WORK PLAN FOR SITE CHARACTERIZATION
AREA OF INTEREST 6

SUNOCO PHILADELPHIA REFINERY
PHILADELPHIA, PENNSYLVANIA

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1.0 INTRODUCTION

The Current Conditions Report and Comprehensive Remedial Plan (CCR), prepared by Sunoco Inc. (R&M) (Sunoco), dated June 30, 2004, proposed Phase II site characterization and corrective action activities for Sunoco's Philadelphia Refinery (Refinery), including preparation of Site Characterization Reports for the individual Areas of Interest (AOIs). The CCR presented a prioritization of all of the eleven AOIs based on specific risk factors. In February 2005, the Phase II Corrective Action Activities Schedule (Figure 19 of the CCR) was modified by moving the characterization of AOI 6 ahead of AOI 2 based on potential risk in accordance with discussions with the Pennsylvania Department of Environmental Protection (PADEP).

This Site Characterization Work Plan has been prepared exclusively for AOI 6, and is the second Work Plan to be submitted to the PADEP since submittal of the CCR. A Work Plan for the investigation of AOI 1 and AOI 4 was submitted to the PADEP in January 2005. AOI 6 includes the Girard Point Chemicals Processing Area located north of the Penrose Avenue Bridge and south of Pennypacker Avenue. It extends in a wedge-shaped section from Lanier Avenue to the Schuylkill River and encompasses approximately 100 acres. The boundary of AOI 6 is shown in Figure 1.

Historically this area of the refinery consisted of numerous above ground storage tanks (ASTs) containing benzene, toluene, naphtha and other fuel stocks. A sulfuric acid plant was located along the northern boundary of the AOI. A gasoline treating unit, two reformer units, a BDDA (soap) unit, and a thermal hydrodealkylation unit were also located in this Area.

Currently, AOI 6 consists of benzene and cumene units, reformers, tankage, boilerhouses, maintenance buildings, laydown yards, office buildings, and includes the Environmental Laboratory. Many ASTs have been removed in recent years. A portion of the refinery's wastewater treatment facility is located in the northwestern corner of the AOI. A bulk head, which is keyed into the Middle Clay Unit, extends along the entire western boundary of the AOI, between the AOI and the Schuylkill River. As shown in Figure 16 of the CCR, approximately 30 percent of AOI 6 is covered by impervious surfaces.

The monitoring well network in AOI 6 includes a total of 49 monitoring wells, three piezometers, and 16 recovery wells. Gauging of selected wells typically occurs on a quarterly basis and is complimented by a more comprehensive gauging event that is performed semi-annually. Sunoco samples selected wells in AOI 6 on an annual basis and other wells have also been sampled as part of routine investigations completed in AOI 6.

1.1 Objectives

The objective of the proposed activities is to characterize current environmental conditions at AOI 6 in accordance with the 2003 Consent Order and Agreement (CO&A) between Sunoco and the PADEP and the 2004 CCR. This Work Plan also includes activities to address any remaining issues pertaining to the characterization of Resource, Conservation and Recovery Act (RCRA) Solid Waste Management Units (SWMU)s in AOI 6 .

General site characterization activities proposed at AOI 6 and summarized in this Work Plan include:

- Review of all available historical environmental reports relating to AOI 6,
- Evaluation of existing and proposed remediation systems,
- Advancement of shallow soil borings and collection of shallow soil samples for laboratory analysis of Site Constituents of Concern (COCs),
- Installation of intermediate groundwater monitoring wells,
- Monitoring and sampling of new and existing shallow, intermediate, and deep groundwater monitoring wells,
- Collection and characterization of light non-aqueous phase liquid (LNAPL) samples from select monitoring wells,
- Completing LNAPL modeling to evaluate LNAPL specific volume and mobility,
- Evaluation of potential vapor migration pathways using the PADEP's vapor intrusion guidance,

- Fate and transport modeling of dissolved COCs in site groundwater,
- Completion of Exposure and Risk Assessment activities, if necessary, and
- Preparation of a Site Characterization Report.

The COCs for the proposed investigation activities include all constituents listed in Tables 5a and 5b of the CCR, and are included as Table 1 of this Work Plan. Data collected from the above activities will be evaluated as part of the AOI 6 site characterization process, and will be presented in the Site Characterization Report for AOI 6, which is anticipated to be submitted to the PADEP and United States Environmental Protection Agency (EPA), Region 3 by October 2, 2006 in accordance with the revised version of Figure 19 of the CCR.

1.2 Overview of Investigative Framework and Remedial Approach for AOI 6

The current remediation program for the Refinery is performed under RCRA, Pennsylvania's Act 2 Program and the 2003 Consent Order and Agreement (CO&A) between PADEP and Sunoco. In April 2004, the PADEP and EPA signed an agreement entitled "One Cleanup Program Memorandum of Agreement (MOA or One-Cleanup Program)," which, among other things, clarifies how sites remediated under Pennsylvania's Act 2 program satisfy RCRA corrective action requirements through characterization and attainment pursuant to Pennsylvania's Act 2.

On November 22, 2005, Sunoco and its representatives met with officials of the PADEP and EPA to discuss the applicability of the Sunoco Philadelphia Refinery to the One Cleanup Program. During the November 22, 2005 meeting, all parties 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. As follow up to the meeting, Sunoco submitted a letter dated December 2, 2005 to EPA and PADEP memorializing the discussions at the meeting (Appendix B). As summarized in this letter, the major aspects of including the Philadelphia Refinery in the One-Cleanup Program include:

1. Submittal of a Notice of Intent to Remediation (NIR) under the PADEP Act 2 Program. The NIR will specifically reference the 2003 CO&A, the CCR Area of Interest approach to site characterization, and inclusion of corrective action requirements under the PA One-Cleanup Program.
2. Development and issuance by EPA Region 3 of a revised Corrective Action Permit for the Philadelphia Refinery that embodies the One Cleanup Plan elements.

The PA One-Cleanup Program approach is timely in that AOI 6 is the first AOI to be characterized which contains existing RCRA SWMUs. An overview of the RCRA Corrective Action Program for the Girard Point portion of the Philadelphia Refinery, which includes AOI 6, is provided in the following section.

1.2.1 Overview of RCRA Corrective Action Program in Girard Point

A number of RCRA investigations were completed in Girard Point between 1989 and 1993, including a Phase II RCRA Facility Assessment for Girard Point in 1989, an investigation of SWMU 73 (Former Bundle Cleaning Area) in 1992, a Site Specific Risk Assessment for SWMU 73 in 1992, a RCRA Verification Investigation for all SWMUs in Girard Point in 1992, and a RCRA Facility Investigation in 1993. A list of all reports reviewed in preparation of this Work Plan is presented in Section 1.4. Based on a review of these studies, two SWMUs were identified for AOI 6 that required further investigation. These are SWMU 92 (Storage Tank Areas: Buried Lead Sludge Area 6) and SWMU 95 (Storage Tank Areas: Buried Lead Sludge Area 9). The only other identified SWMU in AOI 6 is SWMU 73 (Former Bundle Cleaning Area). A Site Specific Risk Assessment was completed in SWMU 73 for lead and benzo(a)pyrene since these were the only compounds identified in the investigation phase that required further evaluation. The Site Specific Risk Assessment determined that these compounds do not present a threat to human health or the environment and do not require corrective action. Therefore, only the two Buried Lead Sludge Area SWMUs (SWMU 92 and SWMU 95) were identified as requiring further investigation.

Based on all the foregoing information, Sunoco's proposed approach is to include SWMU 92 and SWMU 95 within the scope for characterization for AOI 6. All activities will be completed in accordance with the 2003 CO&A, and in the context of the PA One-Cleanup Program approach. The approach to investigating these areas is described in detail in Section 1.2.2. If site characterization and or remediation is completed at the SWMUs in AOI 6 in accordance with the approach discussed herein, the RCRA obligations for all areas within AOI 6 will be satisfied provided that the Refinery has successfully entered into the Pennsylvania One-Cleanup Program and the PADEP and EPA have approved of the work completed as documented in the Site Characterization Report.

1.2.2 Investigation Approach for SWMUs 92 and 95

The proposed approach to address soils within the leaded tank bottom SWMUs will support implementation of a RCRA final remedial measure, as well as support attainment of an Act 2 standard, consistent with the One Cleanup Plan. Leaded tank bottom materials are distinguished by distinctive rust/red to black, metallic mostly oxidized scale materials. Leaded tank bottoms are also sometimes in a matrix of petroleum wax sludge. If materials are encountered within the leaded tank bottom areas, matching the physical description of the leaded tank bottoms, then Sunoco will collect samples for total lead. If the total lead results exceed 450 parts per million (ppm) (this value is PADEP's non-residential MSC for lead) then the samples will be analyzed for lead via Toxicity Characteristic Leaching Procedure, EPA Test Method 1311. Delineated areas that have soils that physically resemble leaded tank bottoms, are greater then 450 ppm of lead and are hazardous for lead will retain the leaded tank bottom designation. None of the soils identified in previous investigations have matched the physical descriptions of the leaded tank bottoms. If no soils are encountered that meet all three of these criteria, then the area will no longer be classified as a leaded tank bottom area. Sunoco will certify that these areas will no longer contain leaded tank bottoms materials, based on the procedures above, in the Site Characterization Report.

1.2.3 Overview of Proposed Approach in Non-RCRA Areas of AOI 6

The proposed approach to address groundwater and soils in the remainder of AOI 6 is in accordance with the Act 2 program. Sampling will be focused on potential source areas such as Tank 1010, Unit 1732 and Tank 797 where historical releases have occurred in AOI 6. Additional activities will also be completed throughout AOI 6 to ensure that site soils and groundwater are fully characterized in accordance with the Act 2 program.

1.3 Overview of Existing and Proposed Phase I Activities in AOI 6

The 27 Pump House Total Fluids Recovery System is the only active remediation system located in AOI-6. This system includes 13 active total fluid recovery wells in the vicinity of 27 Pump House. This system has the capability of pumping total fluids from wells B-136, B-137, B-138, B-142, B-143, SUMP-1, B-133, B-134, B-139, B-140, B-147, and B-124. Currently the system is pumping from wells B-124, B-132, B-135, B-139, B-142, 143, and SUMP-1. Total fluids produced by each of the wells are routed to an oil/water separator where recovered LNAPL is passively skimmed and deposited into two 550-gallon holding tanks that are piped together. The contents of the holding tanks are pumped out, as necessary, and recycled by the refinery. Groundwater is passed through the separator and pumped to the refinery's wastewater treatment plant. Recovery wells are gauged as part of the recovery system maintenance and monitoring program to ensure the system is operating as designed. The system was taken off-line on December 2, 2005, for the winter and will be re-started when weather permits.

No additional corrective action activities are proposed in this Work Plan for AOI 6. The effectiveness of the 27 Pump House Total Fluids system and the need to perform additional active remediation in AOI 6 will be evaluated following completion of the proposed site characterization activities.

1.4 Work Plan Support Activities

Several activities were performed to support the development of this Work Plan. These activities are summarized below:

- Aquaterra Technologies (Aquaterra) performed one round of groundwater monitoring and sampling in AOI 6 between May 24 and 26, 2005. Groundwater samples were collected from all accessible AOI 6 wells, with the exception of recovery wells and wells which contained measurable (>0.01 feet) LNAPL. The samples were submitted to Lancaster Laboratories of Lancaster, Pennsylvania for analysis of Site COCs. The results of these samples are presented in Table 2 of this Work Plan. This data was obtained to enhance the Site Conceptual Model for AOI 6 and to refine Site characterization activities proposed in this Work Plan.

- A comprehensive file review was completed for the Girard Point Section of the Philadelphia Refinery at the United States Environmental Protection Agency, Region III office in Philadelphia, Pennsylvania. Relevant reports and correspondence were reviewed to evaluate the status of RCRA SWMUs in Girard Point (AOIs 5-7).

- Reports used in development of the CCR were reviewed to evaluate and refine Site characterization activities proposed in this Work Plan. These reports included:

  - *Phase II RCRA Facility Assessment of the Chevron USA, Inc. (GULF) Facility, Philadelphia, Pennsylvania,* January 1989, A.T. Kearney, Inc.;
  - *EPA Submittal, RCRA Facility Investigation Work Plan, Chevron Refinery, Philadelphia, Pennsylvania,* April 16, 1990, Dames& Moore;
  - *Environmental Evaluation, Tank 1010 (Benzene Unit), Chevron Refinery, Philadelphia, Pennsylvania*, February 18, 1992, Dames & Moore;
  - *Investigation of SWMU 73 (Former Bundle Cleaning Area), Chevron Refinery, Philadelphia, PA.*, April 10, 1992, Dames & Moore;
  - *Site-Specific Risk Assessment, Former Bundle Cleaning Area, SWMU 73, Chevron Refinery, Philadelphia, Pennsylvania,* July 21, 1992, Dames & Moore;

- *RCRA Verification Investigation Report, Chevron Refinery, Philadelphia, Pennsylvania,* December 30, 1992, Dames & Moore;
- *RCRA Facility Investigation, Chevron Refinery, Philadelphia PA.,* November 24, 1993, Dames & Moore, as well as all related RFI reports and correspondence;
- *Letter Report, Soil Sampling and Analysis, Vicinity of Naphtha Release, Chevron Refinery, Philadelphia, Pennsylvania*, May 6,1994, Dames & Moore;
- *Letter Report, Soil Sampling and Analysis 1732 Unit, Chevron Refinery, Philadelphia, Pennsylvania*, August 2, 1994, Dames & Moore;
- *Act 2 Combined Report, Philadelphia Energy Center, Sunoco Philadelphia Refinery, Girard Point Processing Area*, February 2002. URS;
- *AST 797 Closure Report, Sunoco Philadelphia Refinery, Philadelphia, PA,* July 10, 2002, Secor; and
- *AST 797 Area, Site Characterization Report, Girard Point Processing Area, Philadelphia Refinery*, December 6, 2002, Secor.

2.0 PROPOSED SITE CHARACTERIZATION ACTIVITIES

Based on the identified data collection needs for AOI 6, the following Site characterization tasks are discussed in this Work Plan:

Task 1: Soil Borings and Sampling
Task 2 Installation of Intermediate Groundwater Monitoring Wells
Task 3: Groundwater Monitoring and Sampling
Task 4: Collection and Characterization of LNAPL Samples
Task 5: Aquifer Testing
Task 6: Evaluation of the Potential Indoor Air Pathway
Task 7: Fate and Transport Analysis of Dissolved COCs in Groundwater
Task 8: Exposure/Risk Assessment
Task 9: Surveying
Task 10: Data Evaluation and Site Conceptual Model
Task 11: Reporting

The individual Site characterization tasks are discussed in detail by area in the following sections.

2.1 Task 1: Soil Borings and Sampling

To further characterize soil conditions within AOI 6, a total of 42 soil samples will be collected. Of the 42 samples, 24 will be collected from within the two leaded tank bottom SWMU areas (SWMUs 92 and 95). These samples, as shown on Figure 2 and summarized in Table 3, will be collected from zero to two feet below the ground surface at each proposed sample location. The locations of proposed soil borings in the leaded tank bottom SWMUs were chosen to supplement those locations where soil borings were performed as part of the RCRA Facility Investigation (RFI), yet no shallow (0-2 feet) soil samples were collected. The remainder of the shallow soil data collected in the AOI 6 SWMUs and summarized in the RFI will be relied upon for site characterization not related to the SWMUs.

All soil samples will be submitted to Lancaster Laboratories of New Holland, Pennsylvania (Act 2-certified) for analysis of total lead for the soil samples collected from within SWMU 92 and 95 and for Site COCs for other soil sampling locations to evaluate the potential direct contact pathway at these locations. The soil sampling activities for the leaded tank bottom SWMUs will follow the procedures outlined in Section 1.2.

The proposed well borings and associated soil samples will be completed with a hollow stem auger drill rig. Proposed soil boring only locations will be completed with a Geoprobe® direct push method or by hand-augers. All soil boring and soil sampling activities, including leaded tank bottom identification, will be performed following the procedures provided in Appendix A of this Work Plan and in Section 1.2.2.

2.2 Task 2: Installation of Intermediate Groundwater Monitoring Wells

Fourteen (14) intermediate (Trenton Gravel) groundwater monitoring wells are proposed to be installed in AOI 6 as shown on Figure 2 and summarized on Table 3. The wells will be installed using hollow stem auger drilling technology to a maximum depth of approximately 15 feet below the ground surface, and screened within the Trenton Gravel. All wells will be installed so that the screened interval intercepts the groundwater table, allowing for appropriate measurement of apparent LNAPL thickness. Each well will be developed subsequent to completion. All well installation, well development and waste handling activities will be performed in accordance with the procedures provided in Appendix A of this Work Plan.

Four deep (Lower Sand) groundwater monitoring wells exist in AOI 6. These wells include B-48D, B-132D, B-133D and B-134D. No additional deep groundwater monitoring wells need to be installed to evaluate deep groundwater conditions in AOI 6.

2.3 Task 3: Groundwater Monitoring and Sampling

2.3.1 Groundwater Monitoring

When applicable (i.e., during scheduled shutdowns), site groundwater conditions may be evaluated immediately following scheduled remedial system shutdowns, during such shutdowns, and following the re-start of the remedial systems. This data will be used to evaluate the influence of the remedial systems on the natural site conditions, and to monitor conditions during the shutdown period.

Upon completion of the monitoring well installations and development in AOI 6, a complete round of groundwater water elevation gauging will be performed from all accessible new and existing monitoring wells. All well gauging activities will be performed in accordance with the Liquid Level Gauging Procedures provided in Appendix A of this Work Plan. Gauging data collected during this event will be used to evaluate groundwater flow conditions in this area.

2.3.2 Groundwater Sampling

Following completion of the groundwater gauging activities in the AOI 6, a full round of groundwater sampling will be conducted from all accessible new and existing monitoring wells which do not contain measurable LNAPL. All groundwater samples will be submitted to Lancaster Laboratories for analysis of Site COCs, as listed in Table 1. Groundwater sampling will be conducted in accordance with well sampling procedures provided in Appendix A of this Work Plan.

2.4 Task 4: Collection and Characterization of LNAPL Samples

All LNAPL samples discussed below will be submitted to a specialty laboratory for characterization. The results of the LNAPL characterization analysis will be used to separate LNAPL plumes by product type and to assist in evaluating specific LNAPL volume and mobility.

LNAPL characterization data exists for six wells (B-39, B-43, B-129, B-130, B-144 and WP 9-2) in AOI 6 as summarized in Appendix F of the CCR. This data was obtained from LNAPL sampling activities performed by SECOR and Aquaterra between 2002 and the present.

LNAPL samples will be collected from an additional two existing monitoring wells (B-150 and B-47) in AOI 6 as summarized in Table 3. LNAPL samples will also be collected from all newly-installed monitoring wells which have measurable LNAPL thicknesses and are not located in the immediate vicinity of a well with known LNAPL type. All LNAPL sampling activities will be completed in accordance with the LNAPL Sampling Procedures provided in Appendix A of this Work Plan.

2.5 Task 5: Aquifer Testing

Langan reviewed relevant historical documents prepared for Girard Point to obtain site-specific aquifer data that may have been collected during previous environmental investigations. Based on this review, the following site-specific aquifer data exists:

- Three slug tests were performed in shallow wells in AOI 6 (MW-1, MW-2 and MW-3) in October 2003 by SECOR International, Inc. as part of the AST 797 Site Characterization. The resulting hydraulic conductivity values ranged between 1.66 feet/day and 12.10 feet/day.

- Aquifer testing, consisting of step tests followed by 24-hour constant rate pumping tests, was performed in three wells (B-132, B-134, and B-135) in AOI 6 during April 2001 by URS Corporation. The highest hydraulic conductivity value was calculated at B-132 at a value of 23.98 feet/day.

Based on the available historic aquifer testing data, the highest hydraulic conductivity value calculated from wells in AOI 6 is 23.98 feet/day. This value, which is consistent with the value used for the Trenton Gravel and modeling activities performed previously for AOIs 1 and 4, will be used as the site-specific hydraulic conductivity value for the modeling in AOI 6. Therefore, it is not anticipated that any additional aquifer testing will be required for AOI 6.

2.6 Task 6: Evaluation of the Potential Indoor Air Pathway

An assessment of the potential Indoor Air Pathway will be completed in accordance with the PADEP's Vapor Guidance Manual, (PADEP, 2003). No residential receptors are within AOI 6. Potential non-residential receptors identified in AOI 6 include the Office Building and the Training Building; these buildings are shown on the Current Use Figure for Girard Point which was included in Appendix I of the CCR. All other inhabited structures within AOI 6 are identified as industrial receptors. Sunoco is currently sampling indoor air within the non-residential and industrial receptor structures to evaluate the potential indoor air pathway. The results of this sampling will determine whether further investigation will be performed to assess the potential indoor air pathway at these structures.

2.7 Task 7: Fate and Transport Analysis of Dissolved COCs in Groundwater

Fate and transport calculations will be completed for groundwater to evaluate potential migration pathways and potential impacts to receptors. Fate and transport modeling will be conducted for the constituents listed in Table 1 using Pennsylvania Department of Environmental Protection approved analytical models (QUICK_DOMENICO.XLS and FATBACK.XLS). To support the fate and transport analyses, Sunoco will provide all assumptions, data and information used in the analytical modeling. The parameters used in the analyses will either be site-specific data obtained during previous investigations, values collected as part of future site characterization activities, and/or default parameters provided in the Act 2 regulations or guidance manual.

2.8 Task 8: Exposure/Risk Assessment

In accordance with Section V, subsection E of the PADEP Technical Guidance Manual, Revision 0, dated December 1997, a detailed exposure assessment will be preformed for AOI 6 based on the completed site characterization activities. This exposure assessment will be based on an assumed non-residential current and future site use. If completed exposure pathways are identified, then risk assessment activities will be completed in accordance with Act 2.

2.9 Task 9: Surveying

Following completion of soil boring and groundwater monitoring well installation activities, the new wells and boring locations will be surveyed to establish the location and elevation at each point, and the elevations of the inner and outer casing and ground surface (for wells). The well elevations will be determined to the nearest 0.01 foot relative to mean sea level. All survey activities will be performed by a Pennsylvania-licensed surveyor and tied to the NAVD 88 datum.

2.10 Task 10: Data Evaluation and Site Conceptual Model

Data collected from the site characterization activities will be compiled and evaluated in accordance with the objectives of the CCR. This data will also be used to modify and refine the Site Conceptual Model. Site characterization activities described in this Work Plan will provide the following information which will be used to refine the Site Conceptual Model:

- Soil data collected between zero and two feet below the ground surface from select well borings will further characterize the potential direct contact pathway for soil.
- Soil data collected between zero and two feet below the ground surface from within the leaded tank bottom SWMUs will further be characterized in accordance with the procedures set forth in Section 1.2.
- Installation, monitoring and sampling of new groundwater monitoring wells will further characterize groundwater quality and flow in AOI 6.
- LNAPL data collected in AOIs 6 will allow for more accurate LNAPL classification and distribution and will refine the LNAPL specific volume and mobility modeling predictions for these areas.
- Fate and transport modeling of dissolved phase COCs in groundwater will further characterize the potential for off-site migration in AOI 6.

- Throughout the characterization process of AOI 6, additional information regarding the current and historic uses of these areas will be obtained from available sources. Information obtained will be used to generate more detailed Current and Historic Usage figures which may be included in the Site Characterization Report.

Data collected during this characterization process will augment the existing geographic information system (GIS) for the Refinery. The GIS will be used to further evaluate characterization needs, and to visually depict current and future Site conditions.

2.11 Task 11: Reporting

Following completion of the activities listed above in Tasks 1-10, a Site Characterization Report will be prepared for AOI 6 documenting the results of all Work Plan-related activities. Copies of the report will be submitted to the PADEP and EPA Region 3 for review and approval. The report will include an executive summary, description of physical site characteristics, summary of field investigation and modeling activities, supporting maps, figures and data summary tables, an exposure assessment, refinement of the Site Conceptual Model based on field investigations, and conclusions and recommendations for future Site characterization and/or remedial activities, if any.

All data gathered with respect to the deep aquifer, AOI 11, will be presented in the respective AOI reports, however a formal AOI 11 characterization report will be compiled at the conclusion of all other AOI characterization efforts.

3.0 IMPLEMENTATION SCHEDULE

Site characterization activities are anticipated to begin in February 2006. Any comments to the Work Plan received by the PADEP will be considered and incorporated into the site characterization activities, where appropriate. It is anticipated that all field activities will be completed by August 2006, and the Site Characterization Report for AOI 6 will be submitted to the PADEP and EPA Region 3 by October 2, 2006. This schedule is consistent with the revised Phase II Corrective Action Activities Schedule which was included as Figure 19 of the CCR.

During its implementation, if any significant deviations are required from the proposed scope of work, the PADEP and EPA Region 3 will be notified prior to implementation of any changes.

TABLES

Table 1
Constituents of Concern for Groundwater
AOI 6 Workplan
Sunoco Philadelphia Refinery
Philadelphia, Pennsylvania

METALS	CAS No.
Lead (dissolved)	7439-92-1

VOLATILE ORGANIC COMPOUNDS	CAS No.
1,2-dichloroethane	107-06-2
Benzene	71-43-2
Cumene	98-82-8
Ethylbenzene	100-41-4
Ethylene dibromide	106-93-4
Methyl tertiary butyl ether	1634-04-4
Toluene	108-88-3
Xylenes (total)	1330-20-7

SEMI-VOLATILE ORGANIC COMPOUNDS	CAS No.
Chrysene	218-01-9
Fluorene	86-73-7
Naphthalene	91-20-3
Phenanthrene	85-01-8
Pyrene	129-00-0

Notes:
1. Constituents are from Pennsylvania Corrective Action Process (CAP) Regulation Amendments effective December 1, 2001; provided in Chapter VI, Section E (pgs. 29-30) of PADEP Document, *Closure Requirements for Underground Storage Tank Systems,* effective April 1, 1998.

Table 1 (continued)
Constituents of Concern for Soil
AOI 6 Workplan
Sunoco Philadelphia Refinery
Philadelphia, Pennsylvania

METALS	CAS No.
Lead (total)	7439-92-1

VOLATILE ORGANIC COMPOUNDS	CAS No.
1,2-dichloroethane	107-06-2
Benzene	71-43-2
Cumene	98-82-8
Ethylbenzene	100-41-4
Ethylene dibromide	106-93-4
Methyl tertiary butyl ether	1634-04-4
Toluene	108-88-3
Xylenes (total)	1330-20-7

SEMI-VOLATILE ORGANIC COMPOUNDS	CAS No.
Anthracene	120-12-7
Benzo(a)anthracene	56-55-3
Benzo (g,h,i) perylene	191-24-2
Benzo(a)pyrene	50-32-8
Benzo(b)fluoranthene	205-99-2
Chrysene	218-01-9
Fluorene	86-73-7
Naphthalene	91-20-3
Phenanthrene	85-01-8
Pyrene	129-00-0

Notes:
1. Constituents are from Pennsylvania Corrective Action Process (CAP) Regulation Amendments effective December 1, 2001; provided in Chapter VI, Section E (pgs. 29-30) of PADEP Document, *Closure Requirements for Underground Storage Tank Systems,* effective April 1, 1998.

Table 2
Summary of Groundwater Analytical Results
Sunoco Philadelphia Refinery AOI-6
Philadelphia, Pennsylvania

	CAS No	PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500	Sample ID Sample Date Sample Matrix Unit	B115-052405 5/24/2005 Groundwater ug/l			B116-052405 5/24/2005 Groundwater ug/l			B117-052405 5/24/2005 Groundwater ug/l			B125-052405 5/24/2005 Groundwater ug/l			B126-052405 5/24/2005 Groundwater ug/l			B131-052405 5/24/2005 Groundwater ug/l			B134D-052405 5/24/2005 Groundwater ug/l			B145-052605 5/26/2005 Groundwater ug/l		
Volatile Organic Compounds			**Unit**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**
Ethylene dibromide (EDB)	106-93-4	0.05	ug/l	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029
1,2-Dichloroethane	107-06-2	5	ug/l	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5
Benzene	71-43-2	5	ug/l	ND	U	5	ND	U	5	ND	U	5	**66**		5	**200**		5	**20**		5	ND	U	5	**38**		5
Ethylbenzene	100-41-4	700	ug/l	ND	U	5	ND	U	5	ND	U	5	10		5	19		5	ND	U	5	ND	U	5	ND	U	5
Cumene	98-82-8	2300	ug/l	ND	U	5	ND	U	5	ND	U	5	7		5	26		5	13		5	ND	U	5	62		5
Methyl Tertiary Butyl Ether	1634-04-4	20	ug/l	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5
Toluene	108-88-3	1000	ug/l	ND	U	5	ND	U	5	ND	U	5	75		5	50		5	ND	U	5	ND	U	5	5		5
Xylene (Total)	1330-20-7	10000	ug/l	ND	U	5	ND	U	5	ND	U	5	78		5	87		5	ND	U	5	ND	U	5	13		5
Semi-Volatile Organic Compounds																											
Chrysene	218-01-9	1.9	ug/l	ND	U	**10**	ND	U	**10**	ND	U	**10**	ND	U	**10**	ND	U	**10**	ND	U	**10**	ND	U	**10**	ND	U	**10**
Fluorene	86-73-7	1900	ug/l	ND	U	10	ND	U	10	ND	U	10	15		10	12		10	ND	U	10	ND	U	10	41		10
Naphthalene	91-20-3	100	ug/l	ND	U	10	ND	U	10	ND	U	10	ND	U	10	ND	U	10	ND	U	10	ND	U	10	11		10
Phenanthrene	85-01-8	1100	ug/l	ND	U	10	ND	U	10	ND	U	10	ND	U	10	ND	U	10	ND	U	10	ND	U	10	24		10
Pyrene	129-00-0	130	ug/l	ND	U	10	ND	U	10	ND	U	10	ND	U	10	ND	U	10	ND	U	10	ND	U	10	14		10

Notes:
PADEP - Pennsylvania Department of Environmental Protection
ug/kg - Microgram per kilogram
MSC - PADEP's Medium Specific Concentration for Groundwater
RL - Reporting Limit
ND - Not Detected

Qualifiers:
Q - Qualifier
U - The Analyte Was Analyzed But Not Detected

Exceedance Summary:
10 - Reporting Limit Exceeds the PADEP Non-Residential Groundwater MSC
10 - Compound Exceeds the PADEP Non-Residential Groundwater MSC

Table 2
Summary of Groundwater Analytical Results
Sunoco Philadelphia Refinery AOI-6
Philadelphia, Pennsylvania

	CAS No	PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500	Sample ID Sample Date Sample Matrix Unit	B48-052405 5/24/2005 Groundwater ug/l			B48D-052405 5/24/2005 Groundwater ug/l			WP16-3-052605 5/26/2005 Groundwater ug/l			WP16-5-052605 5/26/2005 Groundwater ug/l			WPM11-052605 5/26/2005 Groundwater ug/l			WPM8-052605 5/26/2005 Groundwater ug/l			B123-052505 5/25/2005 Groundwater ug/l		
Volatile Organic Compounds			**Unit**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**
Ethylene dibromide (EDB)	106-93-4	0.05	ug/l	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029
1,2-Dichloroethane	107-06-2	5	ug/l	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5
Benzene	71-43-2	5	ug/l	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	27		5	ND	U	5
Ethylbenzene	100-41-4	700	ug/l	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5
Cumene	98-82-8	2300	ug/l	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	27		5	36		5
Methyl Tertiary Butyl Ether	1634-04-4	20	ug/l	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	24		5	ND	U	5
Toluene	108-88-3	1000	ug/l	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5
Xylene (Total)	1330-20-7	10000	ug/l	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	5
Semi-Volatile Organic Compounds																								
Chrysene	218-01-9	1.9	ug/l	ND	U	10	ND	U	10	ND	U	10	ND	U	10	300		5	2		1	ND	U	10
Fluorene	86-73-7	1900	ug/l	ND	U	10	ND	U	10	ND	U	10	ND	U	10	36		5	6		1	31		10
Naphthalene	91-20-3	100	ug/l	ND	U	10	ND	U	10	ND	U	10	ND	U	10	ND	U	5	ND	U	1	ND	U	10
Phenanthrene	85-01-8	1100	ug/l	ND	U	10	ND	U	10	ND	U	10	ND	U	10	200		5	2		1	ND	U	10
Pyrene	129-00-0	130	ug/l	ND	U	10	ND	U	10	ND	U	10	ND	U	10	400		5	9		1	ND	U	10

Notes:
PADEP - Pennsylvania Department of Environmental Protection
ug/kg - Microgram per kilogram
MSC - PADEP's Medium Specific Concentration for Groundwater
RL - Reporting Limit
ND - Not Detected

Qualifiers:
Q - Qualifier
U - The Analyte Was Analyzed But Not Detected

Exceedance Summary:
10 - Reporting Limit Exceeds the PADEP Non-Residential Groundwater MSC
10 - Compound Exceeds the PADEP Non-Residential Groundwater MSC

Table 2
Summary of Groundwater Analytical Results
Sunoco Philadelphia Refinery AOI-6
Philadelphia, Pennsylvania

	CAS No	PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500	Sample ID Sample Date Sample Matrix Unit	B134U-052505 5/25/2005 Groundwater ug/l			B149-052505 5/25/2005 Groundwater ug/l			B45-052505 5/25/2005 Groundwater ug/l			B46-052505 5/25/2005 Groundwater ug/l			B92-052505 5/25/2005 Groundwater ug/l			B94-052505 5/25/2005 Groundwater ug/l			WP9-1-052505 5/25/2005 Groundwater ug/l		
Volatile Organic Compounds			**Unit**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**
Ethylene dibromide (EDB)	106-93-4	0.05	ug/l	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029	ND	U	0.029	0.028	U	0.028	ND	U	0.028
1,2-Dichloroethane	107-06-2	5	ug/l	ND	U	5	ND	U	**5000**	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	**100**
Benzene	71-43-2	5	ug/l	**12**		5	**140000**		**5000**	ND	U	5	ND	U	5	ND	U	5	ND	U	5	**1700**		**100**
Ethylbenzene	100-41-4	700	ug/l	ND	U	5	ND	U	**5000**	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	100
Cumene	98-82-8	2300	ug/l	5		5	ND	U	**5000**	5		5	ND	U	5	9		5	ND	U	5	ND	U	100
Methyl Tertiary Butyl Ether	1634-04-4	20	ug/l	ND	U	5	ND	U	**5000**	ND	U	5	ND	U	5	ND	U	5	**34**		5	ND	U	**100**
Toluene	108-88-3	1000	ug/l	ND	U	5	ND	U	**5000**	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	100
Xylene (Total)	1330-20-7	10000	ug/l	9		5	ND	U	5000	ND	U	5	ND	U	5	ND	U	5	ND	U	5	ND	U	100
Semi-Volatile Organic Compounds																								
Chrysene	218-01-9	1.9	ug/l	ND	U	**10**	ND	U	**10**	ND	U	1	ND	U	1	ND	U	**10**	ND	U	**10**	ND	U	**10**
Fluorene	86-73-7	1900	ug/l	29		10	ND	U	10	ND	U	1	ND	U	1	22		10	ND	U	10	ND	U	10
Naphthalene	91-20-3	100	ug/l	ND	U	10	32		10	ND	U	1	ND	U	1	ND	U	10	ND	U	10	ND	U	10
Phenanthrene	85-01-8	1100	ug/l	21		10	ND	U	10	ND	U	1	ND	U	1	15		10	ND	U	10	14		10
Pyrene	129-00-0	130	ug/l	15		10	ND	U	10	ND	U	1	ND	U	1	ND	U	10	ND	U	10	22		10

Notes:
PADEP - Pennsylvania Department of Environmental Protection
ug/kg - Microgram per kilogram
MSC - PADEP's Medium Specific Concentration for Groundwater
RL - Reporting Limit
ND - Not Detected

Qualifiers:
Q - Qualifier
U - The Analyte Was Analyzed But Not Detected

Exceedance Summary:
10 - Reporting Limit Exceeds the PADEP Non-Residential Groundwater MSC
10 - Compound Exceeds the PADEP Non-Residential Groundwater MSC

TABLE 3
Summary of Proposed Site Characterization Activities for AOI 6
AOI 6 Work Plan for Site Characterization
Sunoco Philadelphia Refinery
Philadelphia, Pennsylvania

Proposed Sampling ID	Existing	Proposed	Media	Collection of Soil Sample from 0-2 ft For Site COCs (Non-SWMU Location)	Collection of Soil Sample from 0-2 ft For Site COCs (SWMU Location)	Estimated Completion and/or Sample Depth for Proposed Monitoring Wells and Points	LNAPL Data Exists	COCs	Collection of LNAPL Sample From Existing Well	Objective of Proposed Activity
AOI 6										
B-115	X		Groundwater					1		Characterize Groundwater in AOI 6
B-116	X		Groundwater					1		Characterize Groundwater in AOI 6
B-117	X		Groundwater					1		Characterize Groundwater in AOI 6
B-123	X		Groundwater					1		Characterize Groundwater in AOI 6
B-124	X		Groundwater					1		Characterize Groundwater in AOI 6
B-125	X		Groundwater					1		Characterize Groundwater in AOI 6
B-126	X		Groundwater					1		Characterize Groundwater in AOI 6
B-129	X		Groundwater				X	1		Characterize Groundwater in AOI 6
B-130	X		Groundwater				X	1		Characterize Groundwater in AOI 6
B-131	X		Groundwater					1		Characterize Groundwater in AOI 6
B-132	X		Groundwater					1		Characterize Deep Groundwater in AOI 6
B-132D	X		Groundwater					1		Characterize Groundwater in AOI 6
B-133	X		Groundwater					1		Characterize Groundwater in AOI 6
B-133D	X		Groundwater					1		Characterize Deep Groundwater in AOI 6
B-134	X		Groundwater					1		Characterize Groundwater in AOI 6
B-134D	X		Groundwater					1		Characterize Deep Groundwater in AOI 6
B-135	X		Groundwater					1		Characterize Groundwater in AOI 6
B-136	X		Groundwater					1		Characterize Groundwater in AOI 6
B-137	X		Groundwater					1		Characterize Groundwater in AOI 6
B-138	X		Groundwater					1		Characterize Groundwater in AOI 6
B-139	X		Groundwater					1		Characterize Groundwater in AOI 6
B-140	X		Groundwater					1		Characterize Groundwater in AOI 6
B-141	X		Groundwater					1		Characterize Groundwater in AOI 6
B-142	X		Groundwater					1		Characterize Groundwater in AOI 6
B-143	X		Groundwater					1		Characterize Groundwater in AOI 6
B-144	X		Groundwater				X	1		Characterize Groundwater in AOI 6
B-145	X		Groundwater					1		Characterize Groundwater in AOI 6
B-146	X		Groundwater					1		Characterize Groundwater in AOI 6
B-147	X		Groundwater					1		Characterize Groundwater in AOI 6
B-148	X		Groundwater					1		Characterize Groundwater in AOI 6
B-149	X		Groundwater					1		Characterize Groundwater in AOI 6
B-150	X		Groundwater					1	X	Characterize Groundwater in AOI 6
B-39	X		Groundwater				X	1		Characterize Groundwater in AOI 6
B-40	X		Groundwater					1		Characterize Groundwater in AOI 6
B-41	X		Groundwater					1		Characterize Groundwater in AOI 6
B-42	X		Groundwater					1		Characterize Groundwater in AOI 6
B-43	X		Groundwater				X	1		Characterize Groundwater in AOI 6
B-44	X		Groundwater					1		Characterize Groundwater in AOI 6
B-45	X		Groundwater					1		Characterize Groundwater in AOI 6
B-46	X		Groundwater					1		Characterize Groundwater in AOI 6
B-47	X		Groundwater					1	X	Characterize Groundwater in AOI 6
B-48	X		Groundwater					1		Characterize Groundwater in AOI 6
B-48D	X		Groundwater					1		Characterize Deep Groundwater in AOI 6
B-92	X		Groundwater					1		Characterize Groundwater in AOI 6
B-93	X		Groundwater					1		Characterize Groundwater in AOI 6
B-94	X		Groundwater					1		Characterize Groundwater in AOI 6
PS-1	X		Groundwater					1		Characterize Groundwater in AOI 6
PZ-132A	X		Groundwater					1		Characterize Groundwater in AOI 6
PZ-135A	X		Groundwater					1		Characterize Groundwater in AOI 6
PZ-135B	X		Groundwater					1		Characterize Groundwater in AOI 6
RW16-2	X		Groundwater					1		Characterize Groundwater in AOI 6
RW-9	X		Groundwater					1		Characterize Groundwater in AOI 6
RWM-8	X		Groundwater					1		Characterize Groundwater in AOI 6
SUMP-1	X		Groundwater					1		Characterize Groundwater in AOI 6
U-1	X		Groundwater					1		Characterize Groundwater in AOI 6
U-2	X		Groundwater					1		Characterize Groundwater in AOI 6
U-3	X		Groundwater					1		Characterize Groundwater in AOI 6
U-4	X		Groundwater					1		Characterize Groundwater in AOI 6

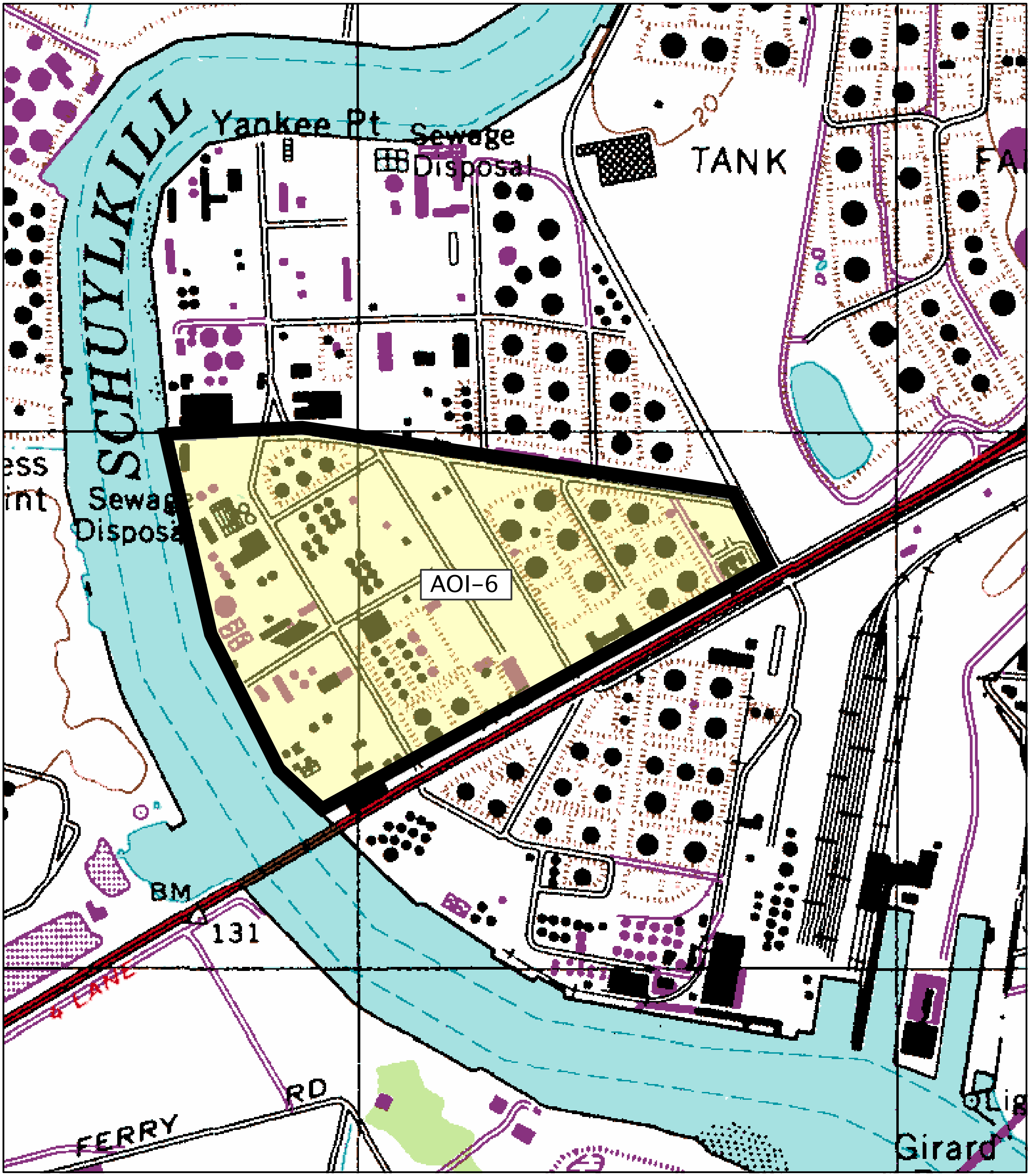
Notes:
Final depth of well and screen placement to be determined by geologist based on field observation while completing the boring
Field procedures will be performed in accordance with Appendix A of the Workplan
All proposed monitoring wells will be completed with a 4 inch inner diameter
Average groundwater level in AOI 6 varies between 0 and 10 feet above mean sea level (approximatley 0 to 10 feet bgs
ft bgs = feet below ground surface
COCs = Constituents of Concern
1 = Analysis of COCs listed in Table 1 of the Work Plar
2= Analysis for Total Lead only
1,2 = Groundwater analysis for COCs listed in Table 1 of the Work Plan, Soil analysis for Total Lead onl
SWMU = Solid Waste Management Unit
LNAPL = Light Non-Aqueous Phase Liquic

TABLE 3
Summary of Proposed Site Characterization Activities for AOI 6
AOI 6 Work Plan for Site Characterization
Sunoco Philadelphia Refinery
Philadelphia, Pennsylvania

Proposed Sampling ID	Existing	Proposed	Media	Collection of Soil Sample from 0-2 ft For Site COCs (Non-SWMU Location)	Collection of Soil Sample from 0-2 ft For Site COCs (SWMU Location)	Estimated Completion and/or Sample Depth for Proposed Monitoring Wells and Points	LNAPL Data Exists	COCs	Collection of LNAPL Sample From Existing Well	Objective of Proposed Activity
U-5	X		Groundwater					1		-
URS-1	X		Groundwater					1		Characterize Groundwater in AOI 6
URS-2	X		Groundwater					1		Characterize Groundwater in AOI 6
URS-3	X		Groundwater					1		Characterize Groundwater in AOI 6
URS-4	X		Groundwater					1		Characterize Groundwater in AOI 6
URS-5	X		Groundwater					1		Characterize Groundwater in AOI 6
WP16-5	X		Groundwater					1		Characterize Groundwater in AOI 6
WP16-5	X		Groundwater					1		Characterize Groundwater in AOI 6
WP9-1	X		Groundwater					1		Characterize Groundwater in AOI 6
WP9-2	X		Groundwater				X	1		Characterize Groundwater in AOI 6
WP9-3	X		Groundwater					1		Characterize Groundwater in AOI 6
WP9-4	X		Groundwater					1		Characterize Groundwater in AOI 6
WP9-7	X		Groundwater					1		Characterize Groundwater in AOI 6
WP9-8	X		Groundwater					1		Characterize Groundwater in AOI 6
WPM-11	X		Groundwater					1		Characterize Groundwater in AOI 6
WPM-8	X		Groundwater					1		Characterize Groundwater in AOI 6
B-151		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-152		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-153		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-154		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-155		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-156		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-157		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-158		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-159		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-160		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-161		X	Soil / Groundwater	X		15 ft bgs		soil 2, groundwater 1		Characterize Soil and Groundwater in AOI 6: SWMU 95
B-162		X	Soil / Groundwater	X		15 ft bgs		soil 2, groundwater 1		Characterize Soil and Groundwater in AOI 6:SWMU 92
B-163		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
B-164		X	Soil / Groundwater	X		15 ft bgs		1		Characterize Soil and Groundwater in AOI 6
BH_01_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_02_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_03_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_04_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_05_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_06_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_07_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_08_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_09_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_10_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_11_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_12_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_13_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_14_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_15_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_16_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 92
BH_17_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 95
BH_18_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 95
BH_19_06		X	Soil		X	2 ft bgs		2		Characterize Soil in AOI 6: SWMU 95
BH_20_06		X	Soil	X		2 ft bgs		2		Characterize Soil in AOI 6: SWMU 95
BH_21_06		X	Soil	X		2 ft bgs		2		Characterize Soil in AOI 6: SWMU 95
BH_22_06		X	Soil	X		2 ft bgs		2		Characterize Soil in AOI 6: SWMU 95
BH_23_06		X	Soil		X	2 ft bgs		1		Characterize Soil in AOI 6
BH_24_06		X	Soil	X		2 ft bgs		1		Characterize Soil in AOI 6
BH_25_06		X	Soil	X		2 ft bgs		1		Characterize Soil in AOI 6
BH_26_06		X	Soil	X		2 ft bgs		1		Characterize Soil in AOI 6
BH_27_06		X	Soil	X		2 ft bgs		1		Characterize Soil in AOI 6
BH_28_06		X	Soil	X		2 ft bgs		1		Characterize Soil in AOI 6
BH_29_06		X	Soil	X		2 ft bgs		1		Characterize Soil in AOI 6

Notes:
Final depth of well and screen placement to be determined by geologist based on field observation while completing the boring
Field procedures will be performed in accordance with Appendix A of the Workplan
All proposed monitoring wells will be completed with a 4 inch inner diameter
Average groundwater level in AOI 6 varies between 0 and 10 feet above mean sea level (approximatley 0 to 10 feet bgs
ft bgs = feet below ground surface
COCs = Constituents of Concern
1 = Analysis of COCs listed in Table 1 of the Work Plan
2= Analysis for Total Lead only
1,2 = Groundwater analysis for COCs listed in Table 1 of the Work Plan, Soil analysis for Total Lead only
SWMU = Solid Waste Management Unit
LNAPL = Light Non-Aqueous Phase Liquid

FIGURES



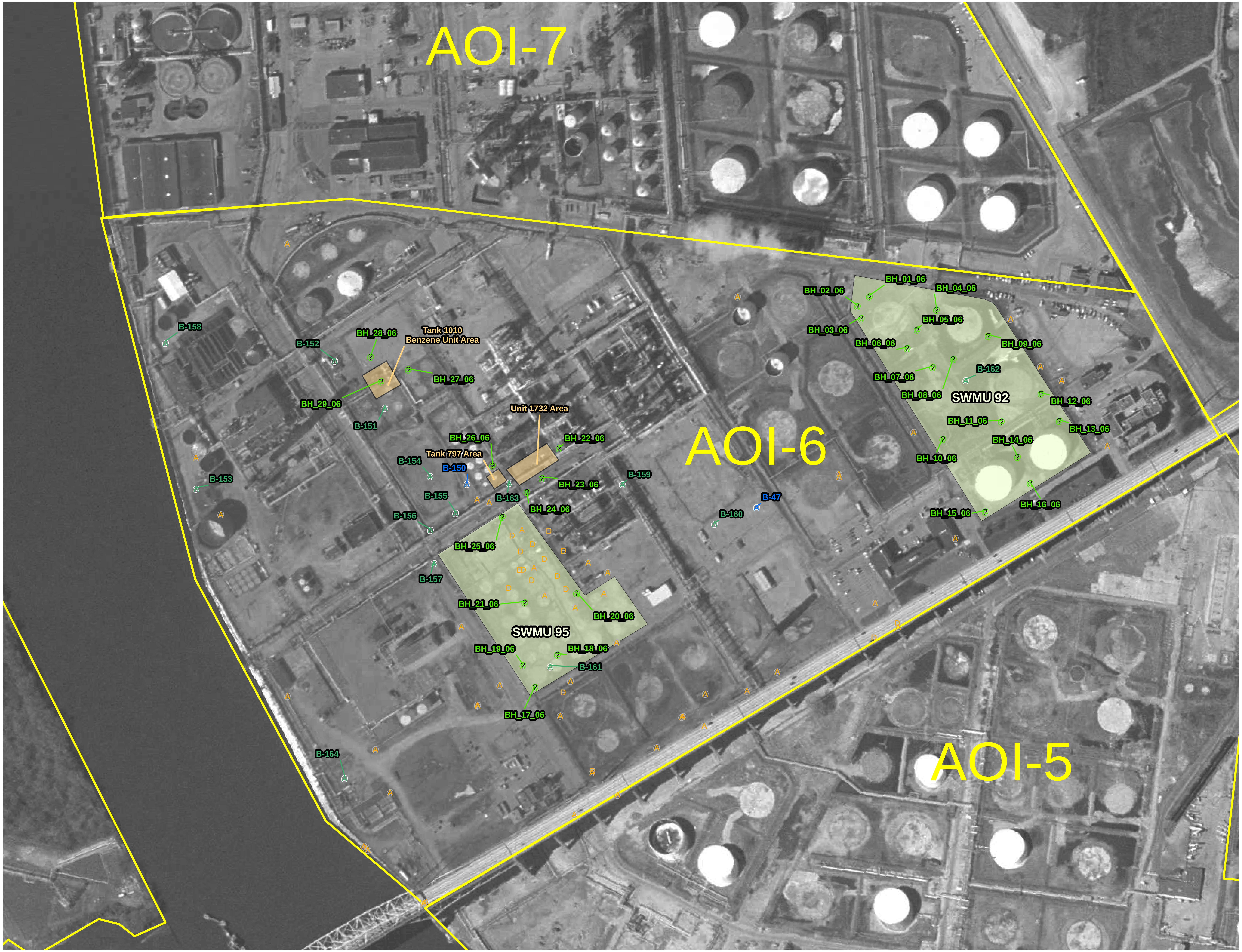
USGS Topographic Map, Philadelphia, PA. Quadrangle, USGS 1995

Sunoco, Inc. (R&M)
Philadelphia Refinery
3144 Passyunk Avenue
Philadelphia, PA. 19145

Figure 1: Site Location Map: AOI 6
AOI 6 Work Plan for Site Characterization
Sunoco Philadelphia Refinery
Philadelphia Pennsylvania

Job Number	Scale: 1" = 800'	Date
2574601	0 400 800 Feet	January 18, 2006

Q:\Data6\2574601\ArcGIS\MapDocuments\AOI 6 work plan\Figure 1- AOI 6 Boundaries.mxd



Legend

Proposed Activities

- Shallow Soil Sample Locations (0-2 feet)
- New Trenton Gravel Monitoring Well
- Proposed LNAPL Sample Location (from existing MW)

Exisiting Features

- Existing Monitoring Point
- Existing Recovery Well
- Leaded Tank Bottom Solid Waste Management Unit
- AOI Boundary

Figure 2: Summary of Proposed Site Characterization Activities for AOI 6
AOI 6 Work Plan for Site Characterization
Sunoco Philadelphia Refinery
Philadelphia, Pennsylvania

Sunoco, Inc. (R&M)
Philadelphia Refinery
3144 Passyunk Avenue
Philadelphia, PA.
19145

0 150 300 Feet

SCALE: 1" = 150'
DATE: January 18, 2006
DRN. BY: JSC
CKD. BY: JH
JOB#: 2574601

Q:\\Data6\2574601\ArcGIS\MapDocuments\AOI 6 Work Plan\Fig

APPENDIX A

FIELD PROCEDURES

APPENDIX A
FIELD PROCEDURES
AOI 6 WORK PLAN FOR SITE CHARACTERIZATION
SUNOCO PHILADELPHIA REFINERY
PHILADELPHIA, PENNSYLVANIA

A.1. LIQUID LEVEL ACQUISITION

Responsible Personnel: Technicians and Geologists

Training Qualifications:

All field personnel involved in liquid level acquisition shall have, as a minimum, completed OSHA 40 HOUR HAZWOPER training and completed the 3-day minimum field training requirements as specified within the Corporate Health and Safety Plan. Prior to solo performance of liquid levels, all field personnel will have performed a minimum of three site visits under the direct supervision of experienced personnel.

Health and Safety Requirements:

Personal Protective Equipment (PPE) Required:

Level D attire including steel toe/steel shank boots. Based on previous site visits or current air monitoring results, Level C attire may be required. The PPE required to upgrade to Level C may include: nitrile gloves, disposable outerboots, Tyvek coveralls, and a respirator. Safety glasses or hard hats may also be required in certain areas.

Site Controls:

Safety cones and or caution tape should be used in high traffic areas. The "Buddy system" may also be employed in high traffic areas.

Potential Hazards:

Traffic, pinch and trip, chemical (airborne and physical contact) and biological. Additional hazards are mentioned in site-specific HASP.

Materials and Equipment Necessary for Task Completion:

Electronic oil/water interface probe or conductivity water line, decontamination supplies (Liquinox, deionized-distilled water, appropriate containers, scrub brush, and sorbent pads or paper towels), air monitoring instrument (optional, based on previous site visits).

Methodology:

The task involves the deployment of a liquid sensing probe into a well (in most cases), recording the reading, and decontaminating the probe. The recorded field readings can then be utilized for one of several applications including: well sampling, water table gradient mapping, separate-phase hydrocarbon occurrence, thickness, and or gradient mapping, and various testing procedures.

The proper procedure for liquid level acquisition from a well is as follows:

1) The wells should be gauged in order of least to most contaminated based on existing sampling data or separate-phase hydrocarbon occurrence.
2) The gauging instrument is decontaminated prior to initial deployment and after each well to prevent cross contamination between wells.
3) Decontamination procedures include the following steps:

    a) Remove gross contaminants with sorbent pad or towel.
    b) Rinse/scrub equipment with water.
    c) Scrub equipment in Liquinox@/deionized-distilled water solution.
    d) Double rinse with deionized-distilled water.
    e) Air dry.

4) The well(s) to be gauged may need to be marked off with safety cones and or caution tape in order to protect personnel from auto traffic; the "Buddy system" may also be employed.
5) The manhole cover is then lifted off of the well head. A pry bar may be needed to prevent personal injury in the case of large manhole covers.
6) The probe is lowered into the well until the instrument signals contact with liquid.
7) The corresponding reading is recorded when the instrument signals either water or product. A clear bailer may be used to verify the existence or approximate amount and appearance of product.
8) The probe is then retracted from the well and decontaminated accordingly.
9) The well is then secured appropriately.
10) Note the start and stop time for gauging round in the field book.

A.2. GROUNDWATER MONITORING PROCEDURES

Responsible Personnel: Technicians and Geologists

Health and Safety Requirements:

Site specific HASP must be completed and reviewed by field personnel. Ambient air monitoring will be performed quarterly at all treatment areas to determine the necessity of PPE upgrade. As a minimum, level "D" attire will be worn.

Training Qualifications:

All field personnel involved in groundwater monitoring shall have, as a minimum completed OSHA 40 HOUR HAZWOPER training and completed the 3 day minimum field training requirements. Prior to groundwater monitoring, all field personnel will have sampled a minimum of three sites under the direct supervision of experienced personnel. Field personnel will also have experience in vapor monitoring techniques and sampling equipment decontamination.

Materials and Equipment Necessary for Task Completion:

A list of equipment required to access, gauge, purge, and sample site monitoring wells is presented below. Also listed are materials necessary to store, label, preserve, and transport groundwater samples.

- Current site map detailing well locations.
- Field data book for recording site data.
- Liquid level gauging device (graduated, optical interface probe).
- Keys and tools to provide well access.
- Appropriate sample containers and labels: volatile samples will be collected in laboratory provided 40 milliliter (ml) glass vials with plastic caps fitted with Teflon ® lined septa; all sample bottles will be laboratory sterilized and will contain the appropriate preservative, if applicable.
- Appropriate well purging apparatus as determined by volume of groundwater to be purged and compounds to be analyzed.
- Teflon ® (or equivalent) bottom-loading bailer to extract groundwater sample.
- Clean nylon or polypropylene bailer cord.
- Disposable nitrile sampling gloves.
- Decontamination supplies.
- Calibrated five-gallon bucket and watch or stopwatch to determine discharge rate during purging.
- Blank chain-of-custody forms.
- Cooler and ice for sample preservation.

Methodology for Three Well Volume Sampling:

Prior to actual site visitation for the groundwater sampling event, the following data will be reviewed to ensure proper preparation for field activities:

- Most recent liquid level data from all wells.
- Most recent analytical data from all wells to determine gauging and sampling sequence.
- Well construction characteristics.

Each monitoring well to be sampled will be gauged to obtain liquid level data immediately prior to initiation of the sampling process. Refer to Liquid Level Gauging SOP for appropriate well gauging procedures. Liquid level data will be recorded in a field book. Should free-phase petroleum product be detected by the gauging process and verified through inspection in a pre-cleaned acrylic bailer, groundwater sampling will not be conducted at that location.

The sampling procedure will be initiated by purging from the well a minimum of three well volumes, except in cases where the well is pumped dry, as referenced below. Well purging is performed to remove stagnant water and to draw representative water from the aquifer into the well for subsequent sampling and analysis for the established parameters. In extreme cases where a well is pumped dry and/or shows little recharge capacity, the well will be evacuated once prior to sample procurement. Well volume calculations will be based on total well depth as determined during well installation and depth-to-water measurements obtained immediately prior to sampling.

Well purging is performed with various equipment including 1) a dedicated bailer for hand bailing low volumes of water, 2) a surface mounted electric centrifugal pump with dedicated polyethylene tubing, or 3) submersible pump (when the depth to water is greater than 20 feet) with dedicated polyethylene tubing. During pumping, the intake will be placed directly below the static water surface and slowly lowered during the purging process. This procedure may not prove necessary in low-yielding wells but is important in high-yielding, permeable strata where an intake initially placed deep in a well may draw laterally and have little influence in exchanging water from shallower depths within the well bore.

Flow rate during well purging will be approximated by the bucket and stop watch method. The duration of pumping required to remove three well volumes will be calculated directly from this flow rate. After purging, the well will be allowed to recover for a period of approximately two hours prior to sample collection. This action will permit a consistent groundwater flux into each well and allow for VOC stabilization prior to sample extraction. All fluids removed during purging will be treated on-site with activated carbon.

The sequence of obtaining site groundwater samples will be based upon available historical site data for existing wells and soil organic vapor analyzer (OVA) readings for newly installed wells. Site wells will be sampled in order from the lowest to highest concentration of water quality indicator parameters based upon the most recent available set of laboratory analyses to reduce the potential for sample cross-contamination. Groundwater samples will not be obtained for analysis from any well containing a measurable free product layer.

The following sequence of procedures will be implemented for the collection of groundwater samples from monitoring wells.

1) Establish a clean work area where sampling equipment will not come in contact with the ground or any potentially contaminated surfaces.
2) Use a laboratory, pre-cleaned Teflon@ sampling bailer for each well.
3) Don an unused, clean pair of nitrile gloves.
4) Attach an appropriate length of unused, clean nylon or polypropylene cord to the designated sampling bailer.
5) Select appropriate laboratory-sterilized sample containers.
6) Slowly lower sampling bailer into well until water surface is encountered; continue to lower the sampling bailer into the standing water column to one foot below the water surface.
7) Retrieve bailer at a steady rate to avoid excess agitation.
8) Visually inspect bailed sample to ensure that no free product or organic detritus has been collected.
9) Uncap first designated sample vial and fill from bailer as rapidly as possible but minimizing agitation; secure septum and lid.
10) Inspect sealed sample for entrapped air; if air is present within sample vial. Remove lid and repeat vial filling, sealing and inspection process until no air is present.

11) Repeat Steps 9 and 10 for the second designated vial; all volatile parameter samples will be collected in duplicate.
12) Complete and attach labels to sample containers noting sample collector, date, time, and location of sample; record same data in field book.
13) Place samples in ice-filled cooler in such a manner as to avoid breakage. Samples collected for VOC analysis will be maintained at a temperature of 4°C.

Discard gloves and bailer cord and move to next sample location.

Methodology for Low-Flow Purging and Sampling:

For wells that will be Low-Flow purged and sampled, the USEPA Region III Bulletin QAD023: *Procedure for Low-Flow Purging and Sampling of Groundwater Monitoring Wells* will be followed. The following data will be reviewed for each well in order to set the pump intake for the low flow sampling:

- Soil boring (lithologic) log and continuous soil sample PID;
- Well construction log showing the screened interval;
- Identification of the most permeable zone screened by the well;
- Approximate depth to static water;
- Proposed pump intake setting; and,
- Technical rationale for the pump intake setting, preferably across from the most impacted/contaminated subsurface interval.

Equipment

Adjustable rate, submersible, bladder pumps in conjunction with Teflon or Teflon-lined polyethylene tubing for purging and sampling will be used. The tubing diameter will be between 3/16-inch to ½-inch inner diameter and the length of the tubing extended outside the well will be minimized. Flow through cells will be used to evaluate parameters during sampling. Monitoring well information, equipment specifications, water level measurements, parameter readings, and other pertinent information will be recorded during monitoring well purging and sampling.

Sampling Procedure

The following protocol details the low-flow sampling procedure that will be used for sampling the monitoring wells.

1. PID Screening of Well. A PID measurement will be collected at the rim of the well immediately after the well cap will be removed and recorded on the sampling form.

2. Depth to Water Measurement. A depth to water measurement will be collected and recorded. To avoid disturbing accumulated sediment and to prevent the inadvertent mixing of stagnant water, measuring the total depth of the well will be done at the completion of sampling on an annual basis.

3. Low Stress Purging Startup. Water pumping will commence at a rate of 100 to 400 milliliters per minute (mL/min). This pumping should cause very little drawdown in the well (less than 0.2-0.3 feet) and the water level should stabilize. Water level measurements are made continuously and will be recorded in milliliters per minute on the sampling form.

4. Low Stress Purging and Sampling. The water level and pumping rate will be monitored and recorded every five minutes during purging, and any pumping rate adjustments will be recorded. During the early phase of purging, emphasis will be placed on minimizing and stabilizing pumping stress, and recording any necessary adjustments. Adjustments, when necessary, will be made in the first 15 minutes of purging. If necessary, pumping rates will be reduced to the minimum capabilities of the pump to avoid well dewatering. If the minimal drawdown exceeds 0.3 feet, but the water level stabilizes above the pump intake setting, purging will continue until indicator field parameters stabilized, as detailed in Step 5 below. If the water level drops below the pump intake setting at the absolute minimum purge rate, the pump will remain in place and the water level will be allowed to recover repeatedly until there will be sufficient water volume in the well to permit the collection of samples.

5. Indicator Field Parameters Monitoring. During well purging, indicator field parameters (DO, turbidity, pH, specific conductance, and redox potential) will be monitored every five minutes (or less frequently, if appropriate). Purging will be considered complete and sampling began when all the aforementioned indicator field parameters had stabilized. Stabilization will be achieved when three consecutive readings, taken at five (5) minute intervals (or less frequently, if appropriate), are within the following limits:

   - DO (±10 percent)
   - turbidity (±10 percent)
   - specific conductance (±3 percent)
   - pH (± 0.1 unit)
   - redox potential [Eh] ±10 mv)

Temperature and depth to water will be also monitored during purging. Should any of the parameter-reading components of the flow-through meter fail during sampling, the sampling team will attempt to locate a replacement flow-through meter. If none is available, the sampling team will measure that parameter with an individual criteria meter. Any other field observations relating to sample quality, such as odor, foaming, effervescence, and sheens, will also be recorded on the sampling form.

6. Collection of Ground Water Samples. Water samples for laboratory analyses will be collected before the groundwater had passed through the flow-through cell by either using a by-pass assembly or by temporarily disconnecting the flow-through cell. All sample containers will be filled by allowing the pump discharge to flow gently down the inside of

the container with minimal turbulence. During purging and sampling, the tubing remains filled with water in order to minimize possible changes in water chemistry upon contact with the atmosphere. Methods employed to ensure that the outlet tubing will be filled include (i) adjusting the tubing angle upward to completely fill the tubing and (ii) restricting the diameter of the tubing near the outlet of the tubing.

The order in which samples will be collected is as follows:

- Volatile organics
- Gas sensitive (e.g., Fe^{+2}, CH_4, H_2S/HS)
- Base/Neutrals or PAHs
- Total Petroleum Hydrocarbons
- Total metals
- Dissolved metals
- Cyanide
- Sulfate and chloride
- Nitrate and ammonia
- Preserved inorganic
- Non-preserved inorganic
- Bacteria

Decontamination Requirements:

Numerous practices are employed throughout the processes of site investigation and sampling to assure the integrity of the resulting data. Of particular significance to the procedures of groundwater measurement and sampling is the limitation, whenever possible, of materials inserted into a well bore and, even more importantly, of materials transferred from well to well.

Many items can be discarded between well sampling and/or gauging locations without significantly impacting project costs. Dedicated sampling equipment which can be discarded between well sampling locations without significantly impacting project costs, will be used whenever possible to preclude decontamination requirements. Sampling equipment included in this category are Teflon ® bailers, nitrile gloves, and bailer cord. However, other investigative and sampling equipment, including such items as liquid level probes, must be reused from well to well.

The danger in multi-well equipment applications lies in the potential of cross-contamination. While the threat of cross-contamination is always present, it can be minimized through the implementation of a consistent decontamination program during sensitive site measurement and data collection activities. The decontamination procedure is outlined below:

All site equipment used in a multi-well capacity will be decontaminated immediately prior to initial use and between each well. Standard site decontamination procedures for the optical interface probes between wells will be performed according to the following schedule:

- Initial rinse with clean tap water to remove excess residuals.
- Scrub equipment with sponge or clean, soft cloth in a distilled water/Liquinox@ (or equivalent) solution.
- Double rinse with deionized/distilled water.

Rinse water generated during decontamination procedures will be treated on-site by passing the water through a bucket filled with activated carbon prior to disposal.

A.3. SOIL SAMPLING & WELL INSTALLATION

Responsible Personnel: Geologist

Training Qualifications: All field personnel supervising drilling activities shall have completed OSHA 40-Hour training, and three days of field training. Personnel supervising the well installation shall have observed drilling procedures for a minimum of three under the direct supervision of experienced personnel. Field personnel will have experience in operating the following field equipment: interface probe and photo-ionization detector (PID). Personnel should be able to describe soils encountered during drilling for generation of well logs.

Health and Safety Requirements:

A site specific HASP must be completed and reviewed by all field personnel. Prior to deploying a rig to the site, a utility call must be made (i.e. Pennsylvania One-Call) to allow mark-out of known subsurface utilities and associated laterals proximal to the site. Site plans, if available, should be reviewed to document and avoid the location of on-site utilities. No drilling should occur on retails sites within the exclusion zone. This zone is defined as the area between the pumps, the tank field and the station building. The area is excluded from drilling activities due to the likely occurrence of subsurface petroleum distribution lines. After review of all known mapped and marked utilities, a site reconnaissance will be performed to document the location of utility meters and storm sewer drains. In addition, the location of overhead utilities must be documented. After completing the subsurface and overhead utility review, the area to drill may be observed as clear or the location may be adjusted to a “clear” location.

Once the drilling location is established, the area must be marked with cones to alert area traffic of the work area. Other health and safety concerns include slip/trip hazards, working with heavy equipment and overhead work hazards. During drilling activities, a minimum of protective work gloves, steel toed boots, hard hats, and safety goggles must be worn.

A final health and safety requirement includes hand clearing the borehole, prior to advancing the borehole with the drill rig. To ensure the safety of workers, the borehole will be cleared by hand or air knife, to depth of 5 feet below ground surface. This will serve to clear the area of utilities, prior to drilling.

Decontamination Requirements:

All down-hole equipment must be steamed cleaned prior to drilling at each boring/well location. All soil sampling equipment must be cleaned with detergent and rinsed with distilled water prior to deployment into the borehole. All well construction materials (i.e. PVC well casing, PVC well screen, sand pack, bentonite seal) should be clean and dedicated to each hole.

Methodology for Borings Outside SWMU Areas in AOI 6:

1) Borehole Advancement

During soil sampling or well installation activities, a borehole is advanced into the unconsolidated subsurface materials or bedrock via a drill rig (or similar). Various types of drilling methods could be deployed to advance the hole. A description of each drilling method is included below:

a) Hollow Stem Auger

A spiral tool form is used to move material from the subsurface to the surface. A bit at the bottom cuts into the subsurface material. Spiral augers on outside convey the material to the surface while spinning. The center of the auger is hollow like a straw when the inner drive rods and plug are removed. During drilling or formation cutting, the center is filled with rods connected to a plug at the bottom bit. Once the desired drilling depth is reached, the center plug and rods can be pulled out, leaving the hollow augers in place. The hollow augers hold the borehole to remain open for sediment sampling and well installation.

b) Air Rotary

A drill bit at the bottom of rods is used to cut into the subsurface material. Air injected into the drill rods escapes through small holes in the drill bit and conveys the drill cuttings to the surface.

c) Geoprobe®

The geoprobe® sampling allows collection of soil by directly pushing (through hydraulic hammering) a sampling device lined with a plastic macrocore into the soil column.

d) Hand Auger

A stainless steel or aluminum hand auger will be physically advanced to the desired soil sampling depth.

2) Soil Sampling

Soil samples will be obtained for lithologic logging and laboratory analysis for chemical contaminants with one of three different sampling devices: Split barrel spoon sampler, hand auger or Geoprobe® soil sampler. For either method, the sampling devices are lowered through the hollow-stem augers or open borehole to allow sampling of the undisturbed sediments below the auger bit. Soil samples will be collected at intervals which appear to be visually impacted or from intervals which exhibit the highest deflections on the screening device (PID or similar).

a) Split barrel spoon sampler (split spoon)

The split spoon sampler will be driven into the soil column in accordance with ASTM Standard Method D1586 (Reference A6, Appendix E). Soil sampling by split barrel spoon will entail drilling a borehole with a hollow-stem auger to the desired sampling depth (standard five foot intervals). After augering to the desired depth, slowly and carefully lower the split barrel spoon sampler attached to the drill rod extension into the borehole. Drive the sampler into the soil by repeated blows from a 140 Lb. hammer with 30 inch travel. Record the blow counts required to drive the split spoon sampler each successive six inch interval. Remove sampler for borehole, split barrel open, remove soil sample utilizing a stainless steel knife to trim the top and edges of the sample and containerize sample in appropriate sample jar.

b) Geoprobe®

The geoprobe® liner is dedicated to each soil sampling interval. After retrieval of the sample, the liner may be sliced open and the soil sample can be logged and containerized in the appropriate sample jar. During shallow soil sampling from fine-grained sediments, the geoprobe® can advance the sampler directly into the ground, without the advance of an augered borehole.

c) Hand Auger

The hand auger allows for soil from the desired interval to be collected directly by removing the soil column that is contained in the auger portion of the device.

Methodology for Borings Inside SWMU Areas in AOI 6:

1) Borehole Advancement

During soil sampling activities, a borehole will be advanced in areas where suspected leaded tank bottoms are located via a geoprobe® or hand auger. Leaded tank bottom materials are distinguished by distinctive rust/red to black, metallic mostly oxidized scale materials. Leaded tank bottoms are also sometimes in a matrix of petroleum wax sludge. In areas where the suspected tank bottom material is located in the vicinity of a tank berm, the boring will be completed immediately adjacent to the tank berm within the tank dike, but still within the suspected leaded tank bottom area. If materials are encountered matching the physical description stated above, they will be delineated through additional borings and sampling.

2) Soil Sampling

Soil samples will be obtained for lithologic logging and laboratory analysis for chemical contaminants with one of two different sampling devices: Geoprobe® soil sampler or hand auger. For either method, the sampling devices are lowered through the hollow-stem augers or open borehole to allow sampling of the undisturbed sediments below the auger bit. Soil samples will be collected at intervals which appear to be visually impacted or from intervals which exhibit the highest deflections on the screening device (PID or similar). If the soil samples collected in the leaded tank SWMU areas exhibit total lead concentrations exceeding 450 mg/kg (Act 2 non-residential MSC for lead), then the samples will be submitted for hazardous characteristic analysis under RCRA.

3) Well Construction

After drilling to the desired depth or the desired interval, permanent monitoring wells can be installed to allow groundwater sampling. In general, wells are constructed with slotted screen, which allows groundwater to flow into the well at the desired monitored interval and well casing, which restricts groundwater flow into the well from undesired interval. In most cases the well materials are constructed of PVC. In conditions where the shallowest groundwater interval is monitored, a single case construction monitoring well is installed. In conditions where multiple water bearing units occur and deep groundwater conditions are selected for monitoring, a double cased well is installed.

a) Single Casing Construction

The construction details of a monitoring well are determined by soil type, depth to groundwater and relative fluctuation of groundwater level. After drilling to the desired depth, a monitoring well is constructed for installation into the evacuated borehole. The well consists of a bottom cap, a length of screen and length of well casing. To determine the length of screen used, seasonal groundwater table or tidal fluctuations should be considered to allow the water table to intercept the well screen throughout the year. The assembled well is then inserted into the borehole.

The annular space between the well screen and subsurface is filled with a sand pack, which consists of clean, sorted sand. The sand pack allows water flow into the well but acts as a filter to prevent subsurface sediments from silting in the well. The sand pack extends one to two feet above the top of well screen. Above the sand pack, a seal is installed in the annular space between the well casing and the subsurface. The seal is comprised of hydrated bentonite and prevents surface water from infiltrating the well screen. Above the well seal, the annular space is backfilled with drill cuttings or cement. A cap is placed on the top of the well to further prevent infiltration of the surface water. The top of the well is protected with either a stand-up pipe or a locking, flush mount box.

b) Double Casing Construction

In cases where multiple water bearing zones occur, a double case well is installed to allow monitoring of the deeper water bearing zones. Construction of a double cased well is similar to that of a single case well; however, to prevent groundwater infiltration from shallower water bearing zones, a second casing is installed. This type of construction requires drilling two different diameter boreholes.

During drilling through the shallower groundwater zones, large diameter augers/bits are used to create a large diameter borehole. The borehole is advanced through the shallower water bearing area which will not be monitored. An outer casing is installed to seal the deeper monitoring well from infiltration from the shallow water bearing zones. After the outer casing is installed, the borehole is advanced deeper with smaller diameter auger/bit. The outside diameter of second augers fit within the inside diameter of the outer casing. The borehole is advanced to allow monitoring of the deeper water bearing zone. Once the desired depth is obtained, a monitoring well is installed within the outer casing, using similar methods as described in the single casing construction (3a, above). The outside casing prevents shallow groundwater infiltration into the well. The inside casing prevents surface water infiltration into the well.

4) Soil Cutting Handling

Cuttings generated from drilling will be containerized or stock-piled, undercover, until appropriate disposal is determined. In the case the soils are not impacted, the cuttings may remain on-site. Impacted soils will be removed using appropriate hazardous waste handling procedures and disposed of with an approved hazardous waste handler.

5) Well Development

After installation, monitoring wells are developed to remove residual sediments within the well and annular space. Water is pumped from the well a low flow rate (to minimize turbulence within the well and associated sand pack) until groundwater flowing from the well appears relatively free of sediments.

Documentation:

All site activities should be detailed in the site investigators fieldbook. The entry shall include the date, time, weather, address, and persons present on-site. In addition, data required to create well construction logs or boring logs (if no well is constructed) should be collected. This data includes soil type, relative moisture content, depth of water table, observed impact, soil screening measurements (if PID is used), blow counts (if split spoon samples are collected), sample recovery, depth of borehole, length of well screen, length of well casing(s), sand pack interval, well seal interval. The site investigator should identify the relative location and number.

A.4. NON-AQUEOUS PHASE LIQUID (NAPL) SAMPLING PROCEDURES

Responsible Personnel: Technicians and Geologists

Training Qualifications:

All field personnel involved NAPL sampling, as a minimum completed OSHA 40 HOUR HAZWOPER training. Prior to NAPL sampling, all field personnel will have worked a minimum of three sites under the direct supervision of experienced personnel. Field personnel will also have experience in sampling and vapor monitoring techniques and sampling equipment decontamination.

Materials and Equipment Necessary for Task Completion:

A list of equipment required to sample NAPL from a monitoring well is presented below:

- Current site map detailing well locations.
- Field data book for recording site data.
- Liquid level gauging device (graduated, optical interface probe).
- Keys and tools to provide well access.
- Appropriate sample containers and labels. NAPL samples will be collected in laboratory provided 40 milliliter (ml) glass vials with plastic caps fitted with Teflon ® lined septa; all sample bottles will be laboratory sterilized and will contain the appropriate preservative, if applicable. A minimum of 10 ml is required for laboratory analysis. In the case that sufficient volume is not obtained, a swabbing technique (described below) will be used.
- Sorbent pads (required for swabbing technique).
- Teflon ® (or equivalent) bottom-loading bailer to obtain NAPL sample.
- Clean nylon or polypropylene bailer cord.
- Decontamination supplies.
- H&S supplies (tyvek, nitrile gloves, safety goggles).
- Blank chain-of-custody forms.
- Cooler and ice for sample preservation.

Health and Safety Requirements:

Site specific HASP must be completed and reviewed by field personnel. As a minimum, modified Level "D" attire will be worn. Individuals performing NAPL sampling are required to wear safety goggles, tyvek suit, and nitrile sampling gloves.

Decontamination Requirements:

During NAPL sampling activities, dedicated sampling equipment (i.e. Teflon ® bailers, nitrile gloves, and bailer cord) are utilized; thereby, eliminating decontamination requirements. The interface probe, used to record the presence of NAPL and relative thickness prior to sampling, does require decontamination between sampling locations.

All site equipment used in a multi-well capacity will be decontaminated immediately prior to initial use and between each well. Standard site decontamination procedures for the optical interface probes between wells will be performed according to the following schedule:

- Initial rinse with clean tap water to remove excess residuals.
- Scrub equipment with sponge or clean, soft cloth in a distilled water/Liquinox@ (or equivalent) solution.
- Double rinse with deionized/distilled water.

Methodology:

Each monitoring well to be sampled will be gauged to obtain liquid level and relative NAPL thickness immediately prior to initiation of the sampling process. Refer to SOP No. 1 for appropriate well gauging procedures. Liquid level data will be recorded in a field book.

Sampling of the NAPL will occur via two different methods: 1) direct sample or 2) swabbing.

The following sequence of procedures will be implemented for the collection of groundwater samples from monitoring wells.

1) Establish a clean work area where sampling equipment will not come in contact with the ground or any potentially contaminated surfaces.
2) Use a laboratory, pre-cleaned Teflon@ sampling bailer for each well.
3) Don an unused, clean pair of nitrile gloves.
4) Attach an appropriate length of unused, clean nylon or polypropylene cord to the designated sampling bailer.
5) Select appropriate laboratory-sterilized sample containers.
6) Slowly lower sampling bailer into well until water surface is encountered; continue to lower the sampling bailer into the standing water column to one foot below the water surface.
7) Retrieve bailer at a steady rate to avoid excess agitation.
8) Visually inspect bailed sample to ensure for relative thickness of NAPL. If sufficient volume is present (>10 ml) place a direct sample of the NAPL into the laboratory vial. If less than 10 ml of NAPL is present, use a sorbent pad to absorb the NAPL from the surface of the groundwater sample. Place is swab sample into the laboratory vial.
9) Complete and attach labels to sample containers noting sample collector and date, time, and location of sample; record same data in field book.
10) Place samples in ice-filled cooler in such a manner as to avoid breakage. Samples collected for VOC analysis will be maintained at a temperature of 4°C.
11) Discard gloves and bailer cord and move to next sample location.

Documentation:

All site activities should be detailed in the site investigators fieldbook. The entry shall include the date, time, weather, address, persons present on-site, and the aforementioned parameters. Only relevant observations should be recorded. The nature of the work being performed is also appropriate.

A.5. PUMPING TESTS

Responsible Personnel: Hydrogeologists, Engineers and Technicians.

Training Qualifications: All field personnel performing pumping tests shall have completed OSHA 40-Hour training, and three days of field training. Personnel directing the pumping test shall have assisted with a minimum of three tests under the direct supervision of experienced personnel. Field personnel will have experience in operating the following field equipment: interface probe, data logger, submersible pump, related piping and fittings, flow meter and portable generator.

Health and Safety Requirements:

A site specific HASP must be completed and reviewed by all field personnel. Caution must be exercised in set up of electrical equipment, particularly the placement of pumps in a well which could be impacted by floating product. Other health and safety concerns include slip/trip hazards, and area traffic.

Decontamination Requirements:

Pump, discharge lines, hand held probes and all pressure transducers must be cleaned with Alconox and distilled water prior to installation in wells at site, and again following removal. Any water sampling activities to be incorporated during the test must be prepared and used in accordance with the Groundwater Monitoring SOP.

Methodology:

1) Pre-test Considerations:

Some site specific information regarding the geology and hydrogeology of the subject site is needed to determine the most appropriate type of pumping test and to estimate the reliability of the test results. Lithologic logs of the subject site will indicate whether the zone of interest is an unconsolidated formation or a bedrock formation. They should also give a strong indication as to whether the zone of interest is a water table formation, a confined formation or a leaky-confined formation, and whether any preferential (vertical or horizontal) transmissivity may be expected. Logs and/or slug test data will also provide indications as to what test yield is sustainable, and provide a rough indication of the areal extent pumping will influence. Additional pre-test considerations include any obvious positive or negative hydraulic barriers, any tidal effects, and /or any influence from other wells pumping in the area.

Often times, budget considerations and/or time limitations will necessitate the use of a monitoring well as the test pumping well. While this is generally acceptable, the well must be screened deep enough to allow design drawdown to be achieved and friction losses (well loss) in the pumping well must be taken into consideration when the test data are analyzed. A minimum of three monitoring wells in the vicinity of the test pumping well are needed to evaluate formation response. Ideally, the wells should all be at varying distances from the test pumping well and screened across the same zone.

Pumping tests are broken into two general classifications: step tests and constant rate tests. Step tests involve pumping a well at progressively higher rates, at set intervals of one or two hours per step. They are often used to determine the yield a well will sustain during a constant rate test and to evaluate well loss (frictional head loss between the screen/gravel pack and the formation). Constant rate tests are used primarily to evaluate aquifer coefficients for design of groundwater treatment systems and/or water supply purposes. In high sensitivity sites, where budgets permit, the best method is to do a step test first, to evaluate well loss and long term sustainable yield, allow 24 hours of recovery and then initiate the constant rate test.

The test duration is subject to site specific data requirements (i.e. sensitivity. required test goals, etc.) and to budget considerations. Optimally, a constant rate test will be run until all drawdowns have stabilized, and gravity drainage effects are curtailed; however, this is seldom practical due to time limitations. In most instances, an 8 hour constant rate test will be adequate, and a 24 hour test will be sufficient for higher sensitivity sites. Occasionally a 72 hour pumping test is warranted, though this is usually reserved for large scale water supply work. If there are any unexplained water level anomalies observed toward the scheduled end of a test, the test should be continued if at all possible.

The approximate test flow rate needs to be determined in advance for proper pump and discharge design selection. If it is not appropriate to perform a step test, sustainable yield can be estimated from slug test data or a brief (<30 minutes) pumping episode the day before the actual test. Generally, it is best to pump the well at as high a rate as is feasible order to obtain the greatest formation response data from the test. However, if floating product is present at or near the pumping well, drawdown needs to be limited so as not to impact uncontaminated soils below the water table. In these instances drawdown should be limited to less than 5 feet. In water table formations, if there is no concern regarding floating product, drawdown should not exceed two-thirds of the wetted screen depth due to the effects of friction loss.

If the test discharge is contaminated, it must either 1) treated prior to discharge or 2) containerized for off-site disposal. If it is to be discharged directly on- site and allowed to re-infiltrate (verses discharged to a catch basin) it must be routed sufficiently far enough from the test area as to avoid any artificial recharge effects. All appropriate discharge permits must be obtained and complied with. If discharge water is to be treated on-site, proper contaminant loading calculations for the test flow rate, approximate contaminant loading and test duration must be done in advance to insure treatment is completely effective. Any on-site treatment should also have at least one discharge effluent sample lab analyzed to document treatment effectiveness.

2) Pumping Test Set Up:

Prior to starting the test, all well measuring points (i.e. top of casing) should be clearly marked and vertically surveyed to the nearest 0.01 feet. The horizontal distance and orientation of all wells should be surveyed to the nearest 0.1 feet, and illustrated on the site base map. If there are any surface water bodies in the vicinity, a staff gauge should be set up and surveyed in to evaluate possible influences.

The preferred pump to be used for a pumping test is a submersible centrifugal pump ("Grundfos", or equivalent), run off either existing site power or a portable generator. These pumps are not explosion proof, so a conductivity probe must be tied into the pump controls to alleviate any possibility of product coming into contact with the pump. If the test pump is designed to pump total fluids (e.g. air operated double diaphragm pump, jack pumps, etc.) discharge must either be containerized, or treatment must include an oil/water separator to handle any floating product. The submersible pump should be positioned just above the bottom of the well, using a handling line to support the pumps weight.

NOTE: extreme care must be taken that the power cord is neither bearing any of the pumps weight, nor damaged during installation due to the potential for sever electric shock.

Discharge piping from the pump should include a flow meter (preferably with totalizer), followed by a flow adjustment valve. The flow meter should be installed in a straight section of hard piping of sufficient length to avoid meter distortion caused by turbulence (typically about 10 pipe diameters on either side of the meter). In low flow pumping tests, flow rate can be calculated by measuring the exact time required to fill a known sized container.

Ideally, groundwater levels should be static prior to starting the test, so that pumping influences alone can be readily evaluated. Water levels in all monitoring wells and/or nearby surface waters should be gauged a minimum of two times during the 24 hours prior to starting test pumping; readings should not have varied by more than 0.10 feet. Any significant precipitation events within the previous several days will usually result in noticeable water level changes (barometric changes have significant influences in confined and semi-confined formations). If there are any major water level changes that cannot be accounted for prior to test pumping, additional investigation into possible area influences (e.g. local well pumping or construction de-watering) should be conducted.

Exact water level measurements (to the nearest 0.01 feet) and exact time denotations during the test are critical to achieving accurate test results. All personnel involved with taking measurements during the test should have watches with a second hand, and they should all be calibrated to the same time. Adequate liquid level measurements can be obtained using an interface probe ("ORS", "Solinst", etc.) for those wells with floating product. In wells clear of floating product, an electric water level detector ("Solinst", "Hazco", "M-Scope", etc.) or chalked steel tape will provide accurate measurements. All non-dedicated probes must be properly decontaminated after each level reading to prevent any possibility of cross contamination between wells.

Automatic water level recorders are typically used during pumping tests to augment hand measurements and to obtain reliable early time-drawdown data. A pressure transducer allows measure of changes in groundwater levels by measuring differences in pressure experienced by the transducer. The pressure transducers are manufactured by “In-Situ” and are available with many types of data loggers. Some data loggers are capable of connecting to several transducers (Hermits) while others collected data from one transducer (Trolls and Mini-Trolls). The measured depth data for each probe is digitally stored in the data logger as depth (in feet) at a specific elapsed time. At the conclusion of the test, the data logger is brought back to the office, and the test data is down loaded into a computer for analysis.

The transducer is installed in each well to a depth several feet lower than the greatest drawdown depth anticipated. The transducer cable is secured at this depth with duct tape or cable ties attached to the well head, and the transducer is plugged into the data logger. The transducer must not be submerged deeper than the allowable operating pressure, which is noted on each transducer cable spool in PSI. Care must be taken that the transducer cable is not damaged from rough edges at the well head, and that no vehicles run over the cable. In addition, any wells with floating product require an inner PVC stilling well to be installed to prevent the transducer cable from being damaged from contact with product. The stilling well will also eliminate the need for any water level corrections for product thickness.

In terms of prioritization, transducers should be utilized in the wells closest to the pumping well and then pumping well. Wells further from the pumping well can be successfully monitored by hand, due to the reduced likelihood that early time drawdown will be critical. Despite having transducers in given wells, back up hand readings should be taken at least hourly during the first 8 hours of the test, and then at least every 3 hours, to verify the transducer levels.

After the transducers are installed in the wells, and connected to the data logger, hand measurements are taken at each well with a transducer. These levels are then entered into the data logger as initial reference points for comparison to the depths measured by the transducers. Readings from the transducers are not completely reliable until they have been emerged for at least 30 minutes, due to the effects of probe temperature equilibrium.

3) Running the Test:

Prior to starting the pumping test, the data logger must be completely formatted for that particular test, and the operator must be completely familiar with the start up sequence. If possible, the pump discharge control valve should be pre-set to the desired flow rate prior to turning on the pump. However, depending on the test pumps performance curves, minor flow rate adjustments are generally needed during the first hour or two of the test to correct for the additional head experienced by the pump due to increasing drawdown. In addition, movement of the discharge hose after the test has been started should be avoided, since any change in the elevation of the discharge will affect the pumping rate. All changes in flow rate should be recorded with the exact time noted.

A minimum of two field personnel are needed to run a pumping test, with additional personnel required for tests with high complexity. One person should be designated to turn on the pump, adjust the flow rate, check on discharge treatment, etc. The second person should be stationed at the data logger to turn it on at the exact moment the pump is turned on. The data logger will record liquid levels very rapidly during the first part of the test, dropping off logarithmically to what ever intervals are formatted (one measurement every 20 minutes is normal). When the data logger has been activated and is running, early time drawdown measurements should be taken by hand from any wells near the pumping well that do not have transducers.

Any hand monitored wells near the pumping well should be measured frequently during the first few hours of the test, with less frequent measurements during the remainder of the test. A rough rule of thumb is one measurement every half minute during the first 5 to 10 minutes, one every 3 to 5 minutes during the first hour, and one every 10 to 20 minutes for the second hour, and then each well hourly. After the test has been running for a few hours, the transducer level readings should be compared to the hand measurements for verification, or later correction.

It is essential that some data reduction be accomplished in the field, so that major water level trends are recognized during the test. At a minimum, drawdown trends from the pumping well and two of the nearest monitoring wells need to be semi-log plotted against time so that deviations indicative of boundary conditions can be discerned before pumping is ceased. This will allow decisions to be made about whether the test should go for longer than planned.

Generally, water quality samples are taken during a test for laboratory analysis of compounds of interest. These are generally taken after the first hour of pumping and just prior to pump shutdown. If the test is of more than 24 hours duration, it is advisable to get running samples during the middle of the test as well. All samples should be obtained following sampling SOP's.

At the conclusion of the test, water level recovery data should be taken. The recovery data should plot out to an approximate inverse mirror image of the drawdown curve, with feet of recovery measured from the theoretical drawdown that would have been observed if pumping had continued. Recovery data behaves as if there were a nearby well recharging the formation, following image well theory. It has the advantage that there are no variations in the curve produced by variations in pumping rate. In water table aquifers, however, the effects of formation de-watering can cause the recovery trends to be substantially different from drawdown trends. Consequently, recovery data should be used for comparison purposes only, but not relied upon as heavily as drawdown data.

1) Data Analysis:

The data produced by pumping tests are analyzed to estimate aquifer performance characteristics, such as transmissivity, conductivity and storage, which in turn are used to predict groundwater flow under various circumstances. One of the more useful analytical products is a determination of capture zone, which is widely utilized in aquifer contamination work. Capture zone (Keely & Tsang, 1983) calculations describe the radial area (down gradient and side gradient) that a pumping well will draw groundwater in from. In the case of a contamination site, this equals to that portion of the plume a given recovery well(s) will influence, at a given pumping rate(s). Aquifer coefficients determined from a pumping test can be applied to a capture zone analysis for the determination of the best recovery system for a given plume. When the recovery system is operational, capture zone calculations can then be used to evaluate the effectiveness of the system at addressing the contamination plume, what pumping rate is optimal for controlling the plume, and the need for any additional wells. It must be noted, however, that capture zone calculations are relatively simplistic, and far from absolute. Consequently, they should be used with considerable margin for safety, and employed with a large measure of common sense.

The mathematical solutions used in pumping test analysis include many assumptions typical "real world" formations violate in one or more way (e.g., "the formation is of uniform thickness and of infinite areal extent"). In addition, some of the values incorporated into typical pumping test solutions are not actually measured, but are educated estimates (e.g. porosity based on lithology, etc.). Consequently, even the most carefully designed and executed pumping tests have severe precision limitations, and the solutions should never be considered absolute. This is why groundwater flow evaluations are generally conceded to be "a mixture of science and art", and all solutions require a strong application of common sense and experience.

Many problems associated with pumping test data evaluation are due to not recognizing, and/or correcting for, deviations from the theoretical solution employed. Some of the more common errors occur due to: partial penetration effects, formation de-watering effects, casing storage effects, poor pumping well efficiency and/or the application of incorrect equations or units. Consequently, a thorough understanding of the underlying assumptions inherent to the solution employed is required before the validity of the results can be trusted. There are numerous references that describe pumping test analyses. Some of the more recommended references include: Driscoll's "Groundwater & Wells" (1986); Lohmans "Ground-water Hydraulics" USGS Professional Paper 708 (1979) and Fetter's "Applied Hydrogeology" (1980). In addition, the USGS published "Aquifer-test Design, Observation, and Data Analysis" in 1983 by Robert W. Stallman (Applications of Hydraulics, Book 3, Chapter B 1). This is an excellent, common sense, guide to pumping test set up, measurements and data analysis.

Two of the more common pumping test equations used and their applications are listed below:

1) Cooper-Jacob (1946); time-drawdown & distance-drawdown methods: Test data is plotted on semi-log paper, and the slope is used in the solution. Both solutions assume the formation is confined; however, this distinction lessens over time as drawdown becomes stabilized. Distance-drawdown has an added advantage in that it allows water level to respond from across the site to be used, which accounts for some lithologic variations.

2) Boulton (1963), modified by Neuman (1975): This solution is used for determining aquifer coefficients in water table formations, taking gravity drainage (delayed yield) effects into account. Time- drawdown data is plotted on log-log paper and two Theis type curves are matched to get early time-drawdown and late time drawdown, respectively. While this solution most closely matches typical floating product recovery work, it is difficult to apply and often subjective, due to the inherent nature of curve matching solutions.

It is usually appropriate to analyze pumping test data by more than one solution to get a range of aquifer performance values. These values can be averaged, or the most conservative value can be used, or the best fit based on experience can be presented. The computer program "Aqtesolv", produced by Geraghty & Miller, is a very useful tool for solving pumping test solutions. Data from an Insitu data logger can be imputed to the Aqtesolv, and curve matching solutions can be produced automatically, or with some adjustments.

A.6. SLUG TESTS

Responsible Personnel: Hydrogeologists, Engineers, and Technicians

Training Qualifications:

All field personnel performing pumping tests shall have completed 40 HOUR OSHA training and 3 day field requirements. Personnel directing slug tests shall have assisted in at least 3 previous slug tests under the supervision of experienced personnel.

Materials and Equipment Necessary for Task Completion:

"Insitu " Hermit data logger, with one pressure transducer; interface tape or equivalent water level measuring device; "slug in" water displacement cylinder, or large bailer, 5 gallon pail, traffic cones and/or barricades, decontamination water and brush, alconox and decontamination pail.

Health and Safety Requirements:

A site specific HASP must be completed and reviewed by all field personnel. Caution must be exercised in test set up, particularly regarding vehicular traffic. Other concerns regard possible handling of free product, and slip/trip hazards.

Decontamination Requirements:

Any water level measuring probes, bailers and the water displacement cylinder must be cleaned with alconox and distilled water prior to use, and between uses at each well monitoring. Any groundwater and/or free product bailed must be disposed of in an approved manner, preferably in a properly installed, on-site holding tank.

Methodology:

Slug tests are utilized to obtain rough estimates of aquifer performance coefficients. They involve calculations based on the water level response of a well to the addition or subtraction of a known volume. They can be broken into two basic types of field exercises: slug-in tests and slug-out tests. As their names imply, slug-in tests involve the addition of water (volume) to the well, while slug-out tests involve the removal of water (volume). Water level response is monitored immediately following the displacement change, and for the next hour or so until the well has returned to approximately 90% of its original static level. Water level responses can be measured either rapidly by hand or with an "Insitu" Hermit data logger (or equivalent).

1) <u>Field Procedures</u>:

Exact well completion details are needed to perform slug test calculations. These include: total depth, total screened interval, depth to static water, casing diameter, screen diameter, gravel pack diameter and gravel pack interval. While these details should be documented on the well log, static water level and total depth should be field confirmed before the test. Where possible, several wells per site should be slug tested to obtain an average conductivity value for a site, or to evaluate lithologic variables across a site. Addition data comparisons are accomplished by performing both slug-in and slug-out tests on the same well, where time permits.

Slug-In Tests: The slug-in method is best accomplished by lowering a cylinder of known volume into the well, and measuring the water level response over time. The displacement volume should be sufficient to cause a several foot initial change in the water level. In the case of a typical 4 inch diameter monitoring well, a simple displacement cylinder can be constructed using a 3 inch diameter PVC casing, capped at both ends and filled with clean sand. An over all length of 5 feet provides adequate displacement volume for a typical water table well having about 10 feet of standing water. A steel eye should be bolted into one cylinder cap for attachment of a disposable lowering rope (discard lowering rope between wells to prevent any cross contamination).

If a Hermit data logger is to be used for a slug-in test, the transducer should be set in the well at least one foot below where the bottom of the displacement cylinder will rest upon insertion, but not lying on the bottom (beware of silt clogging the transducer tip). Depth to water should be measured and compared to the transducer reading for correlation. When the Hermit has been properly imputed for the slug test, the hermit should be activated and the displacement cylinder should be rapidly, but carefully, lowered into the well to below the water surface. *NOTE: Take particular care that insertion of the displacement cylinder does not damage the transducer or cable.* When activated, the Hermit will be automatically recording time and water levels, starting at 6 readings per second, then decreasing exponentially over time. If water level changes are to be taken by hand, they must be carefully obtained at least every minute. When the well has recovered to about 90% of its original static level, the test may be concluded. If the test has proceeded for an hour and not recovered to at least 90% of the original static, additional data will be of marginal value and the test may be concluded.

2) Slug-out Tests:

Slug-out tests are performed in the same basic manner as slug-In tests, only by removing a known volume from the subject well. In wells that recharge rapidly during slug-in tests, a slug-out test can be performed by merely resetting the Hermit and extracting the displacement cylinder. The more conventional method of performing a slug-out test is to use a single long hand bailer to remove a known volume of water from the well. Typical bailers used for 4 inch diameter monitoring wells are either long steel bailers (similar to those often used by drillers to develop monitoring wells) or 2 Lexan sample bailers joined end to end to form one single long bailer. The bailer is lowered into the well prior to starting the Hermit, and the slight water level rise from the bailer is allowed to stabilize back to static. The Hermit is then activated, and the bailer is rapidly removed from the well, thereby creating the instantaneous. The test is run to 90% recovery, or one hour, like the slug-in test. If the bailed water is contaminated, it must be disposed of properly via either storage in an on site holding tank or on-site treatment with a portable carbon treatment container.

The validity of slug test values are highly field dependant. Some of the more common field oriented problems arise from:

a) Subject wells are not adequately developed prior to testing.
b) Formation slough occurred during drilling, so gravel pack volume is underestimated.
c) Water displacement is not instantaneous due to the bailer leaking during extraction.
d) The pressure transducer is jarred during water displacement.
e) Water level changes are too rapid to get accurate measurements.

3) Data Analysis:

Field data from slug tests can be analyzed by hand or using "Geraghty & Millers" Aqtesolv computer program. If the field data was taken with the Hermit, the data can be transferred to Aqtesolv for analysis, saving considerable time over hand analysis. There are four well recognized analytical methodologies general employed. These methods and their assumptions are listed below:

Application	Hvorslev	Bouwer & Rice	Cooper	Nguygen-Pinder
Confined Fm.	**X**	**X**	**X**	**X**
Unconfined Fm.	**X**	**X**		**X**
Screened across water level		**X**		
Accounts for partial penetration	**X**	**X**		**X**
Specific storage >0			**X**	**X**
Allows for anisotropy	**X**			
Assumes infinite borehole storage	**X**	**X**	**X**	**X**

As illustrated on the chart above, slug tests performed in water table formations can be solved using either Hvorslev or Bouwer & Rice methods. The Bouwer & Rice method has the advantage of accounting for screening across the water table, while the Hvorslev method allows for anisotropy. Confined formation slug tests can be analyzed by any of the four methods, though the Cooper method is most often used. It is often beneficial to solve slug tests by more than one method to evaluate possible conductivity ranges.

It must be stressed that slug test data is very approximate and limited in its accuracy. It is generally conceded that conductivity' values derived from slug tests are usually within an order of magnitude of the real conductivity, and therefore are only approximations. Consequently, any judgments based on slug test values must be used with extreme caution and incorporate a large measure of common sense and experience.