; Appendix L**).

10.1 GEOLOGIC FRAMEWORK

As discussed in detail in **Sections 2** and **5** of this report, the geologic framework present beneath and in close proximity to AOI 4 can be summarized as follows:

- The PES Complex occurs within the up-dip limits of the Atlantic Coastal Plain, generally within two miles of the "Fall Line," where crystalline bedrock of the Appalachian foothills intersects the ground surface (outcrops) (**see Figure 2-1**). The Atlantic Coastal Plain is defined as having relatively flat topography and as being underlain by a characteristic wedge of unconsolidated sediments that thicken in a southeasterly direction atop a sloping bedrock surface.

- Depositional environments for the strata present were complex fluvial, estuarine, and marginal marine environments along the passive Atlantic margin. The resulting sedimentary record is complicated, largely incomplete, and under-represented by only Cretaceous and Quaternary deposits, separated by a regional disconformity (see **Figures 2-5** through **2-8**).

- Coastal Plain deposits observed beneath AOI 4 and in close proximity have been interpreted to include, with increasing depth and age, the following (note geologic unit correlations to observed lithologies have been included for reference purposes only):

    1. *Anthropogenic Fill* (discussed further in **Section 10.4**)
    2. *Recent (Holocene) alluvium*: fine-grained, brown to brownish gray silt/clay with occasional lenses of sand and gravel that commonly grades with depth to include some sand; in places

includes decomposing organic material; thickness ranges from a few feet to a maximum of approximately 17 feet.

3. *Pleistocene "Trenton gravel":* brown and reddish brown silty, clayey, poorly-sorted sand with gravel, including secondary sandy gravel and clay/silt lithologies in lenses; very heterogeneous unit; thickness ranges from approximately 10 to 15 feet.
4. *Cretaceous PRM upper clay unit:* reddish yellow, brown, and brownish yellow clay/silt (commonly sandy and laminated); approximately 1 to 5 feet thick where present beneath AOI 4.
5. *Cretaceous PRM upper sand unit:* light gray to pale yellow, fine to medium-grained quartz sand with a trace to little silt but including muddy lenses; ranges in thickness from approximately 5 to 30 feet.
6. *Cretaceous PRM middle clay unit:* medium to high plasticity gray, red, and white clay/silt with intercalating lenses of muddy sand; may contain lignite; thickness ranges from approximately 5 to 20 feet.
7. *Cretaceous PRM middle sand unit:* brown and reddish yellow, silty, occasionally gravelly sand; ranges in thickness from approximately 10 to 30 feet.
8. *Cretaceous PRM lower clay unit:* generally absent beneath AOI 4; if present could occupy troughs in the lower sand unit as lenses of gray or red/white clay/silt.
9. *Cretaceous PRM lower sand unit:* pale gray, pale yellow, and white quartz sand coarsening with depth to white and varicolored sandy gravel and gravelly sand; common lenses of clayey sand and gravel; thickness ranges from approximately 25 feet to over 50 feet.

- Bedrock is present beneath the Coastal Plain deposits in AOI 4 and consists predominantly of variably-weathered mica schist. The bedrock surface is irregular and contains troughs. Beneath AOI 4, bedrock elevations range from approximately -70 feet NAVD 88 to -135 feet NAVD 88 (see **Figure 2-12**).

10.2 HYDROGEOLOGY

As summarized above and discussed in detail in **Section 5** of this report, the geologic framework present beneath and in close proximity to AOI 4 supports the following hydrogeologic conditions:

- Two aquifers have been identified beneath AOI 4 at the PES Complex. In general, these are the water-table (unconfined) and a lower (semi-confined) aquifer (see **Table 5-1**). Their properties are as follows:

1. *Unconfined aquifer:* primarily composed of saturated portions of the "Trenton gravel" and PRM upper sand unit; includes the upper clay unit aquitard where present; on average, the saturated thickness of the unconfined aquifer is approximately 10 to 35 feet; k_h may vary from approximately 12 ft/d to more than 450 ft/d (see **Figure 2-9**); k_v may approximate 10^{-8} cm/s; the fraction organic carbon may range from approximately 0.5% to nearly 2%; estimates of effective porosity range from approximately 7% to 28%.
2. *Lower aquifer:* semi-confined, artesian aquifer primarily composed of the lower sand but as mapped also includes the middle sand unit and where present, the lower clay unit aquitard;

on average, the saturated thickness of the lower aquifer is approximately 50 to 90 feet; k_h is estimated to vary from approximately 65 ft/d to 85 ft/d (see **Figure 2-10** and **Appendix K**); the fraction organic carbon is estimated at approximately 1%.

- Unconfined aquifer groundwater flows radially under a gentle hydraulic gradient (0.001 to 0.004 ft/ft) beneath most of AOI 4 and appears to subtly mirror natural surface topography (see **Figures 5-2** through **5-4**) that creates a southwest-northeast trending groundwater divide. North of that feature, flow appears to be southeast out of higher topography in AOI 2 and converge near the AOI 1/AOI 2 boundary, and in northern AOI 4, along the location of a former stream. The pattern of unconfined aquifer groundwater flow north and east of AOI 4 suggests that infiltration into the 26th Street Sewer, and potentially the Pollock Street/Packer Avenue Sewer, is occurring and influences flow in the northeastern portion of AOI 4.

- Lower aquifer groundwater flows to the south beneath most of AOI 4 under a hydraulic gradient of approximately 0.006 ft/ft (see **Figures 5-5** and **5-7**). Within the overall southerly groundwater flow regime present across the study area, the lower aquifer potentiometric surface can appear non-uniform and flow may be concentric towards an offsite depression along a portion of 26th Street and the former Passyunk Homes property. Along the northeastern perimeter of AOI 4 and areas to the east the lower aquifer potentiometric surface indicates that groundwater flow direction is to the southeast. Variability in patterns of lower aquifer groundwater flow in the area evaluated may be related to aquifer transmissivities through the referenced bedrock troughs, or, as indicated in Stantec (2016), upward leakage into the 26th Street Sewer or offsite unconfined aquifer.

- Near-continuous water-level monitoring data suggest that seasonal aquifer water-level variability (both aquifers) may be limited to approximately 1 foot (2016 data) (**Figure 5-9**). An earth tide and/or river tide signal is superimposed on both aquifer datasets on a semidiurnal timescale. The amplitude of the tidal signal is approximately 0.05 feet in the unconfined aquifer (well S-218 data) and approximately 0.3 feet in the lower aquifer (well S-218D data).

- The middle clay unit appears to be laterally continuous beneath AOI 4 and create overall hydraulic separation between the unconfined and lower aquifers with a k_v of approximately 6.0×10^{-7} to 7.21×10^{-9} cm/s. The upper clay unit is interpreted to pinch out or have been truncated by erosion beneath areas of AOI 4 and is present primarily in troughs incised into the upper sand. As interpreted the lower clay unit is not mappable beneath AOI 4.

- West of AOI 4 beneath AOIs 6 and 7, the middle clay was incised by erosion through the Schuylkill River valley and has been removed and replaced by Quaternary deposits. North and east of AOI 4 beneath the former Passyunk Homes property, the middle clay unit is interpreted to thin relatively rapidly over a short distance and may have been completely eroded prior to deposition of the upper sand unit near well PH-DW-10 (**Figure 2-8**).

- Across most of the study area (including all well pairs in AOI 4), the hydraulic head potential between observed aquifers was positive (downward) in May 2016 (**Figure 5-8**). However, an area of negative (upward) hydraulic head potential is indicated in southern AOI 1 and along 26th Street. A broad zone of nearly equal hydraulic heads is indicated between these areas, generally along northeastern AOI 4 and at the former DSCP Property near the "breach" area identified by others. Overall the positive hydraulic head potentials beneath AOI 4 support the existence of two aquifers and the continuity of the middle clay. Water-level monitoring data for AOI 4 well pairs shown on **Figure 5-9** indicate that the head potentials between the aquifers are consistent throughout the year.

10.3 HYDROLOGY AND TOPOGRAPHY

- LiDAR data collected in 2010 indicates that present-day topography is relatively flat within AOI 4 and proximity, where land surface elevations generally range from approximately 7 feet to 30 feet NAVD 88 (see **Figure 2-2**). Elevations are lowest where historical maps indicate that a stream once bisected the area. Elevations as high as approximately 60 feet NAVD 88 exist just offsite at the CSX property, where fill was placed to elevate the rail lines and spurs present.

- Within AOI 4, much of the surface area present is impervious or assumed to be of limited permeability (see **Figure 2-3**). Note that some inaccuracies are inherent to the regional land surface model shown on **Figure 2-3**.

- No surface water bodies are present within AOI 4. Just west of AOI 4 in AOI 3, two surface water bodies are present and collectively referred to as the Guard Basin. These two basins collect stormwater conveyance from tank containment areas and appear to have no connection to the water table.

- National Weather Service Online Weather Data (NOWData) for Philadelphia, Pennsylvania, indicates that since 1872, mean annual precipitation is approximately 42 inches (ranging from approximately 29 to 64 inches).

- Stormwater runoff within AOI 4 is managed by a PES Complex storm sewer system, assumed to tie into the deeper PWD sewers that bisect or exist adjacent to the site.

- Natural recharge of the unconfined aquifer beneath AOI 4 and proximity is assumed to be spatially variable but limited in overall capacity because of the high percentage of impervious surface coverage present and the fine-grained nature and geographic extent of recent alluvial deposits that exist in most places above the water table. Water-level monitoring data collected through 2016 in AOI 4 supports that recharge to the water table is limited and results in minimal seasonal variability (see **Figure 5-9**).

10.4 ANTHROPOGENIC FEATURES

10.4.1 Historic Fill

Anthropogenic fill is present beneath the existing land surface at most locations in AOI 4 and has been identified to range in thickness from a thin veneer to a maximum of approximately 10 feet. The thickest fill generally correlates with and is reflective of the location of a former incised stream valley that once bisected AOI 4. The fill is generally heterogeneous in nature and is composed of an admixture of sand and gravel, mud, and anthropogenic debris including bricks and other construction debris.

10.4.2 Sewers

Numerous storm sewers exist beneath AOI 4. The primary function of the existing PES Complex storm sewer system is to collect and convey surface runoff derived from precipitation. A portion of storm water is collected from within tank berm areas and managed onsite in sediment ponds (AOI 3). The remainder of surface runoff is presumed to ultimately sheet flow offsite, or drain through shallow sewer conveyance to the Pollock Street, Penrose Avenue, and/or 26th Street Sewers, or the Schuylkill River by means of the Pollock Street and Penrose Avenue Sewers.

Additional details of the deeper sewers adjacent to AOI 4 are provided below. Because these sewers collect stormwater from shallower onsite (and offsite) sewers and generally intersect or are submerged beneath the water table, they are evaluated as potential contaminant migration pathways in this report.

10.4.2.1 Penrose Avenue Sewer

Stantec obtained the following two drawings from the PWD through a Pennsylvania One Call in 2017:

- Sewers, Intercepting Chamber and Appurtenant Work in Penrose Avenue, Railroad Property and City Property from 725' +/- W. of W.H.L. of 26th Street to Pattison Ave., and in Pattison Ave. from Penrose Ave. to 20th St., City of Philadelphia Water Department Return Plan, Work No. S-2810-A, Sheet 1 of 3, dated 2/18/1964
- Penrose Avenue Sewer, Sheet No. 2 of 2 (undated plan)

Stantec has concluded the following regarding the Penrose Avenue Sewer based on review of the referenced as-built drawings:

- The portion of the sewer adjacent to AOI 4 was constructed in 1962.
- The sewer is generally located beneath the southern right-of-way of Penrose Avenue. Currently, the sewer extends west from Pattison Avenue and continues to the Schuylkill River.
- The sewer's construction varies from Pattison Avenue west where it begins as twin reinforced concrete box culverts that are 7 feet by 7.5 feet (V-Bottom). These tie into a concrete flare that connects them to a 10.5 foot diameter concrete sewer (constructed in a tunnel) that passes beneath the elevated railroad over Penrose Avenue. On the west side of the railroad overpass, the sewer ties into a flared end that connects it to another section of twin 7 foot by 7.5 foot reinforced concrete box culverts (V-Bottom). These continue west and enter an Intercepting Chamber on the southwest corner of Penrose Avenue and 26th Street, and exit out of the chamber as dual 7 foot by 9 foot and 7 foot by 6 foot reinforced concrete culverts (flat bottom) that continue west until approximately Lanier Avenue, where only the 7 foot by 9 foot culvert continues west toward the Schuylkill River.
- The sewer was designed to flow west along a grade of approximately 0.05 feet per 100 feet of pipe.
- Inverts indicate that sewer bottom elevations range from approximately -5 feet to -7 feet (undisclosed elevation datum). These elevations generally correspond to present depths below ground surface of greater than approximately 15 feet (for details see discussion in **Appendix L**).

- The concrete sewer appears to have been constructed in open excavations and formed/cured in-place except for the section beneath the elevated rail line, indicated to have been tunneled.
- The sewer connects to the beginning of the 26th Street Sewer through the Intercepting Chamber at 26th Street and Penrose Avenue. The chamber contains a tide dam.

10.4.2.2 26th Street Intercepting Sewer

Stantec obtained the following drawing from the PWD through a Pennsylvania One Call in 2017:

- Intercepting Sewer in 26th Street from Penrose Ave. Sta. 141+90.95 North to Sta. 122+55.50, Lower Schuylkill East Side Intercepting System, City of Philadelphia Water Department, Work No. SD-273-SW, signed 11/18/1965

Stantec (2016) included additional drawings of the 26th Street Sewer (sewer) and has concluded the following based on review of past consultant reports, internet-based concrete pipe information, and the referenced as-built drawings:

- The sewer was constructed circa 1963.
- The sewer is located along the western side of 26th Street, approximately 3 feet to 40 feet east of the AOI 1 boundary/fence line (distance varies along centerline of pipe run).
- The sewer is constructed of vacuum-processed (a process by which excess water and air is removed from the surface of wet concrete by vacuum for the purpose of compacting the concrete, increasing its strength, lowering its permeability and increasing resistance to high-velocity liquid flow), reinforced concrete pipe that increases in diameter from 3 feet to 4 feet along the AOI 4 boundary, from just south of Hartranft Street to former Shunk Street.
- The sewer flows to the north along a grade of 0.195 feet per 100 feet of pipe in the AOI 4 area. The sewer begins at Penrose Avenue where it drops from an Intercepting Chamber in the Penrose Avenue Sewer that allows the sewer to capture gravity flow when not at capacity.
- The sewer appears to have been constructed in both tunnels and open cut excavations.
- Inverts indicate that sewer elevations range from -8.57 feet at the northwest corner of Penrose Avenue and 26th Street to -12.29 feet just south of Hartranft Street (assumed to be referenced to the National Geodetic Vertical Datum of 1929).
- Individual sewer pipe segments are approximately 8 feet to 10 feet long (based on the plan scale). It is assumed that the pipe joints consist of bell ends that were slipped together in the tunnel. The annular space surrounding the sewer pipe was then backfilled with concrete grout (plan indicated 1,500 pounds per square inch [psi]; one-part cement to three parts sand) placed under pressure.
- Test boring data provided on the plan set along AOI 1 is stratigraphically consistent with the framework presented in the AOI 1 RIR and includes: a surficial layer of apparent fill that is thickest within a filled stream valley; muddy, recent alluvial deposits; stratified alluvium consisting of brown sand and gravel/cobbles/boulders with clayey lenses ("Trenton gravel"); hardpans; and red to brown, fine sand, gravel, and sandy silt of the apparent PRM aquifer system (Stantec, 2016).

10.4.3 Active Remediation Systems

Within AOI 4, the Penrose Avenue Remediation System (Penrose System) is the only active remediation system at the time of this RIR (**Figure 1-2**). **Appendix F** provides a detailed discussion of the Penrose System. System design, operation, and totalized fluid recovery can be summarized as follows:

Penrose Avenue Remediation System

- The Penrose Avenue Remediation System is a total fluids remediation system that was originally designed to provide hydraulic control of hydrocarbon impacts resulting from historic petroleum refining operations. The system is located at the southeast AOI 4 boundary.
- Construction of the Penrose System began in December 2011 with the installation of 18 recovery wells (RW-700 through RW-717). Two wells were not piped into the remediation system, RW-707 and RW-710. The operation of the system started on March 20, 2013 and the system is currently active.
- Currently, RW-700, RW-701, RW-702, RW-703, RW-704, RW-708 and RW-714 are pumping. The remaining recovery wells have been disabled due to a lack of recoverable LNAPL at those locations.
- Total fluids (groundwater and LNAPL) are extracted from the recovery wells by top loading pneumatic submersible pumps supplied by compressed air from the PES Complex.
- Total fluids are conveyed through underground piping to avoid seasonal temperature issues and are processed through an oil/water separator and a settling tank within the treatment trailer. Water is discharged to the Philadelphia Water Department sanitary sewer. Recovered LNAPL is stored in a holding tank that is periodically pumped out and recycled by the PES Complex. A biofilter and carbon vessels are used to control odors and vapor emissions.
- Since its inception, the Penrose System has recovered approximately 16 million gallons of groundwater and approximately 2,900 gallons of LNAPL (through March 2017).

10.4.4 Inactive Remediation Systems

In AOI 4, there are 2 inactive remediation systems: S-30 Remediation System (S-30 System) and the S-36 Remediation System (S-36 System). **Appendix F** provides a description of each system. System design, operation, and totalized fluid recovery can be summarized as follows:

S-30 Remediation System

- The system, which was designed to recover LNAPL, was started on January 15, 1996.
- The system consisted of a LNAPL recovery pump installed in monitoring well S-30.
- The system operation ceased on December 30, 2010.
- During its lifetime, the S-30 System recovered approximately 39,650 gallons of LNAPL.
- Due to accumulation of LNAPL in S-30, a new pump, probe, and control panel are planned for installation in 2017.

S-36 Remediation System

- The system, which was designed to recover LNAPL, was started on September 15, 2004.

- The system originally consisted of a LNAPL recovery pump installed in monitoring well S-36. In October 2007, LNAPL recovery pumps were added in monitoring wells S-34 and S-35.
- The system was taken off-line July 28, 2010 due to the absence of recoverable LNAPL.
- The lifetime recovery totals for the system were 1,025 gallons of LNAPL.

10.5 GROUNDWATER CONSTITUENTS OF CONCERN

10.5.1 Unconfined (Water-Table) Aquifer

Concentrations of the following Evergreen Comprehensive List COCs were detected above the MSC in unconfined aquifer groundwater during the 2016 characterization sampling events (see **Table 4-2**): 1,2,4-TMB, EDB, 2-methylnaphthalene, anthracene, benzene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, bis(2-ethylhexyl)phthalate, chrysene, ethylbenzene, MTBE, naphthalene, phenanthrene, pyrene, toluene, vanadium, and zinc.

Available historical analytical data from previous groundwater sampling events were reviewed by Stantec. That data indicates the following additional Evergreen Comprehensive List COCs were identified at concentrations in excess of the current SHS during past AOI 4 unconfined aquifer groundwater sampling: benzo(b)flouranthene, cobalt, indeno(1,2,3-c,d)pyrene, lead, and total xylenes. It should be noted that exceedances of arsenic and chromium, which are not part of the Evergreen Comprehensive List, have been observed over the period of record.

10.5.2 Lower Aquifer

Concentrations of the following COCs were detected above the SHS in lower aquifer groundwater during 2016 characterization sampling events (see **Table 4-3**): benzene, MTBE, and lead.

Available historical analytical data from previous groundwater sampling events was reviewed by Stantec. That data indicates that no additional Evergreen Comprehensive List COCs were identified at concentrations in excess of the current SHS during past AOI 4 lower aquifer groundwater sampling; however, historical arsenic exceedances were noted.

10.6 BENZENE AND MTBE GROUNDWATER PLUME LOCATIONS

For purposes of the qualitative component of AOI 4 contaminant fate and transport, Stantec evaluated available analytical data from Evergreen's electronic database for the three most comprehensive groundwater analytical data sets, assembled from events conducted in 2004/2005, 2012/2013, and 2014/2016 to identify the general locations of areas where elevated COC concentrations (plumes) may be present in unconfined aquifer groundwater. Data from offsite wells at the Steen, ARCO, and former DSCP properties were incorporated to better characterize dissolved COC plumes across AOI 4 boundaries. Offsite datasets from the 2004-2005 timeframe did not include key wells, therefore, a 2007 dataset was supplemented. Of the Evergreen List COCs identified to be present in groundwater in both aquifers beneath AOI 4, benzene and MTBE were chosen as the primary COCs for this discussion. These two COCs were chosen as qualitative-level proxies for other contaminants evaluated because of their higher water solubility and potential to be mobile or migrate in the aquifers, and/or due to their general persistence in groundwater at and near the PES Complex. Other COCs identified in groundwater are discussed below (**Section 10-8**) in the context of benzene and MTBE distributions.

Figures 10-1 through **10-6** present benzene and MTBE concentration plots for the referenced sampling events in the unconfined aquifer. To create the contoured data plots, Stantec selected the maximum concentration (where data for more than one groundwater sample was available per stated time period) of each of the COCs for AOIs 1, 2, 3, and 4. That concentration data was interpolated using the point Kriging gridding method, contoured using a logarithmic scale, and cropped to the extents shown with the overall goal of identifying AOI 4-specific groundwater source areas while utilizing peripheral data (AOIs 1, 2, 3, and offsite) where available. Grid classifications were normalized for all plots (see color scales), with the exception of the lower concentration limit where the MSC was used for each COC (i.e., 5 µg/L for benzene and 20 µg/L for MTBE).

Based on available data, the following dissolved plumes were identified in recent years (2014-2016):

- Three general areas of elevated benzene concentration (dissolved plume cores) have been characterized: in the northeast corner of AOI 4 generally delineated by wells S-369, S-40, S-119, S-368, and AOI 1 well S-95; in the western and central portion of AOI 4, centered around wells S-415 and S-218 and generally delineated by wells within AOI 4; and in the south-central portion of AOI 4 near the PES Complex boundary, generally delineated by AOI 4 well data.
- Except for a few isolated exceedances, elevated MTBE concentrations are limited in time and extent to the Penrose System area (south central AOI 4 in association with the benzene plume) during the recent (2014-2016) timeframe.

Figure 10-7 displays available historic groundwater analytical data for the lower aquifer wells, including benzene and MTBE (interpolation was not warranted due to limited spatial data availability for that aquifer). Although no discernible plume areas are apparent in the lower aquifer data, slightly elevated concentrations of benzene, MTBE, and lead are indicated to be present or have historically been present at times beneath AOI 4.

10.7 BENZENE AND MTBE GROUNDWATER PLUME STABILITY ASSESSMENT

To qualitatively assess the stability of the identified unconfined aquifer groundwater plumes, Stantec utilized the referenced concentration plots to evaluate overall plume size and COC concentration trends through the last decade. In addition, COC concentration trend plots were created for selected wells with historical data that are located near plumes (to evaluate trends), and at locations downgradient of the plume cores (to evaluate potential mobility of dissolved-phase plumes with emphasis near the property boundary) (see **Figures 10-8** through **10-12**).

The following conclusions can be made based on this qualitative assessment of benzene and MTBE.

<u>Eastern AOI 4 Boundary</u>

- Benzene concentrations along the eastern AOI 4 boundary (S-38, S-39, S-40, S-120, and S-122) have been decreasing or non-detect over the period of record (**Figure 10-8**). An exception to this is the area in the northeast corner of AOI 4 near well S-369. Data availability is limited for this well however an increasing trend may be concluded. Based on present-day groundwater flow patterns, the apparent trend may be attributable to migration from AOI 4, AOI 1, and or offsite source (convergent flow).

- MTBE has not been detected along the eastern AOI 4 boundary over the period of record.

Central Portion of AOI 4

- Very limited groundwater analytical data is available for wells located in the western portion of AOI 4. However, for wells with more than two data points over the period of record (such as S-225, S-216, S-218, S-219, S-97, S-28), stable and/or decreasing trends are discernable for benzene and MTBE (**Figure 10-9**). This is indicative of a decaying source from past historic releases in this area.

Penrose System Area

- Benzene concentrations in the recovery wells of the Penrose System show variability based on their location: recovery wells (RWs) located along the northern leg of the system show a slightly increasing trend (RW-700 through 704); whereas, RWs located on the southern leg of the system (RW-705 through 717, except for RW-706 and RW-708) generally show a stable or decreasing trend (**Figures 10-10 and 10-11).** MTBE distribution is similar to benzene distribution, where detections (and MSC exceedances) are limited to RWs 700 through 704. However, MTBE data in this area is only available for the 2010 and 2016 years, and therefore, long term trend analysis is not possible for MTBE. Although a detailed MTBE analysis is not feasible at this time, it is noted that significant increases in MTBE concentration are apparent near the northern leg of actively pumping remediation wells.
- Limited groundwater data for the wells downgradient of the northern leg of the Penrose System (S-124 and S-235) are available over the period of record; however, an increasing trend similar to the northern RWs can be discerned. Benzene concentrations in the downgradient wells of the southern leg of the Penrose System (S-222, S-223, S-224, S-239, and S-243) indicate a generally stable to decreasing trend since 2004 (**Figure 10-12**). MTBE has been non-detect in these wells over the period of record.
- Benzene and MTBE concentrations in the periphery wells of the Penrose System (S-329, S-242, S-245, S-246) are mainly from the 2016 characterization sampling rounds, and therefore, a long-term trend analysis is not feasible at this time.
- No data is available from various upgradient wells in the Penrose System (such as S-240, S-241, S-236, and S-221) due to the historical presence of NAPL in these wells.

10.8 OTHER GROUNDWATER CONSTITUENTS OF CONCERN

Additional Evergreen COCs (co-contaminants) present above the MSCs in AOI 4 groundwater were generally found to be distributed in patterns that mirror or are localized to the benzene and/or MTBE plumes, or have no discernable pattern based on the monitoring well network available (a few scattered well exceedances). As summarized in **Section 9.5** of this report, the following can be qualitatively stated regarding groundwater COCs in AOI 4:

- Recent (2014-2016) distributions of dissolved-phase 1,2,4-TMB, ethylbenzene, and toluene in unconfined aquifer groundwater generally resemble that identified for benzene at AOI 4, and have demonstrated the highest number of exceedances following benzene. The distribution of these substances in groundwater also suggests that they were released in the same areas as benzene and were likely components of the same petroleum hydrocarbon products (e.g., light and middle distillates). As such, benzene is used as a qualitative-level proxy for the fate and transport assessment of these substances in this report. Where these substances are present as co-contaminants along the AOI 4 property boundary and may pose potential risk to offsite receptors, they will be further evaluated during quantitative fate and transport model simulations and documented under future Act 2 submission(s).

- MTBE, naphthalene, and bis(2-ethylhexyl)phthalate demonstrated the highest number of exceedances in AOI 4 in recent years (2014- 2016), following benzene, 1,2,4-TMB, ethylbenzene, and toluene. The remaining COCs identified at concentrations above the MSC in unconfined aquifer groundwater during 2014-2016 sampling were generally only observed in a few AOI 4 well samples. Within AOI 4, no significant spatial distribution of these constituents was observed. Most of these compounds are generally less soluble in groundwater than benzene or MTBE. Where these substances are present as co-contaminants along the AOI 4 property boundary and may pose potential risk to offsite receptors, they will be further evaluated during quantitative fate and transport model simulations and documented under future Act 2 submission(s).

- MSC exceedances of lead in unconfined aquifer groundwater over the period of record have been very limited, and show no pattern of spatial distribution. In 2016, lead was only detected in groundwater sampled from three wells; S-218D (lower aquifer), S-39D (lower aquifer), and S-97 (unconfined aquifer).

10.9 POTENTIAL ONSITE AND OFFSITE RECEPTORS

Based on the identified impacts to groundwater at AOI 4, Stantec has evaluated the following as potential receptors.

- Vapor intrusion effecting potential occupants of buildings in AOI 4 located above groundwater plumes and/or areas of LNAPL was evaluated. The only occupied building in AOI 4 based on communication with PES is the 15 Pump House Building. Indoor air and ambient air were sampled as a part of site characterization activities and identified concentrations of Evergreen Petroleum Short List COCs below the EPA RSLs, with the exception of 1,2,4-TMB.
- Infiltration of groundwater into underground utilities has the potential to generate vapors along subsurface corridors, or direct vapor migration into the vadose zone. The 26th Street and Penrose Avenue sewers were identified as potential vapor migration (external preferential) pathways for petroleum hydrocarbon sources identified in AOI 4 because they either do not meet the 30 foot horizontal proximity distance from AOI 4 identified groundwater impacts, or are submerged beneath the water table in areas of potential groundwater impacts (do not meet the vertical separation distance). A vapor mitigation system (Point Breeze Biofilter System) is currently in operation in AOI 1 to remove and treat potential vapors from the 26th Street Sewer.

- Other potential vapor receptors were not identified within the proximity distances specified in the PADEP Technical Guidance Manual (PADEP, 2017) that warranted further vapor intrusion evaluation. This includes the potential offsite benzene plume area predicted by conservative QD modeling (see below).
- Unconfined and lower aquifer groundwater appears to be infiltrating the 26th Street Sewer. There is no available data that demonstrates groundwater infiltration into the Penrose Avenue Sewer. When capacity exists (dry-season flow), the 26th Street Sewer is designed to intercept flow from the Penrose Avenue Sewer and Pollock Street/Packer Avenue Sewer and convey the combined sewage to the PWD's Southwest Regional Treatment Plant.
- The Schuylkill River is distal to AOI 4 but could receive AOI 4 impacted groundwater by way of infiltration to sewers that collect AOI 4 drainage, particularly during storm flows when the 26th Street Sewer is at or near capacity and sewer flows are directed towards the river (e.g., Penrose Avenue Sewer).
- A Complex-wide (including a one-mile buffer) well search of PaGWIS records was performed by Langan in 2016 (**Appendix N**). A subset of those records, located within one mile of the AOI 4 boundary, was selected by Stantec and is presented on **Table 10-1**. The data indicates that no known potable water supply wells exist at or in close proximity to AOI 4 (one domestic well was identified in the Grays Ferry area, up-gradient of AOI 4). Most identified records are for monitoring or recovery wells at the PES Complex, or monitoring wells installed by others for nearby PADEP facilities (some previously abandoned).
- The PRM aquifer system is utilized for water supply in New Jersey. The aquifers of that system, chiefly the lower sand unit, can receive recharge via vertical leakage through confining units and direct recharge from younger deposits along their subcrop area in south Philadelphia. Groundwater COCs, such as benzene and MTBE, present in the lower aquifer beneath AOI 4 have the potential to migrate offsite.

10.10 FATE AND TRANSPORT ANALYSIS FOR BENZENE USING QD

An analysis of the potential fate and transport of benzene in unconfined aquifer groundwater near the Penrose System is presented in **Appendix L**. The analysis was performed using the Quick Domenico (QD) groundwater fate and transport model spreadsheet developed by the PADEP, in general accordance with the User's Manual for the Quick Domenico Groundwater Fate and Transport Model (PADEP, 2014) and Pennsylvania's Land Recycling Program Technical Guidance Manual Section IV.A.2 (Fate and Transport Analysis) (PADEP, 2002). Goals of the analysis are as follows: to utilize an analytical groundwater model and recent characterization data to build upon previous findings by Langan (2013) and the qualitative fate and transport assessment presented in this RIR; to address PADEP comments provided in response to the Langan (2013) QD models in a letter dated January 16, 2014 (Report Comments); and to apply a conservative analytical modeling approach to reasonably predict a "worst case" dissolved benzene plume length so that the possible extent of offsite impacts in the Penrose System area can be delineated. Results of the QD modeling, discussed in **Section 9.6** and **Section 13.2.1,** indicate that benzene has the potential to migrate and/or have migrated offsite. The possible extent of offsite benzene migration in groundwater is predicted to impact offsite properties, and those properties are identified.

10.11 PLANS FOR COMPREHENSIVE FATE AND TRANSPORT ANALYSIS

Stantec is presently developing a groundwater flow model, using the USGS MODFLOW2000 computer code and Groundwater Vistas software. The MT3DMS contaminant transport module will be utilized to comprehensively simulate predictive scenarios of the fate and transport of selected COCs in groundwater. The modeling is being performed to assist in the process of attainment of a remediation standard under Act 2, Pennsylvania's Land Recycling Program. Under Act 2 and in consideration of the One Cleanup Program, an analysis of the fate and transport of petroleum-related constituents is needed, in general, to assess risk to potential receptors, assess plume stability, assist in selection of remedial alternatives, and estimate time to project closure.

The model will focus on groundwater movement within the Coastal Plain of south Philadelphia, Pennsylvania, near the PES Complex. The model domain was adopted from an earlier USGS model developed by Schreffler (2001), later updated by Sloto (2012), and has been updated by Stantec to more-closely simulate site-specific groundwater flow conditions beneath the PES Complex. Updates to the Schreffler (2001) model have included model layer refinement, grid discretization, updates to the model layer hydraulic properties using site-specific testing data, and the inclusion of drains to simulate water withdrawals near the PES Complex. It is anticipated that updates to the model will be completed by the summer of 2017, and that the model and preliminary fate and transport modeling results will be presented to the PADEP. Evergreen also anticipates that a fate and transport assessment based on the numerical modeling results will be submitted to PADEP under a separate Act 2 submission.

11.0 ECOLOGICAL ASSESSMENT

The majority of AOI 4 is covered with soil, gravel, and impervious surfaces. The soil and gravel-covered portions of AOI 4 are not likely to serve as a breeding area, migratory stopover, or primary habitat for wildlife. On October 31, 2016, a survey of endangered, threatened, and special concern wildlife and habitat was conducted by submitting a search request through the Pennsylvania Natural Diversity Inventory (PNDI) Environmental Review Tool. The results of the PNDI search identified no known impacts by the Pennsylvania Game Commission and the U.S. Fish and Wildlife Service.

The PNDI search identified potential endangered species impacts that required further review by the Pennsylvania Department of Conservation and Natural Resources (PA DCNR) and the Pennsylvania Fish and Boat Commission (PA FBC). No effect letter requests were submitted to PA DCNR and PA FBC on October 31, 2016. A response was received from the PA DCNR on November 8, 2016, and from the PA FBC on November 28, 2016 indicating that no impact is anticipated to the species of special concern. All ecological assessment documentation is included in **Appendix H**.

12.0 COMMUNITY RELATIONS ACTIVITIES

A Community Relation Plan (CRP) that includes public involvement with local residents to inform them of the anticipated investigations and remediation activities was completed as part of the original NIR submittal in 2006. A revised NIR was submitted in 2014. The purpose of the CRP is to provide a mechanism for the community, government officials, and other interested or affected citizens to be informed of onsite activities related to the investigation activities at the Site. This plan incorporates aspects of public involvement under both PADEP's Act 2 program and EPA's RCRA Corrective Action program. This report and future Act 2 reports will include the appropriate municipal and public notices in accordance with the provisions of Act 2. Notices will be published in the Pennsylvania Bulletin and a summary of the notice will appear in a local newspaper. As part of the CRP, Sunoco held an initial public meeting in the City of Philadelphia to present the strategy and give status updates of the project at the CRP meeting on an as requested basis. A copy of the original NIR, the 2014 NIR, and the Act 2 report notifications for this RIR are included in **Appendix A**.

13.0 CONCLUSIONS AND RECOMMENDATIONS

Stantec has prepared this RIR for AOI 4 of the PES Complex to satisfy the requirements under Act 2, as specified under 25 PA Code §250.408 (Remedial Investigation Report). The documented investigation activities were performed in general accordance with a 2011 revised Work Plan for Site Wide Approach, and were conducted in support of Evergreen's commitment to remediate legacy environmental impacts that existed at the PES Complex prior to its conveyance to PES in 2012 (Buyer-Seller Agreement). In support of those stated objectives, this RIR has described a comprehensive evaluation of available historical data pertaining to AOI 4, and has documented a remedial investigation strategy that included the collection of a significant amount of additional subsurface information in the time since previous AOI 4 Act 2 deliverables were submitted to the PADEP. Investigations performed as a part of this report also considered and where relevant, sought to address PADEP comments directed towards previous RIR submissions for the overall PES Complex.

The following summarizes Stantec's conclusions and recommendations regarding AOI 4.

13.1 SOIL

Lead was identified in AOI 4 surface soil samples at concentrations higher than the SSS for lead. Where identified in surface soil to exceed the SSS, lead has been delineated both horizontally and vertically through characterization activities and review of existing soil sample analytical data. Concentrations of COCs in all other collected soil samples (including subsurface soil) were below the highest of the SHS, the non-residential direct contact MSC, or the numeric lead SSS.

Soil from locations with lead SSS exceedances will require further pathway evaluation or a remedial measure in order to attain a standard under Act 2. It is noted that although preliminary, Stantec has observed some correlation between the locations of lead exceedances in surface soil and the occurrence of (presumably smelter) slag and cinders in areas of historic fill onsite. Metals contained within those fill materials are commonly encountered in the Philadelphia area and are generally presumed to be chemically inert under average geochemical conditions.

13.2 GROUNDWATER

13.2.1 Unconfined (Water-Table) Aquifer

Concentrations of the following Evergreen Comprehensive List COCs were detected above the MSC in unconfined aquifer groundwater during the 2016 characterization sampling events: 1,2,4-TMB, EDB, 2-methylnaphthalene, anthracene, arsenic, benzene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, bis(2-ethylhexyl)phthalate, chrysene, ethylbenzene, MTBE, naphthalene, phenanthrene, pyrene, toluene, vanadium, and zinc. Historical data indicates that in addition to those substances, arsenic, benzo(b)flouranthene, chromium, cobalt, indeno(1,2,3-c,d)pyrene, lead, and total xylenes have also previously exceeded the current MSC in that aquifer beneath AOI 4.

The unconfined aquifer beneath AOI 4 includes the "Trenton gravel," PRM upper clay unit aquitard (where present) and PRM upper sand unit. Unconfined aquifer groundwater flows radially under a gentle hydraulic gradient (0.001 to 0.004 ft/ft) beneath most of AOI 4 and appears to subtly mirror natural surface topography that creates a southwest-northeast trending groundwater divide. North of that feature, flow appears to be southeast out of higher topography in AOI 2 and converge near the AOI 1/AOI 2/AOI 4 boundary along the location of a former stream. The pattern of unconfined aquifer groundwater flow north and east of AOI 4 suggests that infiltration into the 26th Street Sewer, and potentially the Pollock Street/Packer Avenue Sewer, is occurring and influences flow in the northeastern portion of AOI 4.

A qualitative assessment of the potential fate and transport of benzene and MTBE in AOI 4 unconfined aquifer groundwater was performed as a proxy for future quantitative analyses of those and potentially other compounds. The qualitative assessment has indicated the following.

- Three general areas of elevated benzene concentration (dissolved plume cores) have been characterized: in the northeast corner of AOI 4 generally delineated by wells S-369, S-40, S-119, S-368, and AOI 1 well S-95; in the western and central portion of AOI 4, centered around wells S-415 and S-218 and generally delineated by wells within AOI 4; and in the south-central portion of AOI 4 at the Penrose System, generally delineated by AOI 4 well data.
- Except for a few isolated exceedances, elevated MTBE concentrations are limited in time and extent to the Penrose System area (south central AOI 4 in association with the benzene plume) in recent (2014-2016) times.
- Except for the Penrose System area plume identified, AOI 4 groundwater plume areas for benzene exhibit stable to decreasing trends based on historical data from as much as 13 years where available.
- Dissolved benzene located in central and western portions of AOI 4 may be correlated to overlying LNAPL plumes delineated in those areas in this RIR. Dissolved benzene in the northeastern corner of AOI 4 does not appear to be associated with an overlying or nearby, significant LNAPL source.
- Recent observations of significant MTBE concentrations in groundwater at the Penrose System were evaluated and may be attributable to a historic, onsite source that may have been mobilized in association with recent (post-2015) pipeline excavations and repair in the area.
- Recent (post-2015) product releases in the Penrose System area may be the causal factor for the increasing benzene concentration trend on the northern (upgradient) side of the Penrose System wells. Groundwater extraction at the Penrose System since 2013 may be partly responsible for the decreasing benzene trend observed at the southern AOI 4 boundary.
- Elevated benzene concentrations are present along the northeastern AOI 4 boundary near Hartranft Street. Based on proximity to the property boundary and nearby influence of the 26th Street Sewer, dissolved benzene may be migrating offsite by means of the sewer.
- Offsite benzene and MTBE contamination present to the northeast of AOI 4 beyond 26th Street may be the result of historical LNAPL or dissolved-phase migration from AOI 1/AOI 4 or other, nearby sites with documented or undocumented releases of petroleum hydrocarbons.

A predictive analysis of the potential fate and transport of dissolved benzene in unconfined aquifer groundwater near the Penrose System was performed using QD. The "worst case" analysis utilized conservative and site-specific input parameters to evaluate benzene plume lengths and delineate potential offsite impacts in that area where efforts to install delineation wells have been unsuccessful. The analysis indicates that dissolved benzene in unconfined aquifer groundwater near the southern AOI 4 boundary has the potential to migrate and/or have migrated offsite. This is based on recent benzene data and analysis of historical benzene concentrations in the area, and on the assumptions inherent to the QD model. Offsite properties within the modeled benzene plume area have been identified, and the Penrose sewer has been identified as a potential receptor of impacted groundwater, although available groundwater data does not suggest that the Penrose sewer may be leaking (infiltrating groundwater).

Evergreen COCs in addition to benzene and MTBE are present in AOI 4 unconfined aquifer groundwater at concentrations above the SHS. Most of these COCs (e.g., dissolved-phase 1,2,4-TMB, ethylbenzene, and toluene) appear to be spatially-associated with the locations of benzene and/or MTBE and were likely released in the same general area(s) as components of the same petroleum hydrocarbon products, such as leaded gasoline. Other COCs, such as naphthalene and bis(2-ethylhexyl)phthalate exhibit no significant spatial distribution in unconfined aquifer groundwater at concentrations above the MSCs. In general, most of these compounds are less soluble in groundwater than benzene or MTBE. Other related compounds (e.g., lead alkyls) or COCs (e.g., EDB and EDC) have a tendency to biodegrade or degrade into less soluble end products that adsorb to soil. As such, these additional dissolved-phase constituents are considered delineated to the extent of the benzene and MTBE plumes presented in this report. Where present at the AOI 4 property boundary, these COCs may be further evaluated during future quantitative fate and transport model simulations and documented under Act 2 submission, particularly where benzene and/or MTBE are found to pose potential risk to offsite receptors such as the 26^{th} Street and Penrose Avenue Sewers.

Stantec recommends continued operation of the Penrose System to mitigate the potential for offsite migration of dissolved-phase COCs along the AOI 4 boundary in that area, in addition to continued groundwater and LNAPL monitoring at the AOI 4 points of compliance. As a part of Cleanup Plan activities, the Penrose System should be evaluated for performance improvements and capture zone delineation. Alternative remedial technology screening and LNAPL mobility/recoverability testing should also be considered. Offsite unconfined aquifer groundwater along the northeastern AOI 4 boundary (former ARCO Property) should be continually monitored for potential migration of COCs beyond the 26th Street Sewer through the analysis of contaminant trend data. It is noted that existing, offsite groundwater contamination in the unconfined aquifer in this area may be the result of other, nearby sites with documented or undocumented releases of petroleum hydrocarbons. The groundwater contamination may have been distributed by means of past aquifer hydraulic conditions/flow patterns created by regional groundwater pumping.

A comprehensive evaluation of the fate and transport of selected COCs dissolved in groundwater at the PES Complex is being performed using a numerical groundwater flow (MODFLOW) model that is more well-suited to the geologically (and anthropogenically) complex environment beneath AOI 4 and proximity. Evergreen anticipates that the model will also be used to aid in optimization of the Penrose and other remediation systems during Cleanup Plan Activities. It is anticipated that Stantec and Evergreen will present the numerical model to the PADEP in the summer of 2017.

13.2.2 Lower Aquifer

Benzene, MTBE, arsenic, and lead were identified in AOI 4 lower aquifer groundwater at concentrations in excess of the MSCs over the period of record. Historical data indicates that no other Evergreen COCs have previously exceeded the current MSCs in that aquifer beneath AOI 4.

The lower aquifer beneath AOI 4 is primarily composed of nearly equal thicknesses of the middle and lower sand units as the lower clay unit appears to be absent in this area. Groundwater flows to the south beneath most of AOI 4 under a hydraulic gradient of approximately 0.006 ft/ft. Within the overall southerly groundwater flow regime present across the area evaluated in this RIR, the lower aquifer potentiometric surface can appear non-uniform and flow may be convergent towards an offsite depression along a portion of 26th Street and the former Passyunk Homes property. Along the northeastern perimeter of AOI 4 and areas to the east the lower aquifer potentiometric surface indicates that groundwater flow direction is to the southeast. Variability in patterns of lower aquifer groundwater flow in the area evaluated may be related to aquifer transmissivities through the referenced bedrock troughs. As indicated in Stantec (2016), these observed patterns of lower aquifer groundwater flow may also be related to upward leakage into the 26th Street Sewer, or into the unconfined aquifer through an offsite hydraulic connection.

A qualitative assessment of the fate and transport of previously detected COCs in AOI 4 lower aquifer groundwater was performed as a proxy for future quantitative analyses. Although detailed analyses were not performed based on lack of spatial and historical data availability in this aquifer, no discernible plume areas are apparent. However, when compared to the SHS, slightly elevated concentrations of benzene, MTBE, and lead are indicated to be present or have historically been present beneath AOI 4. It is noted that the present hydraulic regime at AOI 4 does not support an AOI 4 source for the contamination observed in the lower aquifer and does not support that AOI 4 lower aquifer contamination is presently a source for nearby offsite contamination observed to the north and east. There are other documented sources for petroleum hydrocarbons in the area. It is likely that regional groundwater production from the lower aquifer and possibly construction dewatering for the 26th Street Sewer historically lowered hydraulic heads near AOI 4 and were the mechanism that may have allowed for the downward migration of contamination from the unconfined aquifer into the lower aquifer. This concept would be particularly applicable to areas outside of AOI 4 where the middle clay is absent, or where the middle clay may have been excavated during construction of the 26th Street Sewer interceptor. As such, the Evergreen Petroleum Short List COCs present above the SHS in the lower aquifer beneath AOI 4 are considered characterized for the purposes of this RIR.

The PRM aquifer system is utilized for water supply in New Jersey. The aquifers of that system, chiefly the lower sand unit, can receive recharge via vertical leakage through confining units and direct recharge from younger deposits along their subcrop in the south Philadelphia area. Groundwater COCs, such as benzene and MTBE, present in the lower aquifer beneath AOI 4 have the potential to migrate offsite. As indicated previously for the unconfined aquifer, a MODFLOW model will be utilized during quantitative fate and transport analyses to evaluate that potential based on the COC source areas identified in this and other RIRs at the PES Complex.

13.2.3 Aquifer Discussion

Stantec supports the following conclusions regarding the presence or absence of a hydraulic connection between the unconfined and lower aquifers beneath AOI 4 and proximity.

- The middle clay unit appears to be the sole "clay" unit of the PRM that is laterally continuous beneath AOI 4, and supports overall hydraulic separation between the unconfined and lower aquifers.
- To the west of AOI 4 beneath AOIs 6 and 7, the middle clay was incised by erosion through the Schuylkill River valley and has been removed and replaced by Quaternary deposits. North and east of AOI 4 beneath the former Passyunk Homes property, the middle clay unit is interpreted to thin relatively rapidly over a short distance and may have been completely eroded prior to deposition of the upper sand unit. In this "breach" area as identified by others, it appears that the aquifers defined at AOI 4 may be hydraulically connected through muddy strata of the apparent middle sand unit.
- Across most of the study area, the hydraulic head potential between observed AOI 4 aquifers was positive (downward) in May 2016. However, an area of negative (upward) hydraulic head potential is indicated in southern AOI 1 and along 26th Street. A broad zone of nearly equal hydraulic heads is indicated between these areas, generally along northeastern AOI 4 and at the former DSCP Property near the "breach" area identified by others.
- Overall the positive hydraulic head potentials beneath AOI 4 support the existence of two aquifers and the continuity of the middle clay unit aquitard. Water-level monitoring data for AOI 4 well pairs indicate that the head potentials between the aquifers are consistent throughout the year.
- Direct losses from the lower aquifer to the 26th Street Sewer are possible where sewer excavations appear to have encountered PRM deposits near the elevation of the middle clay unit along an area where the middle clay is interpreted to be relatively thin. For this reason, it is possible that a connection between Quaternary alluvium and the PRM middle/lower sand (i.e., the water-table and lower aquifers) was established through construction of the 26th Street Sewer. Data presented in this RIR suggest that the present-day lower aquifer is semi-confined in the area evaluated and that a direct hydraulic connection between aquifers is not present onsite but may exist nearby (i.e., either along the 26th Street Interceptor or offsite "breach" area).

13.3 VAPOR INTRUSION

Concentrations of COCs in indoor and ambient air were evaluated in and near the only occupied building in AOI 4 (15 Pump House). Observed COC concentrations were below the EPA RSLs, with the exception of 1,2,4-TMB in three samples. Upon the completion of remediation activities, it is assumed that volatilization to the breathing zone will be the only potentially complete pathway for legacy petroleum impacts in AOI 4. As such, these screening values are applicable. It is noted that this conclusion is dependent upon the remainder of the exposure pathways being eliminated through other remedial activities and controls.

Evergreen will continue to operate the sewer ventilation system present for the 26th Street and Pollock Street/Packer Avenue Sewers (Point Breeze Biofilter System) and report performance information in semi-annual Philadelphia Refinery Groundwater Remediation Status Reports. Details regarding plans to maintain this vapor mitigation system will be included in future Act 2 deliverables for AOI 4. Stantec plans to conduct an additional round of air sampling pursuant to the VI Guidance. In order to evaluate data trends, a minimum of one indoor air sample and one ambient air sample are planned for the 15 Pump House area, and one ambient air sample may be collected near the vicinity of well S-104. Samples will be collected for an 8-hour period during the heating season to represent the most conservative scenario. Exceedances of any EPA RSLs in air samples will be evaluated in the Cleanup Plan.

13.4 LNAPL

LNAPL present in the subsurface beneath and directly adjacent to AOI 4 has been delineated and characterized into 6 general plume areas. The majority of LNAPL sampled though time has been characterized as a mixture of light and middle distillates and is indicative of multiple product releases at different times with subsequent co-mingling of plumes in the subsurface.

Data evaluated in this RIR indicates that the majority of LNAPL at AOI 4 is the result of relatively old petroleum hydrocarbon releases and is residual. In general, based upon the multiple lines of evidence presented above, LNAPL observed at AOI 4 appears to be stable or decreasing (not migrating) as a whole. However, wells located in three distinct areas of AOI 4 indicate potentially mobile LNAPL: (1) S-30 System area (based on wells S-30 and S-31); (2) Penrose System area (based on S-221, S-240, S-241, and RW-701); and (3) in the vicinity of S-220 (between the S-30 System and Penrose System areas).

Based on LDRM evaluations, areas of potentially mobile and practically recoverable LNAPL are still present in AOI 4, particularly in the currently active Penrose System area. LNAPL in this and other areas of AOI 4 are continually monitored through well gauging. LNAPL recovery is ongoing at the Penrose System, and is anticipated to resume in 2017 for the inactive S-30 System once it has been rehabilitated. It is noted that the PES Complex remains an active refinery and as such, may be impacted by additional petroleum releases through time.

14.0 SIGNATURES

The following parties are participating in the remediation at this time and are seeking relief of liability under Act 2 of 1995.

Tiffani L. Doerr, P.G.
Project Manager
Evergreen Resources Management Operations

This RIR has been prepared in accordance with the final provisions of Act 2 and the June 8, 2002 Land Recycling Program Technical Guidance Manual.

15.0 REFERENCES

NOTE: ELECTRONIC COPIES OF REFERENCED REPORTS ARE INCLUDED IN **APPENDIX I** AS A COMPACT DISK ATTACHMENT.

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