RADFORD ARMY AMMUNITION PLANT, VIRGINIA

Area O
RCRA Facility Investigation/ Corrective Measures Study Report

Prepared for:

USACE Baltimore District
10 S. Howard St.
Baltimore, MD 21201

Prepared by:

Shaw Environmental, Inc.
2113 Emmorton Park Rd.
Edgewood, MD 21040

Draft Document

August 2008

received 5-12-09

09-47

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

April 29, 2009

Commander,
Radford Army Ammunition Plant
Attn: SJMRF-OP-EQ (Jim McKenna)
P.O. Box 2
Radford, VA 24141-0099

P.W. Holt
Environmental Manager
Alliant Techsystems, Inc.
Radford Army Ammunition Plant
P.O. Box 1
Radford, VA 24141-0100

Re: Radford Army Ammunition Plant, Va.
Area of Concern (AOC) O

Dear Mr. McKenna and Ms. Holt:

The U.S. Environmental Protection Agency (EPA) and the Virginia Department of Environmental Quality (VDEQ) have agreed that closure of Area of Concern (AOC) O at the Radford Army Ammunition Plant (RAAP) in Radford, Va, will be handled under the VDEQ Oil Control Program. A No Further Action Decision for AOC O will be issued under RAAP's Resource Conservation and Recovery Act (RCRA) Permit.

If you have any questions, please call me at 215-814-3413, or Jim Cutler at 804-698-4498. Thanks.

Sincerely,

William Geiger
RCRA Project Manager
Office of Remediation (3LC20)

cc: Jim Cutler, VDEQ

COMMONWEALTH of VIRGINIA

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March 3, 2009

Mr. Jim J. McKenna
Radford Army Ammunition Plant
P. O. Box 2
Building 220
Radford, Virginia 24143

RE: Site Characterization and Abatement Measures Closure: Area O - Radford Army Ammunition Plant, Route 114, Peppers Ferry Road, Montgomery County, Radford, Virginia, LAST PC-2009-2046A, Facility I.D. No. 2-000051, CEDS I.D. No. 200000082410

Dear Mr. McKenna:

The Virginia Department of Environmental Quality, Blue Ridge Regional Office – Roanoke Office (VA DEQ-BRRO-RO) staff has completed a review of the "Area O RCRA Facility Investigation/Corrective Measures Study Report" prepared by Shaw Environmental, Inc.

Based on the information provided, it appears that acceptable site characterization and abatement measures have been achieved. Specifically:

1.) Free product, petroleum saturated soils, and highly contaminated soils were removed from the site during initial abatement measures activities completed in the 1980's. Currently free product, petroleum saturated soils, and highly contaminated soils are not known to exist at area O.

2.) Vapor phase contamination has not been detected at this site and is not excepted to be an issue due to the nature of the product released, fuel oil.

3.) The remaining residual phase contamination levels are overall low and not expected to pose a significant risk to any known receptors.

4.) The current dissolved phase contamination levels are overall low and are not expected to pose a significant risk to any known receptors.

5.) The source of the release has been abated by the repair of the leaking line.

6.) Public water is available to the affected site and the immediate area.

7.) No potable water wells are located near or down gradient from the release.

8.) The nearest sensitive receptor to the site is a small ditch that runs alongside the road before joining other ditches and cutting across the facility aboveground and belowground to discharge into Stroubles Creek. After examining the ditch and the current groundwater and sediment contamination levels, it does not appear that this release poses a significant risk to the surface water receptor.

At this time, **no further action** with respect to this site's petroleum release characterization is required. If significant contamination associated with this release is detected, that presents environmental and/or human health/safety risk, then further investigation and corrective action may be required at that time.

Observation or monitoring wells **must** be properly abandoned in accordance with the Virginia Department of Health Regulations, Section 3.11, or another method as pre-approved by the DEQ, within 90 days of cessation of use. The DEQ can provide you with information on reimbursement codes and methods that are appropriate for your site. Continued use of such wells may be appropriate if designated to meet other ground water monitoring needs.

Please be aware that Virginia Law prohibits the payment of corrective action and third party liability reimbursement claims, which are filed more than two years after DEQ closes a case. All claims for this release must be received by DEQ no later than March 3, 2011, in order to be considered for reimbursement.

Should you have questions our office will be glad to assist you.

Sincerely,

Robert L. Howard

Robert L. Howard, PG
Geologist Supervisor
Site Coordinator

CLOSURE.DOC

cc: Robert J. Weld, DEQ-BRRO-RO
File LAST PC-2009-2046A
Facility I.D. No. 2-000051, Montgomery County
Jeff Parks, Shaw Environmental, Inc.

ATK

Ammunition Systems Group
Energetic Systems Division
Radford Army Ammunition Plant
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September 4, 2008

Mr. William Geiger
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Philadelphia, PA 19103-2029

Mr. James L. Cutler, Jr.
Virginia Department of Environmental Quality
629 East Main Street
Richmond, VA 24143-0100

Subject: Area O RCRA Facility Investigation/Corrective Measures Study Report,
Draft Document, August 2008, With Certification
Radford Army Ammunition Plant
EPA ID# VA1 210020730

Dear Mr. Geiger and Mr. Cutler:

Enclosed is the certification for the subject documents that were sent to you on August 26, 2008. Also enclosed is a copy of the transmittal email message.

Please coordinate with and provide any questions or comments to myself at (540) 639-8658, Jerry Redder of my staff (540) 639-7536 or Jim McKenna, ACO Staff (540) 731-5782.

Sincerely,

P.W. Holt, Environmental Manager
Alliant Techsystems Inc.

c: Durwood Willis
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08-815-135
JMcKenna

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J. McKenna

MA Miano
M. A. Miano

08-815-135
JMcKenna

Concerning the following:

Radford Army Ammunition Plant
Area O RCRA Facility Investigation/Corrective Measures Study Report,
Draft Document, August 2008

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fines and imprisonment for knowing violations.

SIGNATURE:
PRINTED NAME: Jon R. Drushal
TITLE: Lieutenant Colonel, US Army
Commanding

SIGNATURE:
PRINTED NAME: Kent Holiday
TITLE: Vice President and General Manager
ATK Energetics Systems Division

08-815-135
JMcKenna

Greene, Anne

From: McKenna, Jim
Sent: Tuesday, August 26, 2008 11:38 AM
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Subject: Radford AAP - Draft Area O RFI/CMS Report (UNCLASSIFIED)

Importance: High

Classification: UNCLASSIFIED
Caveats: NONE

All:

Note the contractor will ship the subject document with a copy of this email to the POCs and tracking numbers below.

Certification letter will follow from Radford AAP under separate cover.

Immediately below are the POCs with tracking numbers:

Rich Mendoza, USAEC-RIA, 1 hard copy, 1 CD, 1Z63V8840198380525 William Geiger, US EPA Region III, 1 hard copy, 1 CD, 1Z63V8840196849345 Jim Cutler, VDEQ, 1 hard copy, 1 CD, 1Z63V8840199266139 Elizabeth Lohman, VDEQ, 1 CD, 1Z63V8840199549299 Tom Meyer, USACE-Baltimore, 1 hard copy, 1 CD, 1Z63V8840197536510 Dennis Druck, USACHPPM, 1 CD, 1Z63V8840195494088

Thank you for your support of the Radford AAP Installation Restoration Program.

Jim McKenna
540 731 5782
Classification: UNCLASSIFIED
Caveats: NONE

Classification: UNCLASSIFIED
Caveats: NONE

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LIST OF ACRONYMS AND ABBREVIATIONS

µg/kg	micrograms per kilogram
µg/L	micrograms per liter
ARCS	Assessment and Remediation of Contaminated Sediments
AST	Aboveground Storage Tank
ASTM	American Society for Testing and Materials
ATK	Alliant TechSystems
ATSDR	Agency for Toxic Substances Disease Registry
AWQC	Ambient Water Quality Criteria
bgs	below ground surface
BTAG	Biological Technical Assistance Group
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
CCME	Canadian Council of Ministers of the Environment
CDI	Chronic Daily Intake
cells/mL	cells per milliliter
CFR	Code of Federal Regulations
CMO	Corrective Measures Objective
CMS	Corrective Measures Study
COI	Contaminant of Interest
COPC	Chemical of Potential Concern
COPEC	Chemical of Potential Ecological Concern
CSF	Cancer Slope Factor
CSM	Conceptual Site Model
DA	dose absorbed per unit area per event
DHC	*Dehalococcoides* sp.
DO	Dissolved Oxygen
DQO	Data Quality Objective
EPC	Exposure Point Concentration
EPD	Effective Prediction Domain
EqP	Equilibrium Partitioning
ER-L	Effects Range – Low
ER-M	Effects Range – Median
FA	fraction absorbed dose
FDEP	Florida Department of Environmental Protection
ft	feet
ft msl	feet above mean sea level
HHRA	Human Health Risk Assessment
HI	Hazard Index
HQ	Hazard Quotient
HWMU	Hazardous Waste Management Unit
IRIS	Integrated Risk Information System
ISEB	In-Situ Enhanced Bioremediation
ISQG	Interim Sediment Quality Guideline
LTM	Long-Term Monitoring
MCL	Maximum Contaminant Level
MDC	Maximum Detected Concentration
MDL	Method Detection Limit
mg/L	milligrams per liter
MMA	Main Manufacturing Area
MNA	Monitored Natural Attenuation
MTBE	Methyl Tert-Butyl Ether
mV	millivolts
MW	Molecular Weights
MWP	Master Work Plan
NEC	No Effect Concentration
NOAA	National Oceanic and Atmospheric Administration
ORC	Oxygen Releasing Compound
ORP	Oxidation-Reduction Potential
PAH	Polynuclear Aromatic Hydrocarbon
PCE	Tetrachloroethene
PEC	Probable Effect Concentration

PEL	Probable Effects Level
PPRTV	Provisional Peer Reviewed Toxicity Value
QA	Quality Assurance
QC	Quality Control
r-RBC	Residential Risk-Based Concentration
RAGS	Risk Assessment Guidance for Superfund
RBC	Risk-Based Concentration
RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RFAAP	Radford Army Ammunition Plant
RfD	Risk Reference Dose
RFI	RCRA Facility Investigation
Shaw	Shaw Environmental, Inc.
SIM	Selective Ion Monitoring
SLERA	Screening Level Ecological Risk Assessment
SQB	Sediment Quality Benchmark
SSL	Soil Screening Level
SVOC	Semivolatile Organic Compound
TCL	Target Compound List
TEC	Threshold Effect Concentration
TEL	Threshold Effect Level
TOC	Total Organic Carbon
TOX	Total Organic Halides
TPH	Total Petroleum Hydrocarbons
tw-RBC	Tap Water Risk-Based Concentration
UCL	Upper Confidence Limit
USACE	U.S. Army Corps of Engineers
USCS	Unified Soil Classification System
USEPA	U.S. Environmental Protection Agency
VDEQ	Virginia Department of Environmental Quality
VOC	Volatile Organic Compound
WHO	World Health Organization

EXECUTIVE SUMMARY

Shaw Environmental, Inc. conducted a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) at Area O (RAAP-038), the Underground Fuel Oil Spill, during 2007. The investigation is required by the 2000 RCRA Corrective Action permit (USEPA, 2000a) for Radford Army Ammunition Plant (RFAAP) and was performed in accordance with *Master Work Plan (MWP) Addendum 019* (Shaw, 2007). MWP Addendum 019 was prepared to facilitate the investigation effort to comply with the requirements set forth in the 2000 RCRA Corrective Action permit and was approved by the U.S. Environmental Protection Agency (USEPA) Region III and the Virginia Department of Environmental Quality.

In addition to the MWP Addendum 019 field investigation, two other investigations were conducted at Area O. These investigations included an RFI in 1994 and a 1982 investigation of nearby downgradient Hazardous Waste Management Unit (HWMU) 4, the Former Acidic Wastewater Lagoon. Contamination was originally detected when wells were installed for the 1982 investigation of downgradient HWMU 4.

During the development of MWP Addendum 019, a review of the data indicated that there was no existing soil chemical data for the area where the pipe leaked at Area O, representing a data gap. Once the data needs were identified, sampling strategies were developed to complete characterization and delineation of the impacted soil area(s). 2007 RFI activities included the collection and chemical analysis of three soil samples, twelve groundwater samples, two sediment samples, and two surface water samples from Area O and nearby HWMU 4. Chemical results from these samples were evaluated to assess the nature and extent of contamination (*Section 4.0*), fate and transport analysis (*Section 5.0*), and potential impacts to human health (*Section 6.0*) and/or ecological receptors (*Section 7.0*).

Contamination Assessment

Soil. The contamination assessment (*Section 4.0*) of Area O soil indicated that volatile organic compounds (VOCs), polynuclear aromatic hydrocarbons (PAHs), and semivolatile organic compounds (SVOCs) are not a concern in soil at the study area. Analysis of the chemical results from soil samples collected from the site indicate that soil has not been impacted by the former oil leak. Therefore, soil is not a concern at Area O.

Surface Water/Sediment. Two surface water/sediment pairs were collected at the ditch, where oily water was discharging from groundwater to the surface in the early 1980s. The contamination assessment indicated that there were no contaminants exceeding surface water or sediment screening criteria. Therefore, surface water and sediment are not a concern at Area O.

Groundwater. The contamination assessment (*Section 4.0*) of Area O groundwater indicated that chloroform, tetrachloroethene (PCE), 2-methylnaphthalene, acenaphthene, acenaphthylene, fluorene, naphthalene, phenanthrene, pyrene, bis(2-ethylhexyl)phthalate, and carbazole were detected at concentrations exceeding groundwater screening levels in Area O wells.

Fate and Transport Analysis

Fate and transport analysis (*Section 5.0*) indicates that no analytes were detected above screening levels in soil at Area O. Constituents detected at concentrations exceeding groundwater levels of concern in 2007 included two VOCs (chloroform and PCE), seven PAHs (2-methylnaphthalene, acenaphthene, acenaphthylene, fluorene, naphthalene, phenanthrene, and pyrene), and one SVOC [bis(2-ethylhexyl)phthalate]. This indicates that these constituents are mobile under site conditions since they were detected in groundwater and not in site soil.

Human Health Risk Assessment (HHRA)

An HHRA (*Section 6.0*) was conducted at Area O to evaluate the potential human health risks associated with previous activities at the site. The risks associated with seven exposure scenarios were calculated at the site: current maintenance workers, future maintenance workers, future industrial workers, future excavation workers, future adult residents, future child residents, and lifetime residents. Five more exposure scenarios for off-site adult and child residents, off-site maintenance workers, off-site industrial workers, and off-site excavation workers were also evaluated for potential exposures to groundwater in the event that groundwater migrates off site in the future. The total cancer risk for future maintenance workers, future excavation workers, future off-site maintenance workers, and future off-site excavation workers was below the USEPA's target risk range of 1E-06 to 1E-04. The total cancer risks for future industrial workers, future lifetime residents, future child residents, future off-site child residents, future off-site lifetime residents, and future off-site industrial workers were all within the target risk range of 1E-06 to 1E-04.

The hazard indices (HIs) for the future maintenance worker, future excavation worker, future off-site maintenance worker, and future off-site excavation worker were less than one. The HI for the future industrial worker and the future off-site industrial worker were equal to one. Finally, the HIs for the future adult resident, future child resident, future off-site adult resident, and future off-site child resident were greater than one, primarily due to 1-methylnaphthalene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene.

Screening Level Ecological Risk Assessment (SLERA)

A SLERA (*Section 7.0*) was performed to provide an estimate of current and future ecological risk associated with potential hazardous substance releases at Area O.

The data, results, and conclusions of the SLERA evaluated risks to ecological populations inhabiting Area O. Conclusions are derived from the risk assessment. There were no important bioaccumulative chemicals of potential ecological concern (COPECs) or complex surface water to fish exposure pathways associated with Area O surface water or sediment; therefore, a food chain exposure assessment was not conducted.

The direct contact assessment results suggest that the following COPECs in surface water (1-methylnaphthalene and phenanthrene) and sediment (acetone) may adversely affect aquatic life associated with the ditch alongside the roadway. However, as viable populations of aquatic organisms are not expected in the drainage ditch, direct contact risks were over-estimated.

Based on the results of the SLERA conducted at Area O, no further action to address ecological concerns is recommended for surface water or sediment.

Corrective Measures Study (CMS)

Because the RFI demonstrated that bis(2-ethylhexyl)phthalate, 1-methylnaphthalene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene are present in the groundwater at concentrations associated with unacceptable human health concerns, an evaluation of corrective measures to address impacted groundwater at Area O was performed.

Three corrective measures alternatives were evaluated as part of this RFI/CMS Report. These alternatives consist of the following:

- Alternative One: No Further Action.
- Alternative Two: Monitored Natural Attenuation (MNA) and Long-Term Monitoring (LTM).
- Alternative Three: In-Situ Enhanced Bioremediation and MNA.

These three alternatives were evaluated using the selection criteria: effectiveness, implementability, and cost. The corrective measures objective (CMO) for this RFI/CMS is to reduce contaminant concentrations in groundwater to levels that are protective of human health and the environment. Selection of remedial goals for groundwater at Area O is based on tap water risk-based concentrations since they are more conservative than maximum contaminant levels (MCLs) and because several of the contaminants of interest do not have an associated MCL.

Alternative Two was selected as the final alternative for Area O because it can be readily implemented and provides a level of protection to human health and the environment not provided by Alternative One. In addition, Alternative Two has a lower cost than Alternative Three.

This alternative includes the following:

- Installation of one monitoring well.
- LTM.
- Reporting.

Alternative Two can be implemented in approximately 1 year. This timeframe is considered an estimate, and the actual time to attain CMOs will be dependent on data obtained during LTM activities.

1.0 INTRODUCTION

Shaw Environmental, Inc. (Shaw) was tasked by the U.S. Army Corps of Engineers (USACE), Baltimore District, to perform a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) and Corrective Measures Study (CMS) at Area O (RAAP-038), the Underground Fuel Oil Spill, located in the east section of the Main Manufacturing Area (MMA) of Radford Army Ammunition Plant (RFAAP), southwest of the Inert Gas Plant and on the southeast side of a northeastward sloping drainage valley (**Figure 1-1**). The work was performed in accordance with RFAAP's *Master Work Plan (MWP)* (URS, 2003) and *MWP Addendum 019* (Shaw, 2007) under Contract No. W912QR-04-D-0027.

Previous investigations have been conducted as a collective effort at or adjacent to Area O [Hazardous Waste Management Unit (HWMU) 4] and are discussed in the following section of this report. A data review, including the development of a conceptual site model (CSM) and a data gap analysis, was performed in *MWP Addendum 019* (Shaw, 2007). Review of the data indicated that additional samples needed to be collected to characterize the current state of potentially impacted media, representing a data gap. Once the data needs were identified, sampling strategies were developed to complete the characterization of Area O.

The objectives of the field investigation at Area O were designed to:

- Characterize the vertical and horizontal extent of the impacted area(s) from the oil spill.
- Confirm that impacted soil is not acting as a continuing source for groundwater contamination.
- Evaluate the current concentrations of fuel-related constituents in groundwater.
- Analyze the concentration trends over time by comparing current groundwater data to the existing groundwater data.
- Assess the surface water and sediment at the seep location within the ditch at Area O.
- Generate sufficient data to evaluate risk through a Human Health Risk Assessment (HHRA) and a Screening Level Ecological Risk Assessment (SLERA).
- Reach a final decision regarding what future action, if any, is needed.

The new data, in conjunction with the existing data, provided a sufficient data set for completion of a Nature and Extent of Contamination Assessment (*Section 4.0*), a Fate and Transport Evaluation (*Section 5.0*), an HHRA (*Section 6.0*), and a SLERA (*Section 7.0*) for the Area O study area.

Based on the results of the Nature and Extent of Contamination, the HHRA and the SLERA, potential remedial actions were evaluated to address bis(2-ethylhexyl)phthalate, 1-methylnaphthalene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene in groundwater at the site was necessary. The purpose of the CMS portion of this document was to develop and evaluate corrective measure alternatives and to recommend corrective measures to be implemented at Area O. The CMS portion of this report presents corrective action objectives (*Section 8.0*), development of alternatives (*Section 9.0*), a detailed analysis of alternatives (*Section 10.0*), a ranking (*Section 11.0*), and a substantiation (*Section 12.0*) for the selection of the final remedy for Area O.

LEGEND

🟥 Area O Boundary

⬛ Other SWMU Boundary

🟨 Installation Boundary

Notes:
1) Aerial photo, dated 25 May 2000, was obtained from the Army Topographic Engineering Center.

N

Scale:
0 500 1,000 2,000 Feet

U.S. Army Corps of Engineers

Shaw® Shaw Environmental, Inc.

FIGURE 1-1

Area O Site Location Map

Radford Army Ammunition Plant,
Radford, VA

ArcGIS File: RFAAP_Fig1-1_AREAO_Site_Loc_Map.mxd (2/5/2008 1:42:02 PM)

Field activities were conducted in accordance with the MWP, Master Quality Assurance Plan, Master Health and Safety Plan (URS, 2003), and *MWP Addendum 019* (Shaw, 2007), as approved by the U.S. Environmental Protection Agency (USEPA) Region III and the Virginia Department of Environmental Quality (VDEQ). Modifications to MWP Addendum 019 proposed sampling activities are presented in *Section 3.1.6*.

The CMS was performed in compliance with the RFAAP RCRA Permit requirements (EPA ID No. VA1210020730) and the Final RCRA Corrective Action Plan (USEPA, 1994a). These documents provided guidance on the scope and the approach for the CMS portion of this report.

2.0 SITE BACKGROUND

2.1 Site Description

Area O (RAAP-038) consists of one 269,000-gallon fuel oil aboveground storage tank (AST) situated on a concrete base, surrounded by a concrete secondary containment system (**Figure 2-1**). The site is located in the east section of the MMA, southwest of the Inert Gas Plant, located on the southeast side of a northeastward sloping drainage valley. Ground surface elevations range from 1,775 feet above mean sea level (ft msl) near well P-1 (at the southwest end of the site) to 1,740 ft msl at the asphalt road northeast of the tanks. The base of the tank containment structure has an elevation of 1,771 ft msl. The southeast side of the valley remains relatively level for 300 feet (ft) north of the tanks. The ground surface drops more abruptly at that point and the scarp in the hillside has a 30-foot drop over approximately 150 ft. An asphalt road cuts across the valley at the base of this scarp, and there is a drainage ditch along the road where oily water reportedly discharged from the hillside in the 1980s.

2.2 Site History and Operations

According to a Radford employee, the oil tank in Area O was reportedly built in the early 1970s, at the time of the first gas shortage in order to help alleviate some of the supply problems. There are two additional 269,000-gallon ASTs that are situated adjacent to Area O. The tank immediately to the southwest of Area O also contained fuel oil. The tank immediately to the southwest of that tank contained alcohol (Dames and Moore, 1994).

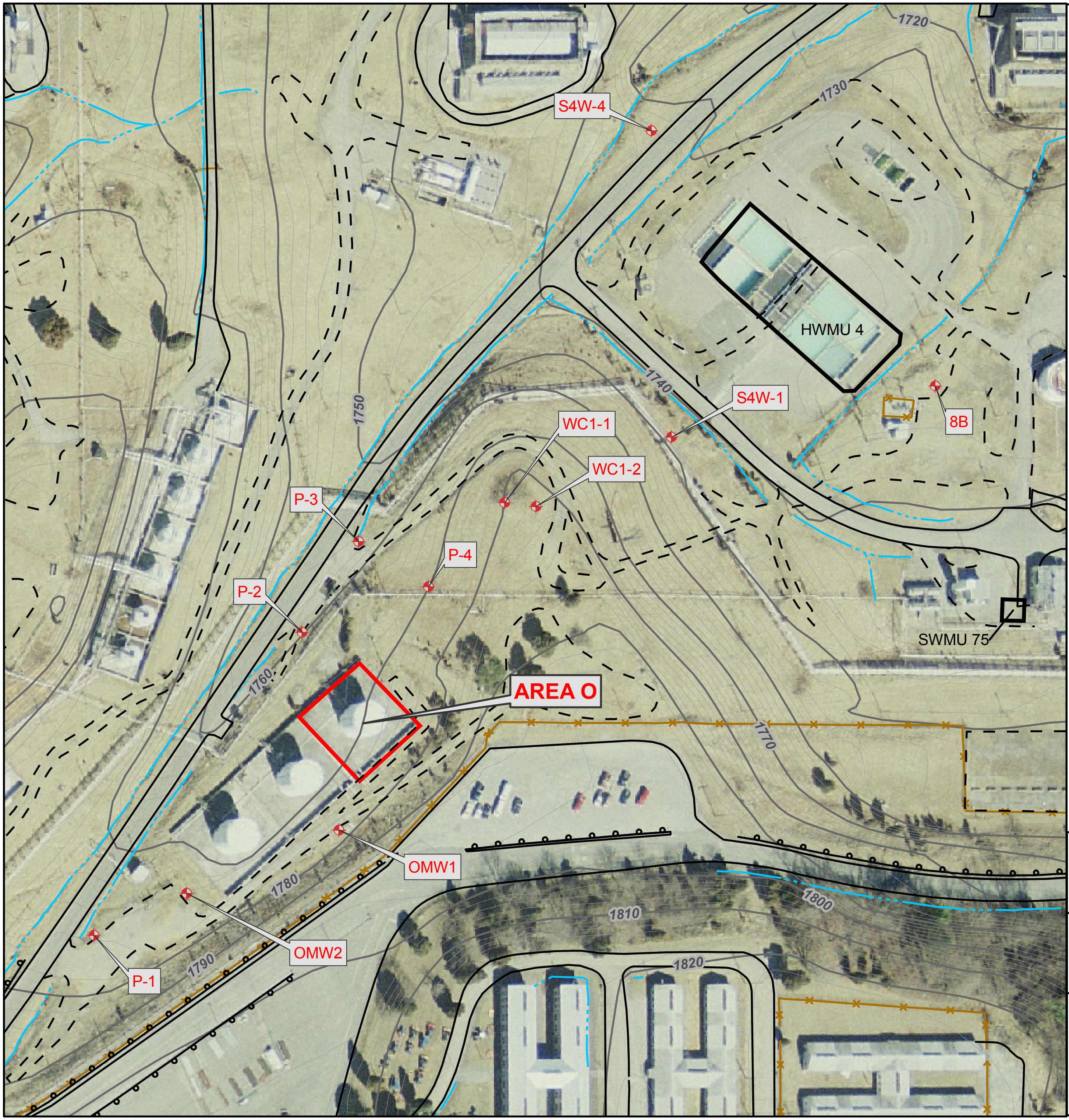
An Oil Audit, performed by USACE in 1982, reported a fuel leakage of approximately 3,000 gallons originating from an underground pipeline connecting a filling station to the fuel tank. In 1983, four monitoring wells were installed to characterize groundwater flow and quality at the site.

Area O was identified as a site in the 1987 RCRA Facility Assessment (RFA). At the time of the RFA, oily water was visible in the ditch northeast of the site (USEPA, 1987). A facility visit by plant personnel in 1990 indicated that the leaking line was not a fuel line connected to the filling station as described in 1982, but instead was a discharge line connecting the northeastern-most fuel tank to a pumping station. After this discovery, the discharge line was replaced with an aboveground line.

In 1992, an RFI was performed that involved a soil gas survey, and the collection of soil, groundwater, surface water, and sediment samples. In 1994, during Phase II of the RFI, additional soil and groundwater samples were collected from the site.

2.3 Site Soil

The U.S. Department of Agriculture has mapped Unison-Urban Land Complex soils as underlying Area O with slope modifiers of 2 to 7 percent at the tank area and 15 to 25 percent under the hill and steep slope area to the northeast (SCS, 1985). Unison soil makes up roughly half, Urban Land a quarter, and other soils a quarter of the total unit (**Figure 2-2**). A typical profile of Unison soil has a surface layer of dark brown and brown loam about 15 inches thick, a yellowish-red sticky and plastic clay subsoil about 43 inches thick, and the substratus is red sandy clay loam below 58 inches.



LEGEND

⌖ Monitoring Well
- - - Dirt Road
—— Paved Road
—— Water Feature
—— Fence
—— 10 Ft Elevation Contour
▭ Area O Boundary
▭ Other SWMU Boundary

Notes:
1) Aerial photo, dated 2005, was obtained from Montgomery County, VA Planning & GIS Services.

N

Scale:
0 75 150 300
Feet

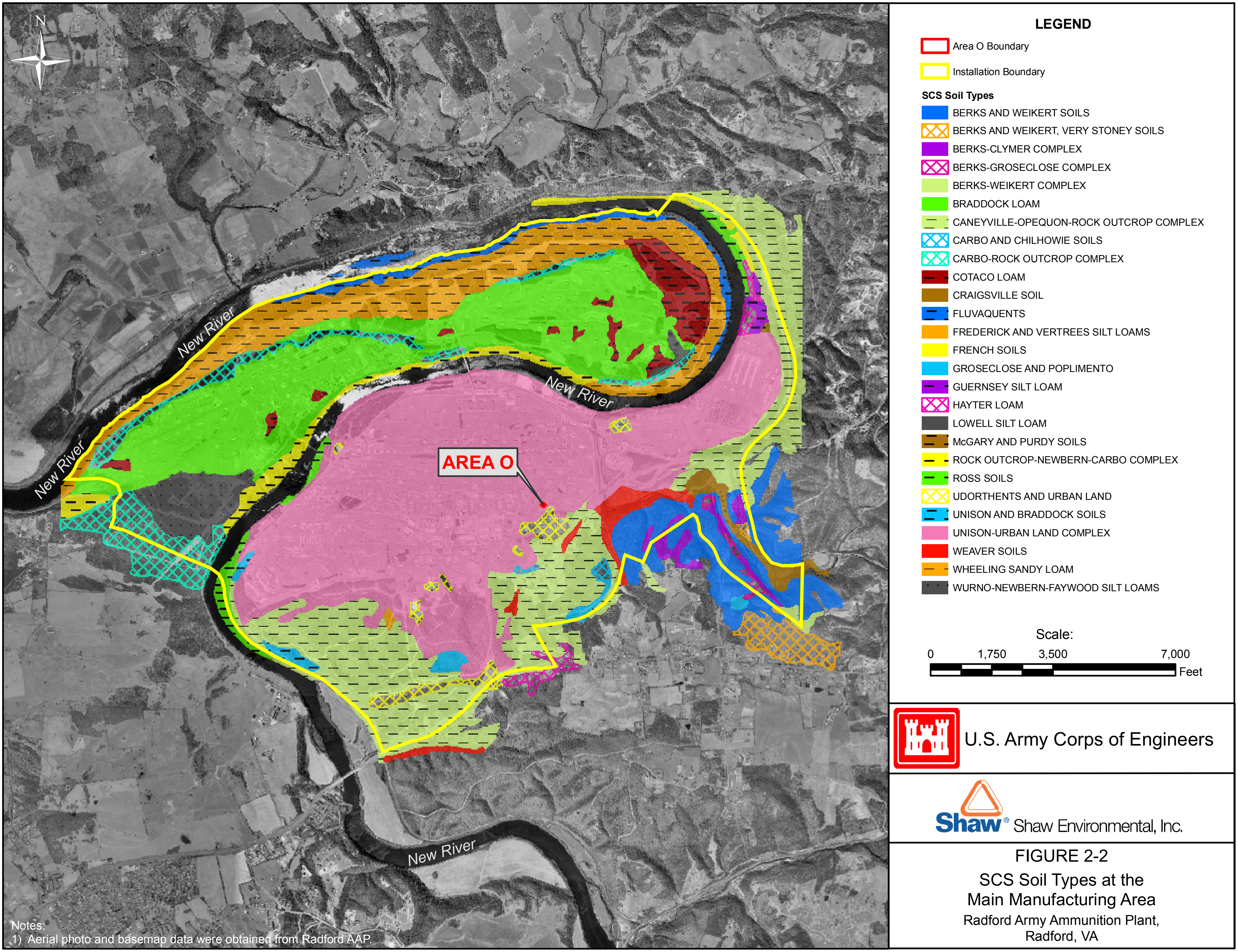
U.S. Army Corps of Engineers

Shaw® Shaw Environmental, Inc.

FIGURE 2-1
Area O Site Map

Radford Army Ammunition Plant,
Radford, VA

ArcGIS File: RFAAP_Fig2-1_AREAO_Site_Map.mxd (2/5/2008 5:03:09 PM)



Notes:
1) Aerial photo and basemap data were obtained from Radford AAP.

ArcGIS File: RFAAP_Fig2-2_AREAO_MMA_SCS_Soils.mxd (2/5/2008 6:08:52 PM)

U.S. Army Corps of Engineers

Shaw® Shaw Environmental, Inc.

FIGURE 2-2

SCS Soil Types at the
Main Manufacturing Area

Radford Army Ammunition Plant,
Radford, VA

The surface soil layer is classified in the Unified Soil Classification System (USCS) as clay (CL), silt (ML), and silty-clay (CL-ML); the subsoil is CL and CH; and the substratum classifications are silty clay (CL-ML), clay (CL), silt (ML), and silty or clayey gravel (GM-GC) (USCS).

The soil in the immediate vicinity of the tank has been extensively reworked during construction activities at the site. Numerous underground utilities have been run through the area, and the area has been regraded/excavated for the roads in the area and the installation of the AST and containment facilities.

2.4 Site Geology

RFAAP is located in the New River Valley, which crosses the Valley and Ridge Province approximately perpendicular to the regional strike of bedrock, and cross cuts Cambrian and Ordovician limestone or dolostone. Deep clay-rich residuum is prevalent in areas underlain by carbonate rocks. The valley floor is covered by river floodplain and terrace deposits; karst topography is dominant throughout the area.

Four cross-sections running through the site (**Figure 2-3**) are presented in detail on **Figures 2-4 through 2-7**. Boring logs and well construction diagrams for the wells at Area O are presented in **Appendix B-1**. The site is underlain by 10 to 37 ft of unconsolidated soil deposits, consisting principally of terrace alluvial deposits. Most of the unconsolidated soil deposits below Area O consist of a brown to yellowish-brown, fine-grained, plastic silt and clay. These deposits are highly interbedded in most locations with occasional thin sand and gravel zones. Soil samples collected from borings were usually described as being stiff in consistency and moist. Where the silts and clays exhibited a higher plasticity (MH-CH), the soils were generally more soft and moist. Borings performed in the area of the ASTs (OMW1, OSB4, OSB2, OSB10) encountered fill associated with the construction of the ASTs and the parking lot bordering the site to the east. The deposits of river jack overlying bedrock, which were encountered in boring S4W-1, were noticeably absent from the exploratory borings performed for the 1994 RFI (Dames and Moore, 1994). However, a 3-foot layer of gravel and cobbles was encountered above bedrock in boring OSB13 advanced approximately 10 ft west of monitoring well P-4, and thin layers of river jack were also encountered in borings OSB11 and OSB19. Minor amounts of gravel were encountered in other borings; therefore, it is likely that the thicker gravel deposits encountered in S4W-1 are localized along the steep slope in the vicinity of the scarp at the north end of the site.

Underlying the terrace deposits in some areas of the site (noticeably in the area of OSB5 and OSB8) is a layer of saprolite, a fine-grained residual soil weathered of the underlying limestone/dolostone bedrock. Residual soil usually consists of yellowish-brown silt (ML), which is stiff in consistency. The extent of the saprolite is apparently limited due to the erosion and deposition of alluvial deposits over bedrock in most areas below the site.

Underlying the unconsolidated soils in Area O is the gray limestone/dolostone of the Elbrook Formation. Previous investigations at Area O penetrated from 7 to 25 ft of bedrock using NX rock coring. The limestone/dolostone below the site is finely laminated, argillaceous, with frequent brecciated, conglomeratic, and vuggy zones. The bedrock is highly weathered and fractured with small quartz and calcite veins (BCM, 1984; USACE, 1988). The observation of bedrock outcropping at the western border of the site along a steep scarp confirms the above descriptions of bedrock below the site. The apparent dip of bedrock from this outcrop is approximately 30 degrees to the southeast with a strike trending northeast-southwest. Extensive

LEGEND

● Previous Investigation Soil Sample Location

⊕ Monitoring Well

— Geologic Cross Section Line

🟥 Area O Boundary

⬛ Other SWMU Boundary

Notes:

1) Aerial photo, dated 2005, was obtained from Montgomery County, VA GIS & Planning Services.

N

Scale:

0 75 150 300 Feet

U.S. Army Corps of Engineers

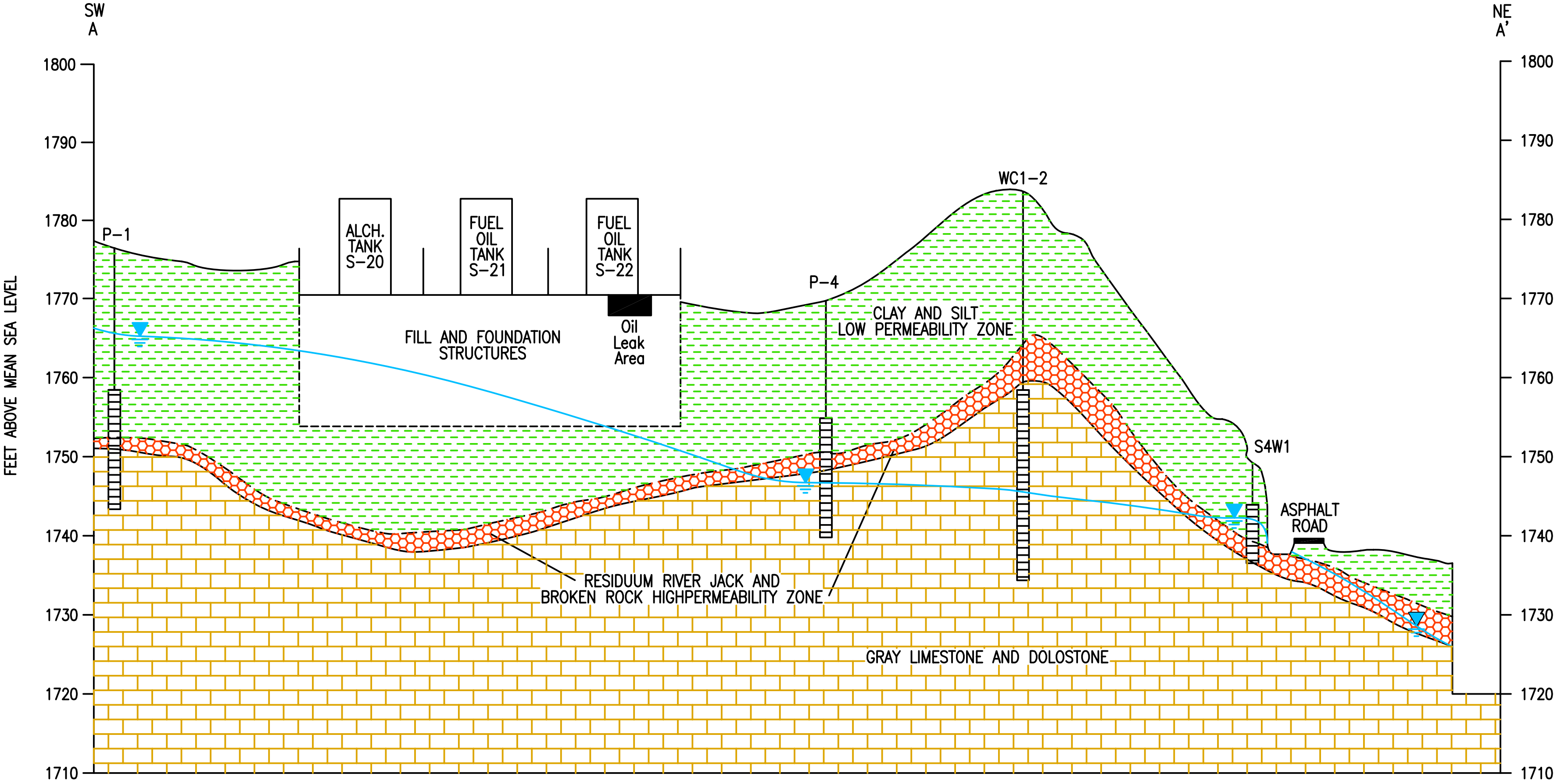
Shaw® Shaw Environmental, Inc.

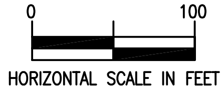
FIGURE 2-3

Area O Geologic Cross Sections

Radford Army Ammunition Plant,
Radford, VA

RFAAP_Fig2-3_AREAO_XSect.mxd (joy.pasquarelli) (2/12/2008 1:05:35 PM)





LEGEND

▦ BEDROCK (DOLOSTONE, LIMESTONE AND INTERLAYERED SHALE)

▤ UNDIFFERENTIATED SILTS, CLAYS, THIN SAND LAYERS

▩ RIVERJACK (FINE TO COURSE GRAVEL, VARYING SAND, SILT)

MONITORING WELL

SCREEN INTERVAL

▼ GROUNDWATER ELEVATION (MEASURED AUGUST 2007)

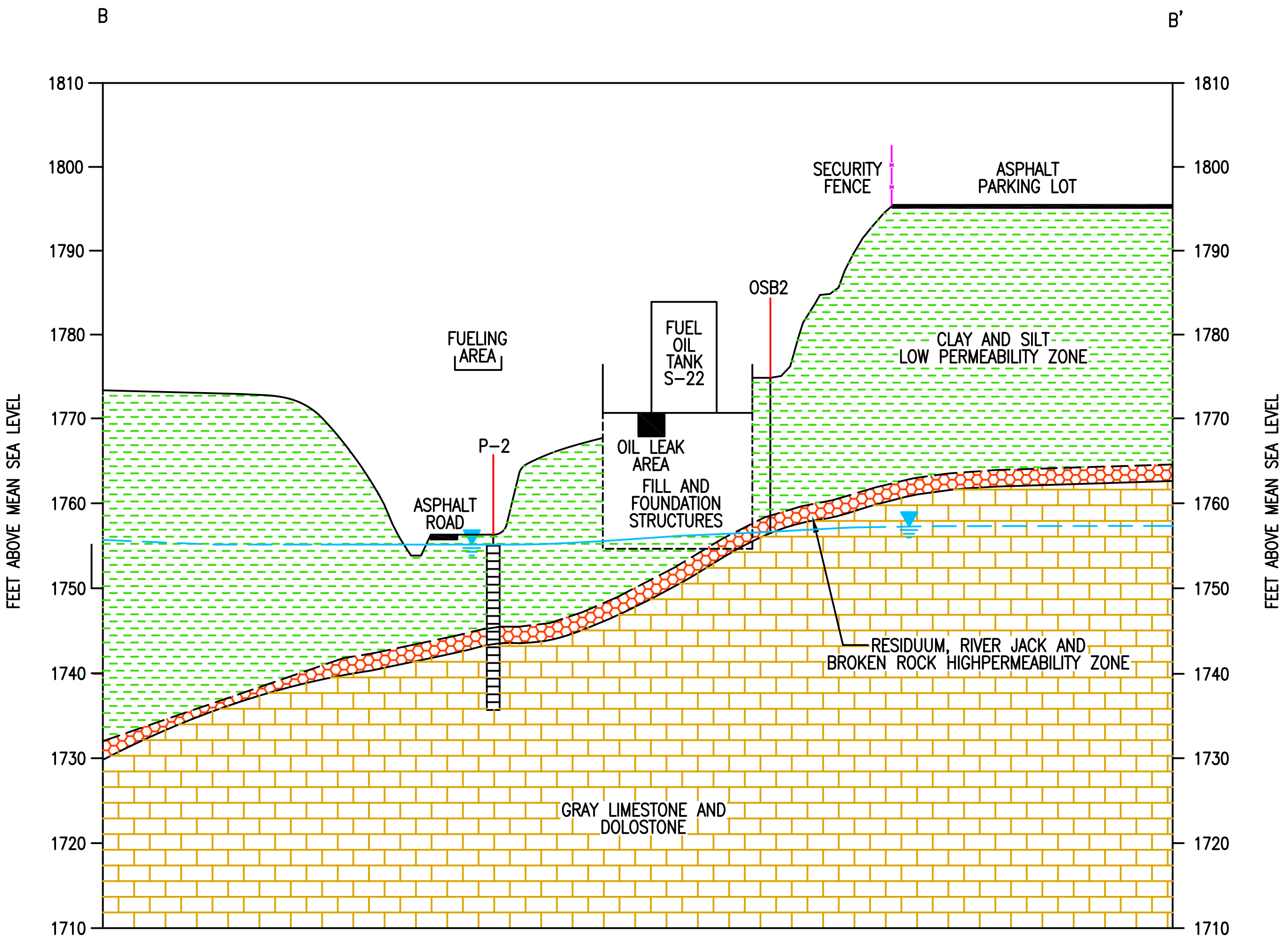
NOTE: CROSS SECTION LINE IS SHOWN ON FIGURE 4-2
ADAPTED FROM DAMES & MOORE, 1994

RADFORD AAP

PREPARED BY: SHAW
CHECKED: TL
DATE: JANUARY 2007
TASK NO: -
SHAW DWG NO: Figure 2-4

Figure 2-4

CROSS-SECTION A-A'
AREA O
RADFORD ARMY
AMMUNITION PLANT



0 100
HORIZONTAL SCALE IN FEET

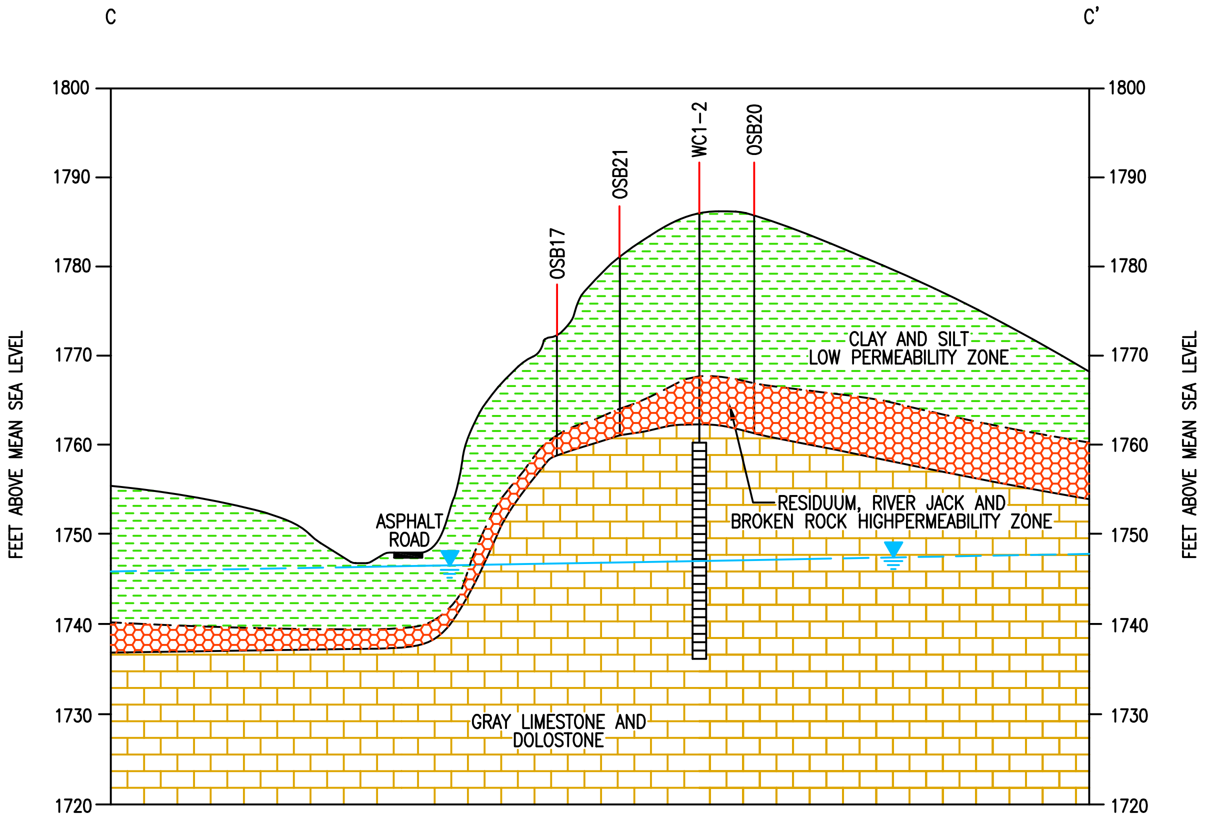
LEGEND

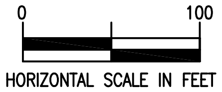
▦ BEDROCK (DOLOSTONE, LIMESTONE AND INTERLAYERED SHALE)
🟩 UNDIFFERENTIATED SILTS, CLAYS, THIN SAND LAYERS
🟥 RIVERJACK (FINE TO COURSE GRAVEL, VARYING SAND, SILT)

← MONITORING WELL
← SCREEN INTERVAL
▼ GROUNDWATER ELEVATION (MEASURED AUGUST 2007)

NOTE: CROSS SECTION LINE IS SHOWN ON FIGURE 4-2
ADAPTED FROM DAMES & MOORE, 1994

RADFORD AAP		Figure 2-5
PREPARED BY: SHAW	TASK NO: -	CROSS-SECTION B-B' AREA O RADFORD ARMY AMMUNITION PLANT
CHECKED: RS	SHAW DWG NO: Figure 2-5	
DATE: JANUARY 2008		





LEGEND

▦ BEDROCK (DOLOSTONE, LIMESTONE AND INTERLAYERED SHALE)

🟩 UNDIFFERENTIATED SILTS, CLAYS, THIN SAND LAYERS

🟥 RIVERJACK (FINE TO COURSE GRAVEL, VARYING SAND, SILT)

MONITORING WELL

SCREEN INTERVAL

▼ GROUNDWATER ELEVATION
(MEASURED AUGUST 2007)

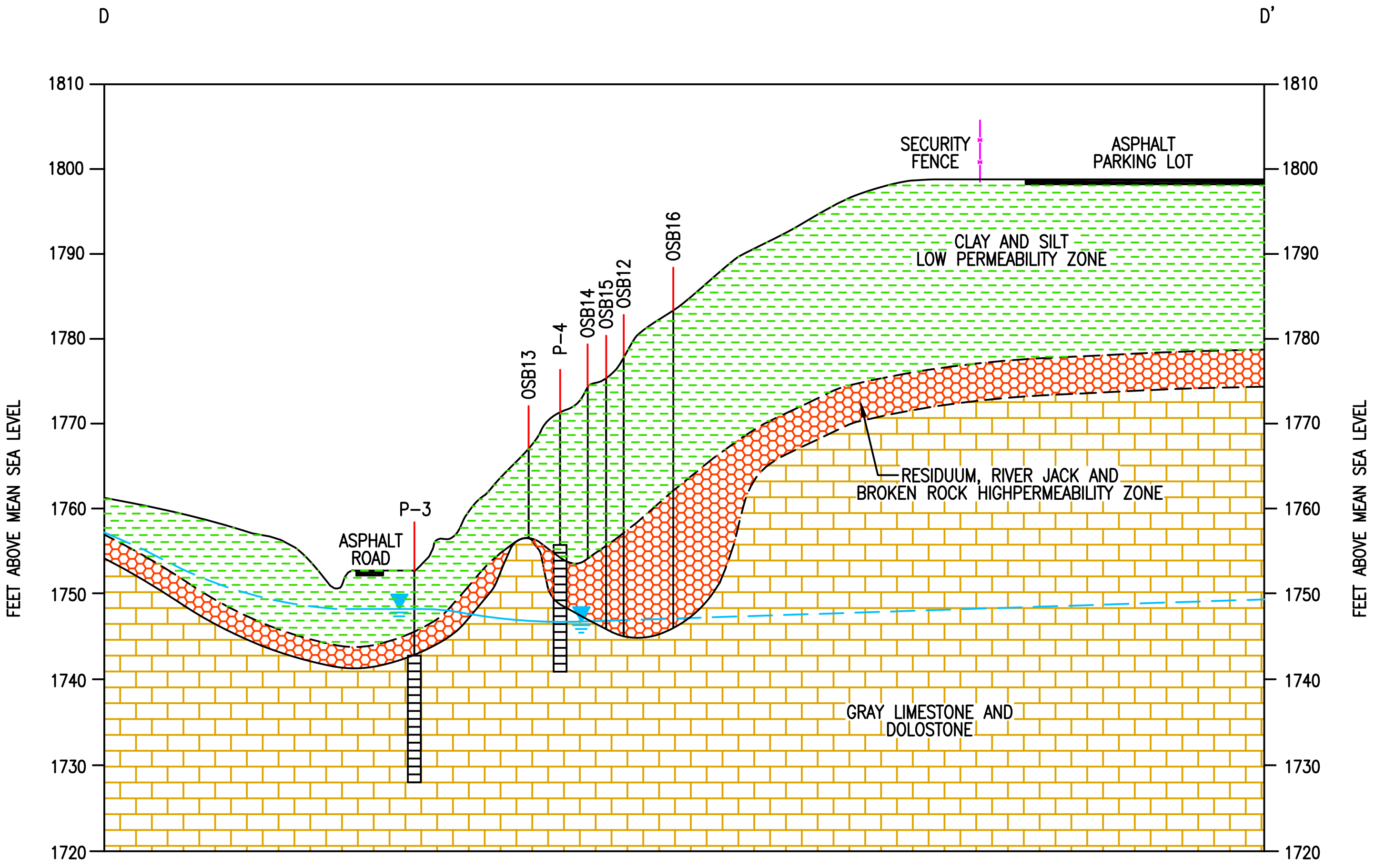
NOTE: CROSS SECTION LINE IS SHOWN ON FIGURE 4-2
ADAPTED FROM DAMES & MOORE, 1994

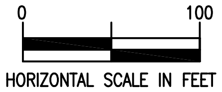
RADFORD AAP

PREPARED BY: SHAW
CHECKED: RS
DATE: JANUARY 2008
TASK NO: -
SHAW DWG NO: Figure 2-6

Figure 2-6

CROSS-SECTION C-C'
AREA O
RADFORD ARMY
AMMUNITION PLANT





LEGEND

- ▨ BEDROCK (DOLOSTONE, LIMESTONE AND INTERLAYERED SHALE)
- 🟩 UNDIFFERENTIATED SILTS, CLAYS, THIN SAND LAYERS
- 🟥 RIVERJACK (FINE TO COURSE GRAVEL, VARYING SAND, SILT)
- MONITORING WELL
- SCREEN INTERVAL
- ▼ GROUNDWATER ELEVATION (MEASURED AUGUST 2007)

NOTE: CROSS SECTION LINE IS SHOWN ON FIGURE 4-2
ADAPTED FROM DAMES & MOORE, 1994

RADFORD AAP

PREPARED BY: SHAW	TASK NO: -
CHECKED: RS	SHAW DWG NO: Figure 2-7
DATE: JANUARY 2008	

Figure 2-7

CROSS-SECTION D-D'
AREA O
RADFORD ARMY
AMMUNITION PLANT

exposures of bedrock were also observed in the excavation for the new neutralization basins in the HWMU 4 area. Bedrock was penetrated during the 1991 sampling to a depth of 3 ft during the installation of monitoring well OMW1. The bedrock was soft and highly weathered as indicated by the rapid penetration of the roller bit used during drilling.

The bedrock surface below Area O generally follows the surface topography. Two apparent bedrock lows are present below Area O; the first near the southwestern end of the ASTs, the second in the vicinity of borings OSB12 and OSB16. The depth to bedrock in these areas ranges from about 33 to 37 ft below ground surface (bgs), significantly greater than other areas at Area O.

2.5 Site Hydrogeology

A relatively shallow groundwater table is present below the site at a depth ranging from 1728.44 to 1765.23 ft msl (**Figure 2-8**). Based on groundwater measurements obtained in August 2007, the unconfined water table gradient slopes northeast at an average gradient of 2 percent in the southern half of the site, and an average gradient of 5 percent in the northern half of the site. Because of the low hydraulic gradient over most of the site and the considerable bedrock elevation differences below the site, water table conditions may be found in either unconsolidated-consolidated materials or only within consolidated bedrock. Groundwater flow occurs through bedrock only in the areas of highest bedrock elevation. The measured water table does not appear to be significantly affected by whether it is in soil or bedrock.

A local groundwater discharge zone for the site occurs along the steep scarp bordering the site on the north. Several seeps/springs discharge along nearly the entire length of this scarp. The seeps/springs have apparently been formed as the result of an outcropping of a gravel and cobble lens present between the clay soil and the bedrock. Based on information from previous investigations conducted at the site, this discharge zones (seeps/springs) were created when the scarp hillside was excavated after the discovery of liquid hydrocarbons in monitoring well S4W-1.

Apparently, the surging during development of this well flushed liquid hydrocarbons out of the seep and into the drainage ditch bordering Area O (BCM, 1984; USACE, 1988). Another possible groundwater discharge zone is located just west of the site across the asphalt road in the drainage ditch area. Wells located in this area have groundwater levels close to the ground surface with water frequently observed in this drainage ditch.

Surface Water Hydrology

Surface water drainage at the site is expected to flow northeastward down the valley towards Stroubles Creek and ultimately the New River. There are several engineered drainage ditches along the roads near the site that would channel storm water runoff in the same general direction.

2.6 Previous Investigations

One previous investigation has been conducted at Area O. The contamination was originally detected when wells were installed for the 1982 investigation of downgradient HWMU 4, the Former Acidic Wastewater Lagoon. An RFI was performed in 1994 by Dames and Moore and incorporated relevant data from HWMU 4 investigations. The following section summarizes the investigation and findings of the 1994 RFI.

LEGEND

⊕	Groundwater Sample Location
→	Groundwater Flow Direction
- - -	Inferred Groundwater Contour
—	Groundwater Contour
🟥	Area O Boundary
☐	Other SWMU Boundary

Notes:
1) Aerial photo, dated 2005, was obtained from Montgomery County, VA GIS & Planning Services.
2) Water levels are expressed in feet above mean sea level.
3) All water levels were measured in August, 2007.

N

Scale:

0 75 150 300 Feet

U.S. Army Corps of Engineers

Shaw® Shaw Environmental, Inc.

FIGURE 2-8

Area O Potentiometric Surface Map

Radford Army Ammunition Plant,
Radford, VA

RFAAP_Fig2-8_AREAO_Potentiometric_Surface.mxd (joy.pasquarelli) (2/12/2008 12:01:48 PM)

2.6.1 RFI, Dames and Moore, 1994

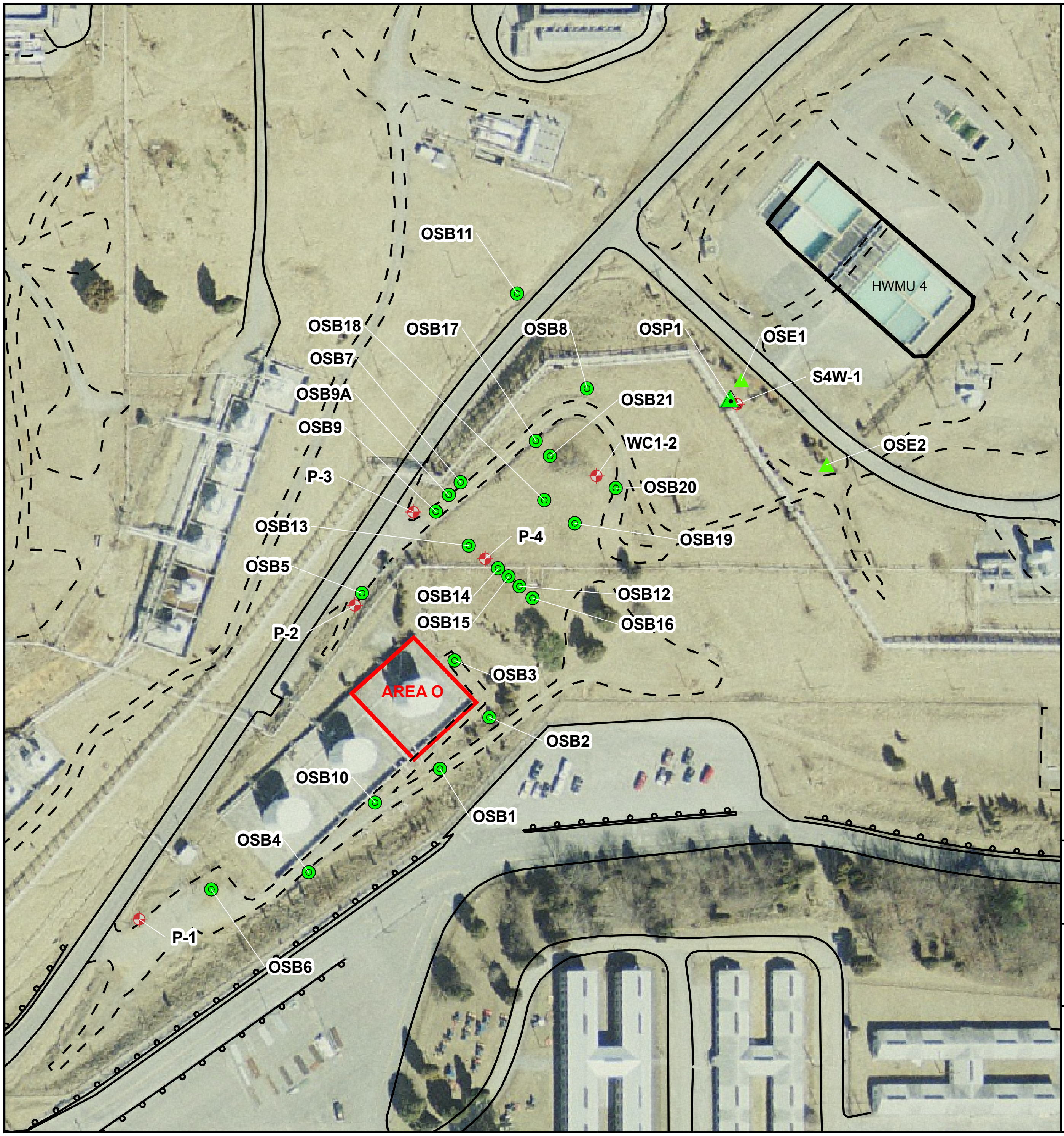
The 1994 RFI was conducted at the site to evaluate the migration of oil constituents resulting from the underground leak. In order to provide information on the potential pathways carrying fuel oil from the leakage area, a soil gas survey was conducted in 1991. The field procedures and data resulting from that survey are included in **Appendix B-2**. The survey was conducted for investigation of the subsurface routes through the unconsolidated soils in which fuel has migrated. Each soil sample was analyzed for the volatile organic compounds (VOCs) most likely associated with the fuel oil under investigation. Pentane/methyl tert-butyl ether (MTBE), benzene, toluene, ethylbenzene, and xylene (BTEX), and total volatiles were analyzed. The targeted VOCs (pentane, MTBE, and BTEX) were below detectable limits [1.0 microgram per liter (µg/L)] in the 27 samples collected during the soil gas survey. The only detections occurring in any of the 27 samples collected were in three samples collected near the seep and one sample by the tanks. The three samples (13, 16, and 32) by the seep exhibited total volatile concentrations ranging from 1.1 to 4.3 µg/L. A total volatile concentration of 33 µg/L was detected in sample 33 collected near the source area. It is likely that the fuel contaminants are essentially highly weathered and are probably in the form of less volatile semivolatile organic compounds (SVOCs). Because the fuel contaminants remaining at the site were SVOCs, the soil gas survey did not have sufficient VOCs to sample and could not be used to locate the migration pathways of the leaked fuel.

Groundwater, soil, surface water, and sediment samples were collected in 1991/1992 and 1993 in order to aid in the RFI evaluation. The previous investigation sample locations are shown on **Figure 2-9**. Samples and analyses collected in support of these sampling events are provided in **Table 2-1**. Results from these samples are presented in **Tables 2-2 through 2-7**. A summary of the results from the two sampling events is as follows:

- 1991/1992 Sampling
    - VOCs – no screening level exceedances in soil (**Table 2-2**) or sediment (**Table 2-5**). Methylene chloride exceeded its tap water risk-based concentration (tw-RBC) in spring sample OSP1 (**Table 2-4**). Benzene exceeded its tw-RBC in well OMW1 and chloroform exceeded its tw-RBC in wells OMW1 and P-1 (**Table 2-6**).
    - SVOCs – One polynuclear aromatic hydrocarbon (PAH) (naphthalene) exceeded its tw-RBC in spring sample OSP1 (**Table 2-4**). Four of eight exceeded their tw-RBCs in well S4W-1 (**Table 2-6**).
- 1993 Sampling
    - VOCs were not analyzed.
    - One PAH (2-methylnaphthalene) and one SVOC (dibenzofuran) exceeded their tw-RBCs in well OMW1 (**Table 2-6**).
    - Total organic carbon (TOC) – reported in wells OMW1 and S4W-1 at concentrations about four times less than the results reported for corresponding 1992 samples.
    - Total organic halides (TOX) – reported in all three 1993 samples at concentrations three to four times greater than the corresponding 1992 samples.

- Nitrite/nitrate – reported in samples OMW1 and S4W-1 at concentrations about 3 times greater than the nitrate maximum contaminant level (MCL), and about 1 order of magnitude less than the MCL in sample OMW2.

Based on the investigation data, the 1994 RFI made the following conclusions. The first most-likely path for contaminant migration appears to have been via shallow groundwater through unconsolidated soil (near the source area). The second most-likely path seems to be via groundwater flowing through fractured bedrock downgradient of the source area. Contaminants flowing through bedrock eventually became trapped in gravelly and low-permeability sediments, which intersected the water table in the hillside area near well S4W-1. The migration pathway, based on the boring and well-sampling program, extended in a nearly-straight line from the source area and through the area of borings OSB12 and OSB15, until reaching the hillside in the vicinity of well S4W-1.



LEGEND

▲	Previous Investigation Sediment Sample Location
▲	Previous Investigation Seep Sample Location
◎	Previous Investigation Soil Sample Location
⊕	Monitoring Well
- - -	Dirt Road
———	Paved Road
🟥	Area O Boundary
☐	Other SWMU Boundary

Notes:
1) Aerial photo, dated 2005, was obtained from Montgomery County, VA GIS & Planning Services.

N

Scale:
0 75 150 300
Feet

U.S. Army Corps of Engineers

Shaw® Shaw Environmental, Inc.

FIGURE 2-9
Area O Previous Investigation
Sample Locations
Radford Army Ammunition Plant,
Radford, VA

RFAAP_Fig2-9_AREAO_Previous_Samp_Locations.mxd (joy.pasquarelli) (4/4/2008 11:44:43 AM)

Table 2-1
Previous Investigation Samples and Analyses

Media	Sampling ID	Depth (ft bgs)	Analytes
1991/1992 Investigation Samples - Dames and Moore			
Soil	OSB1 (RFIS*86)	14-16	VOCs and SVOCs
	OSB1 (RFIS*87)	20-22	VOCs and SVOCs
	OSB2 (RFIS*88)	14-16	VOCs and SVOCs
	OSB3 (RFIS*90)	16-18	VOCs and SVOCs
	OSB4 (RFIS*92)	20.5-22.5	VOCs and SVOCs
	OSB4 (RFIS*93)	33-35	VOCs and SVOCs
	OSB5 (RFIS*94)	5-7	VOCs and SVOCs
	OSB6 (RFIS*96)	21.5-23.5	VOCs and SVOCs
	OSB7 (RFIS*98)	17.5-19.5	VOCs and SVOCs
	OSB8 (RFIS*99)	27-29	VOCs and SVOCs
	OSB9 (RFIS*100)	10-12	VOCs and SVOCs
	OSB10 (RFIS*104)	14-16	VOCs and SVOCs
	OSB10 (RFIS*101)	30-32	VOCs and SVOCs
	OSB11 (RFIS*102)	11-13	VOCs and SVOCs
Surface Water	OSP1 (RDWA*37)	na	VOCs and SVOCs
Sediment	OSE1 (RFIS*106)	0-0.5	VOCs and SVOCs
	OSE2 (RFIS*107)	0-0.5	VOCs and SVOCs
Groundwater	8B (RDWC*47)	na	VOCs, SVOCs, TOC, TOX, and pH
	OMW1 (RDWC*51)	na	VOCs, SVOCs, TOC, TOX, and pH
	P-1 (RDWC*43)	na	VOCs, SVOCs, TOC, TOX, and pH
	P-2 (RDWC*48)	na	VOCs, SVOCs, TOC, TOX, and pH
	P-3 (RDWC*49)	na	VOCs, SVOCs, TOC, TOX, and pH
	P-4 (RDWC*50)	na	VOCs, SVOCs, TOC, TOX, and pH
	S4W-1 (RDWC*44)	na	VOCs, SVOCs, TOC, TOX, and pH
	S4W-4 (RDWC*46)	na	VOCs, SVOCs, TOC, TOX, and pH
	WC1-2 (RDWC*45)	na	VOCs, SVOCs, TOC, TOX, and pH
1993 Investigation Samples - Dames and Moore			
Soil	OSB12 (RDSX*43)	31-33	SVOCs
	OSB14 (RDSX*45)	15-17	SVOCs
	OSB15 (RDSX*46)	27-29	SVOCs
	OSB16 (RDSX*47)	35.5-37.5	SVOCs
	OSB17 (RDSX*48)	10.5-12.5	SVOCs
	OSB18 (RDSX*49)	10-12	SVOCs
	OSB19 (RDSX*50)	27-29	SVOCs
	OSB20 (RDSX*51)	15-17	SVOCs
	OSB21 (RDSX*44)	18-20	SVOCs
Groundwater	OMW1 (RDWX*46)	na	SVOCs, chloride, nitrite, nitrate, phosphate, sulfate, TOC, TOX, and TPH
	OMW2 (RDWX*47)	na	SVOCs, chloride, nitrite, nitrate, phosphate, sulfate, TOC, TOX, and TPH
	S4W-1 (RDWX*48)	na	SVOCs, chloride, nitrite, nitrate, phosphate, sulfate, TOC, TOX, and TPH

Table 2-2
Analytes Detected in 1992 and 1993 Soil Samples
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Analyte																			
	Sample ID		**OSB1 (RFIS*86)**				**OSB1 (RFIS*87)**				**OSB2 (RFIS*88)**				**OSB3 (RFIS*90)**				
	Sample Date		**10/24/91**				**10/24/91**				**10/23/91**				**10/23/91**				
	Sample Depth		**14-16**				**20-22**				**14-16**				**16-18**				
	i-RBC	**r-RBC**	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MDL	MRL
VOCs (ug/kg)																			
Acetone	92000000	7000000	17	U		*17*	17	U		*17*	17	U		*17*	17	U			*17*
Chloroform	1000000	78000	0.87	U		*0.87*	0.87	U		*0.87*	2.4				0.87	U			*0.87*
Ethylbenzene	10000000	780000	1.7	U		*1.7*	1.7	U		*1.7*	1.7	U		*1.7*	1.7	U			*1.7*
SVOCs (ug/kg)																			
2-Chlorophenol	510000	39000	60	U		*60*	60	U		*60*	60	U		*60*	60	U			*60*
2-Methylnaphthalene	410000	31000	49	U		*49*	49	U		*49*	49	U		*49*	290				
Acenaphthene	6100000	470000	36	U		*36*	36	U		*36*	36	U		*36*	36	U			*36*
Acenaphthylene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*	33	U			*33*
Anthracene	31000000	2300000	33	U		*33*	33	U		*33*	33	U		*33*	33	U			*33*
bis(2-Ethylhexyl)phthalate	200000	46000	620	U		*620*	620	U		*620*	620	U		*620*	620	U			*620*
Dibenzofuran	100000	7800	35	U		*35*	35	U		*35*	35	U		*35*	35	U			*35*
Di-n-butylphthalate	10000000	780000	61	U		*61*	61	U		*61*	61	U		*61*	61	U			*61*
Fluorene	4100000	310000	33	U		*33*	33	U		*33*	33	U		*33*	99				
Naphthalene	2000000	160000	37	U		*37*	37	U		*37*	37	U		*37*	37	U			*37*
Phenanthrene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*	200				
Pyrene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*	33	U			*33*

*RBCs from USEPA Region III (October, 2007)

Table 2-2
Analytes Detected in 1992 and 1993 Soil Samples
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Analyte	Sample ID		**OSB4 (RFIS*92)**				**OSB4 (RFIS*93)**				**OSB5 (RFIS*94)**					**OSB6 (RFIS*96)**			
	Sample Date		**11/2/91**				**11/2/91**				**10/25/91**					**11/2/91**			
	Sample Depth		**20.5-22.5**				**33-35**				**5-7**					**21.5-23.5**			
	i-RBC	**r-RBC**	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MRL
VOCs (ug/kg)																			
Acetone	92000000	7000000	17	U		*17*	17	U		*17*	17	U			*17*	17	U		*17*
Chloroform	1000000	78000	0.87	U		*0.87*	0.87	U		*0.87*	0.87	U			*0.87*	0.87	U		*0.87*
Ethylbenzene	10000000	780000	1.7	U		*1.7*	1.7	U		*1.7*	1.7	U			*1.7*	1.7	U		*1.7*
SVOCs (ug/kg)																			
2-Chlorophenol	510000	39000	60	U		*60*	60	U		*60*	60	U			*60*	60	U		*60*
2-Methylnaphthalene	410000	31000	30000				49	U		*49*	49	U			*49*	49	U		*49*
Acenaphthene	6100000	470000	2300				36	U		*36*	36	U			*36*	36	U		*36*
Acenaphthylene	3100000	230000	33	U		*33*	33	U		*33*	33	U			*33*	33	U		*33*
Anthracene	31000000	2300000	810				33	U		*33*	33	U			*33*	33	U		*33*
bis(2-Ethylhexyl)phthalate	200000	46000	620	U		*620*	620	U		*620*	620	U			*620*	620	U		*620*
Dibenzofuran	100000	7800	990				35	U		*35*	35	U			*35*	35	U		*35*
Di-n-butylphthalate	10000000	780000	61	U		*61*	61	U		*61*	61	U			*61*	61	U		*61*
Fluorene	4100000	310000	3100				33	U		*33*	33	U			*33*	33	U		*33*
Naphthalene	2000000	160000	2200			*37*	37	U		*37*	37	U			*37*	37	U		*37*
Phenanthrene	3100000	230000	4700				33	U		*33*	33	U			*33*	33	U		*33*
Pyrene	3100000	230000	400				33	U		*33*	33	U			*33*	33	U		*33*

*RBCs from USEPA Region III (October, 2007)

Table 2-2
Analytes Detected in 1992 and 1993 Soil Samples
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Analyte		Sample ID	**OSB7 (RFIS*98)**				**OSB8 (RFIS*99)**				**OSB9 (RFIS*100)**				**OSB10 (RFIS*104)**			
		Sample Date	**11/4/91**				**10/25/91**				**11/4/91**				**10/24/91**			
		Sample Depth	**17.5-19.5**				**27-29**				**10-12**				**14-16**			
	i-RBC	**r-RBC**	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL
VOCs (ug/kg)																		
Acetone	92000000	7000000	17	U		*17*	17	U		*17*	17	U		*17*	17	U		*17*
Chloroform	1000000	78000	0.87	U		*0.87*	0.87	U		*0.87*	0.87	U		*0.87*	0.87	U		*0.87*
Ethylbenzene	10000000	780000	1.7	U		*1.7*	1.7	U		*1.7*	1.7	U		*1.7*	3.3			
SVOCs (ug/kg)																		
2-Chlorophenol	510000	39000	60	U		*60*	60	U		*60*	60	U		*60*	60	U		*60*
2-Methylnaphthalene	410000	31000	49	U		*49*	49	U		*49*	49	U		*49*	10000			
Acenaphthene	6100000	470000	36	U		*36*	36	U		*36*	36	U		*36*	36	U		*36*
Acenaphthylene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*	180			
Anthracene	31000000	2300000	33	U		*33*	33	U		*33*	33	U		*33*	33	U		*33*
bis(2-Ethylhexyl)phthalate	200000	46000	620	U		*620*	620	U		*620*	620	U		*620*	620	U		*620*
Dibenzofuran	100000	7800	35	U		*35*	35	U		*35*	35	U		*35*	420			
Di-n-butylphthalate	10000000	780000	61	U		*61*	61	U		*61*	61	U		*61*	61	U		*61*
Fluorene	4100000	310000	33	U		*33*	33	U		*33*	33	U		*33*	1000			
Naphthalene	2000000	160000	37	U		*37*	37	U		*37*	37	U		*37*	1900			*37*
Phenanthrene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*	2000			
Pyrene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*	120			

*RBCs from USEPA Region III (October, 2007)

Table 2-2
Analytes Detected in 1992 and 1993 Soil Samples
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Analyte	Sample ID Sample Date Sample Depth		**OSB10 (RFIS*101)** **10/24/91** **30-32**				**OSB11 (RFIS*102)** **10/25/91** **11-13**				**OSB12 (RDSX*43)** **8/18/93** **31-33**				**OSB14 (RDSX*45)** **8/18/93** **15-17**			
	i-RBC	**r-RBC**	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL
VOCs (ug/kg)																		
Acetone	92000000	7000000	28				17	U		*17*	NT				NT			
Chloroform	1000000	78000	0.87	U		*0.87*	0.87	U		*0.87*	NT				NT			
Ethylbenzene	10000000	780000	1.7	U		*1.7*	1.7	U		*1.7*	NT				NT			
SVOCs (ug/kg)																		
2-Chlorophenol	510000	39000	60	U		*60*	60	U		*60*	190			*60*	60	U		*60*
2-Methylnaphthalene	410000	31000	140				49	U		*49*	330			*49*	49	U		*49*
Acenaphthene	6100000	470000	36	U		*36*	36	U		*36*	36	U	`	*36*	36	U		*36*
Acenaphthylene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*	33	U		*33*
Anthracene	31000000	2300000	33	U		*33*	33	U		*33*	33	U		*33*	33	U		*33*
bis(2-Ethylhexyl)phthalate	200000	46000	620	U		*620*	620	U		*620*	620	U		*620*	620	U		*620*
Dibenzofuran	100000	7800	35	U		*35*	35	U		*35*	35	U		*35*	35	U		*35*
Di-n-butylphthalate	10000000	780000	61	U		*61*	61	U		*61*	61	U		*61*	61	U		*61*
Fluorene	4100000	310000	87				33	U		*33*	110			*33*	33	U		*33*
Naphthalene	2000000	160000	37	U		*37*	37	U		*37*	210			*37*	37	U		*37*
Phenanthrene	3100000	230000	230				33	U		*33*	380			*33*	33	U		*33*
Pyrene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*	33	U		*33*

*RBCs from USEPA Region III (October, 2007)

Table 2-2
Analytes Detected in 1992 and 1993 Soil Samples
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Analyte		Sample ID Sample Date Sample Depth	**OSB15 (RDSX*46) 8/18/93 27-29**				**OSB16 (RDSX*47) 8/19/93 35.5-37.5**				**OSB17 (RDSX*48) 8/20/93 10.5-12.5**				**OSB18 (RDSX*49) 8/20/93 10-12**			
	i-RBC	**r-RBC**	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL
VOCs (ug/kg)																		
Acetone	92000000	7000000	NT				NT				NT				NT			
Chloroform	1000000	78000	NT				NT				NT				NT			
Ethylbenzene	10000000	780000	NT				NT				NT				NT			
SVOCs (ug/kg)																		
2-Chlorophenol	510000	39000	60	U		*60*	60	U		*60*	60	U		*60*	60	U		*60*
2-Methylnaphthalene	410000	31000	49	U		*49*	49	U		*49*	49	U		*49*	49	U		*49*
Acenaphthene	6100000	470000	36	U		*36*	36	U		*36*	36	U		*36*	36	U		*36*
Acenaphthylene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*	33	U		*33*
Anthracene	31000000	2300000	33	U		*33*	33	U		*33*	33	U		*33*	33	U		*33*
bis(2-Ethylhexyl)phthalate	200000	46000	2200			*620*	620	U		*620*	620	U		*620*	620	U		*620*
Dibenzofuran	100000	7800	35	U		*35*	35	U		*35*	35	U		*35*	35	U		*35*
Di-n-butylphthalate	10000000	780000	140			*61*	61	U		*61*	130			*61*	61	U		*61*
Fluorene	4100000	310000	130			*33*	33	U		*33*	33	U		*33*	33	U		*33*
Naphthalene	2000000	160000	37	U		*37*	37	U		*37*	37	U		*37*	37	U		*37*
Phenanthrene	3100000	230000	310			*33*	33	U		*33*	33	U		*33*	33	U		*33*
Pyrene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*	33	U		*33*

*RBCs from USEPA Region III (October, 2007)

Table 2-2
Analytes Detected in 1992 and 1993 Soil Samples
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Analyte	Sample ID Sample Date Sample Depth		**OSB19 (RDSX*50)** **8/19/93** **27-29**				**OSB20 (RDSX*51)** **8/19/93** **15-17**				**OSB21 (RDSX*44)** **8/19/93** **18-20**			
	i-RBC	**r-RBC**	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL	Result	Lab Q	Val Q	MRL
VOCs (ug/kg)														
Acetone	92000000	7000000	NT				NT				NT			
Chloroform	1000000	78000	NT				NT				NT			
Ethylbenzene	10000000	780000	NT				NT				NT			
SVOCs (ug/kg)														
2-Chlorophenol	510000	39000	60	U		*60*	60	U		*60*	60	U		*60*
2-Methylnaphthalene	410000	31000	49	U		*49*	49	U		*49*	49	U		*49*
Acenaphthene	6100000	470000	36	U		*36*	36	U		*36*	36	U		*36*
Acenaphthylene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*
Anthracene	31000000	2300000	33	U		*33*	33	U		*33*	33	U		*33*
bis(2-Ethylhexyl)phthalate	200000	46000	620	U		*620*	620	U		*620*	620	U		*620*
Dibenzofuran	100000	7800	35	U		*35*	35	U		*35*	35	U		*35*
Di-n-butylphthalate	10000000	780000	61	U		*61*	520			*61*	61	U		*61*
Fluorene	4100000	310000	33	U		*33*	33	U		*33*	33	U		*33*
Naphthalene	2000000	160000	37	U		*37*	37	U		*37*	37	U		*37*
Phenanthrene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*
Pyrene	3100000	230000	33	U		*33*	33	U		*33*	33	U		*33*

*RBCs from USEPA Region III (October, 2007)

Table 2-3
Summary of Analytes Detected in 1992 and 1993 Soil Samples

Analyte	i-RBC	r-RBC	# of i-RBC Exceedances	# of r-RBC Exceedances	# of Detections	# of Samples	Minimum Concentration	Maximum Concentration	Location of Maximum
VOCs (ug/kg)									
Acetone	92000000	7000000	0	0	1	14	28	28	OSB10 (RFIS*101)
Chloroform	1000000	78000	0	0	1	14	2.4	2.4	OSB2 (RFIS*88)
Ethylbenzene	10000000	780000	0	0	1	14	3.3	3.3	OSB10 (RFIS*104)
SVOCs (ug/kg)									
2-Chlorophenol	510000	39000	0	0	1	23	190	190	OSB12 (RDSX*43)
2-Methylnaphthalene	410000	31000	0	0	5	23	140	30000	OSB4 (RFIS*92)
Acenaphthene	6100000	470000	0	0	1	23	2300	2300	OSB4 (RFIS*92)
Acenaphthylene	3100000	230000	0	0	1	23	180	180	OSB10 (RFIS*104)
Anthracene	31000000	2300000	0	0	1	23	810	810	OSB4 (RFIS*92)
bis(2-Ethylhexyl)phthalate	200000	46000	0	0	1	23	2200	2200	OSB15 (RDSX*46)
Dibenzofuran	100000	7800	0	0	2	23	420	990	OSB4 (RFIS*92)
Di-n-butylphthalate	10000000	780000	0	0	3	23	130	520	OSB20 (RDSX*51)
Fluorene	4100000	310000	0	0	6	23	87	3100	OSB4 (RFIS*92)
Naphthalene	2000000	160000	0	0	3	23	210	2200	OSB4 (RFIS*92)
Phenanthrene	3100000	230000	0	0	6	23	200	4700	OSB4 (RFIS*92)
Pyrene	3100000	230000	0	0	2	23	120	400	OSB4 (RFIS*92)

Table 2-4
Analytes Detected in 1992 RFI Surface Water Samples

Analyte	Sample ID Sample Date		OSP1 (RDWA*37) 9/26/91		
	MCL	**tw-RBC**	Result	Lab Q	Val Q
VOCs (ug/L)					
Chloromethane	na	19	10		
Methylene chloride	5	4.1	4.9		B
SVOCs (ug/L)					
2-Methylnaphthalene	na	2.4	2.1		
Acenaphthene	na	36	2.4		
Dibenzofuran	na	3.7	1.8		
Fluorene	na	24	5.2		
Naphthalene	na	0.65	2.3		
Phenanthrene	na	18	2.2		

*Refer to legend immediately following this table for a list of definitions and table notes.

Table 2-4
Legend

12	J	Shading and black font indicate an MCL exceedance.
12	J	Bold outline indicates a tw-RBC exceedance.
12	*12*	Shading in the MDL/MRL columns indicates the MDL exceeds a criterion.

tw-RBCs for non-Carcinogenic compounds have been recalculated to an HI of 0.1.

The pyrene tw-RBCs were used for acenaphthylene, benzo(g,h,i)perylene and phenanthrene.

The 2-methylnaphthalene tw-RBC was used for 1-methylnaphthalene.

Secondary MCLs were used for aluminum, iron, manganese, silver, and zinc.

MCL Action Levels were used for copper and lead.

MCL = Maximum Contaminant Level (USEPA, 2006).

tw-RBC = Tap Water Risk-Based Concentration (USEPA, October 2007).

tw-RBC value in table is for the more conservative chromium VI.

    tw-RBC value for chromium III is 5,500, which was not exceeded.

ng/L = nanograms per liter (parts per trillion).

µg/L = micrograms per liter (parts per billion).

NA = not applicable.

NT = analyte not tested.

Lab Q = Lab Data Qualifiers

B = (organics) Blank contamination. Value detected in sample and associated blank.

A (Dioxins) = B = (metals) Value <MRL and >MDL and is considered estimated.

E (metals) = Reported value is estimated because of the presence of interferences.

EMPC (Dioxins) = The ion-abundance ratio between the two characteristic PCDD/PCDF ions was outside accepted ranges. The detected PCDD/PCDF was reported as an estimated maximum possible concentration (EMPC).

J = (organics) Value <MRL and >MDL and is considered estimated.

U = Analyte not-detected at the method reporting limit.

X = (dioxins) Ion abundance ratio outside acceptable range. Value reported is EMPC.

Val Q = Validation Data Qualifiers

B = blank contamination. Value detected in sample and associated blank.

J = estimated concentration.

K = estimated concentration bias high.

L = estimated concentration bias low.

N = presumptive evidence for tentatively identified compounds using a library search.

U = analyte not detected.

UJ = estimated concentration non-detect.

UL = estimated concentration non-detect bias low.

Table 2-5
Analytes Detected in 1992 RFI Sediment Samples

Analyte		Sample ID	**OSE1 (RFIS*106)**					**OSE2 (RFIS*107)**				
		Sample Date	**9/26/91**					**9/26/91**				
		Sample Depth	**0-0.5**					**0-0.5**				
	i-RBC	**r-RBC**	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL
VOCs (ug/kg)												
Acetone	92000000	7000000	61					120				
SVOCs (ug/kg)	None detected											

*RBCs from USEPA Region III (October, 2007)

Table 2-6
Analytes Detected in 1992 and 1993 Groundwater Samples
Page 1 of 2

Analyte		Sample ID Sample Date	OMW1 (RDWC*51) 2/24/92			OMW1 (RDWX*46) 7/28/93			OMW2 (RDWX*47) 7/29/93			P-1 (RDWC*43) 2/24/92			P-2 (RDWC*48) 2/20/92			P-3 (RDWC*49) 2/20/92		
	MCL	**tw-RBC**	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q
VOCs (ug/L)																				
Benzene	5	0.34	2.2			NT			NT			0.5	U		0.5	U		0.5	U	
Carbon disulfide	na	100	0.5	U		NT			NT			0.5	U		0.5	U		0.5	U	
Chloroform	80	0.15	0.7			NT			NT			2.7			0.5	U		0.5	U	
Chloromethane	na	19	3.2	U		NT			NT			3.2	U		3.2	U		3.2	U	
Ethylbenzene	700	130	0.9			NT			NT			0.5	U		0.5	U		0.5	U	
Toluene	1000	75	0.5	U		NT			NT			5.2			0.5	U		0.5	U	
SVOCs (ug/L)																				
2-Methylnaphthalene	na	2.4	1.7	U		4			1.7	U		1.7	U		1.7	U		1.7	U	
Acenaphthene	na	36	1.7	U		2.7			1.7	U		1.7	U		1.7	U		1.7	U	
bis(2-Ethylhexyl)phthalate	6	4.8	4.8	U		4.8	U		4.8	U		4.8	U		4.8	U		4.8	U	
Dibenzofuran	na	3.7	1.7	U		3.8			1.7	U		1.7	U		1.7	U		1.7	U	
Fluoranthene	na	150	3.3	U		3.3	U		3.3	U		3.3	U		3.3	U		3.3	U	
Fluorene	na	24	3.7	U		5.3			3.7	U		3.7	U		3.7	U		3.7	U	
N-nitrosodiphenylamine	na	14	3	U		3	U		3	U		3	U		3	U		3	U	
Phenanthrene	na	18	0.5	U		3.1			0.5	U		0.5	U		0.5	U		0.5	U	
Pyrene	na	18	2.8	U		2.8	U		2.8	U		2.8	U		2.8	U		2.8	U	
Misc. (ug/L)																				
Total Organic Carbon	na	na	7110			1760			1000	U		6340			1940			2060		
Total Organic Halides	na	na	36			176			232			41.2			58.8			60.7		
Chloride	na	na	NT			46000			53000			NT			NT			NT		
Nitrate/Nitrite	10000	na	NT			30000			1200			NT			NT			NT		
Sulfate	na	na	NT			16400			146000			NT			NT			NT		
pH	na	na	7.13		J	NT			NT			6.96		J	7.04			7.02		

Table 2-6
Analytes Detected in 1992 and 1993 Groundwater Samples
Page 2 of 2

Analyte		Sample ID Sample Date	**P-4 (RDWC*50) 2/20/92**			**S4W-1 (RDWC*44) 2/24/92**			**S4W-1 (RDWX*48) 7/28/93**			**S4W-4 (RDWC*46) 2/28/92**			**8B (RDWC*47) 2/25/92**			**WC1-2 (RDWC*45) 2/28/92**		
	MCL	**tw-RBC**	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q
VOCs (ug/L)																				
Benzene	5	0.34	0.5	U		1	U		NT			0.5	U		0.5	U		0.5	U	
Carbon disulfide	na	100	0.5	U		1	U		NT			0.79			4.8			0.5	U	
Chloroform	80	0.15	0.5	U		1	U		NT			0.5	U		0.5	U		0.5	U	
Chloromethane	na	19	3.2	U		6	U		NT			3.2	U		6.8			6		
Ethylbenzene	700	130	0.5	U		1	U		NT			0.5	U		0.5	U		0.5	U	
Toluene	1000	75	0.5	U		1	U		NT			0.5	U		0.5	U		0.5	U	
SVOCs (ug/L)																				
2-Methylnaphthalene	na	2.4	1.7	U		53			1.7	U		1.7	U		1.7	U		1.7	U	
Acenaphthene	na	36	1.7	U		18			1.7	U		1.7	U		1.7	U		1.7	U	
bis(2-Ethylhexyl)phthalate	6	4.8	4.8	U		4.5			4.8	U		4.8	U		4.8	U		4.8	U	
Dibenzofuran	na	3.7	1.7	U		1.7	U		1.7	U		1.7	U		1.7	U		1.7	U	
Fluoranthene	na	150	3.3	U		4			3.3	U		3.3	U		3.3	U		3.3	U	
Fluorene	na	24	3.7	U		43			8.2			3.7	U		3.7	U		3.7	U	
N-nitrosodiphenylamine	na	14	3	U		46			3	U		3	U		3	U		3	U	
Phenanthrene	na	18	0.5	U		87			3.4			0.5	U		0.5	U		0.5	U	
Pyrene	na	18	2.8	U		5.5			2.8	U		2.8	U		2.8	U		2.8	U	
Misc. (ug/L)																				
Total Organic Carbon	na	na	1000	U		9930			2500			14900			6570			18300		
Total Organic Halides	na	na	134			46.1			150			75			102			60.3		
Chloride	na	na	NT			NT			30400			NT			NT			NT		
Nitrate/Nitrite	10000	na	NT			NT			33000			NT			NT			NT		
Sulfate	na	na	NT			NT			10000	U		NT			NT			NT		
pH	na	na	7.27			7.28		J	NT			7.49		J	7.67		J	7.42		J

* Refer to legend immediately following this table for a list of definitions and table notes.

Table 2-6
Legend

12	J	Shading and black font indicate an MCL exceedance.
12	J	Bold outline indicates a tw-RBC exceedance.
12	*12*	Shading in the MDL/MRL columns indicates the MDL exceeds a criterion.

tw-RBCs for non-Carcinogenic compounds have been recalculated to an HI of 0.1.
The pyrene tw-RBCs were used for acenaphthylene, benzo(g,h,i)perylene and phenanthrene.
The 2-methylnaphthalene tw-RBC was used for 1-methylnaphthalene.
Secondary MCLs were used for aluminum, iron, manganese, silver, and zinc.
MCL Action Levels were used for copper and lead.
MCL = Maximum Contaminant Level (USEPA, 2006).
tw-RBC = Tap Water Risk-Based Concentration (USEPA, October 2007).
tw-RBC value in table is for the more conservative chromium VI.
    tw-RBC value for chromium III is 5,500, which was not exceeded.
ng/L = nanograms per liter (parts per trillion).
µg/L = micrograms per liter (parts per billion).
NA = not applicable.
NT = analyte not tested.

Lab Q = Lab Data Qualifiers

B = (organics) Blank contamination. Value detected in sample and associated blank.
A (Dioxins) = B = (metals) Value <MRL and >MDL and is considered estimated.
E (metals) = Reported value is estimated because of the presence of interferences.
EMPC (Dioxins) = The ion-abundance ratio between the two characteristic PCDD/PCDF ions was outside accepted ranges. The detected PCDD/PCDF was reported as an estimated maximum possible concentration (EMPC).
J = (organics) Value <MRL and >MDL and is considered estimated.
U = Analyte not-detected at the method reporting limit.
X = (dioxins) Ion abundance ratio outside acceptable range. Value reported is EMPC.

Val Q = Validation Data Qualifiers

B = blank contamination. Value detected in sample and associated blank.
J = estimated concentration.
K = estimated concentration bias high.
L = estimated concentration bias low.
N = presumptive evidence for tentatively identified compounds using a library search.
U = analyte not detected.
UJ = estimated concentration non-detect.
UL = estimated concentration non-detect bias low.

Table 2-7
Summary of Analytes Detected in 1992 and 1993 Groundwater Samples

Analyte	MCL	tw-RBC	# of MCL Exceedances	# of tw-RBC Exceedances	# of Detections	# of Samples	Minimum Concentration	Maximum Concentration	Location of Maximum
VOCs (ug/L)									
Benzene	5	0.34	0	1	1	9	2.2	2.2	OMW1 (RDWC*51)
Carbon disulfide	na	100	na	0	2	9	0.79	4.8	8B (RDWC*47)
Chloroform	80	0.15	0	2	2	9	0.7	2.7	P-1 (RDWC*43)
Chloromethane	na	19	na	0	2	9	6	6.8	8B (RDWC*47)
Ethylbenzene	700	130	0	0	1	9	0.9	0.9	OMW1 (RDWC*51)
Toluene	1000	75	0	0	1	9	5.2	5.2	P-1 (RDWC*43)
SVOCs (ug/L)									
2-Methylnaphthalene	na	2.4	na	2	2	12	4	53	S4W-1 (RDWC*44)
Acenaphthene	na	36	na	0	2	12	2.7	18	S4W-1 (RDWC*44)
bis(2-Ethylhexyl)phthalate	6	4.8	0	0	1	12	4.5	4.5	S4W-1 (RDWC*44)
Dibenzofuran	na	3.7	na	1	1	12	3.8	3.8	OMW1 (RDWX*46)
Fluoranthene	na	150	na	0	1	12	4	4	S4W-1 (RDWC*44)
Fluorene	na	24	na	1	3	12	5.3	43	S4W-1 (RDWC*44)
N-nitrosodiphenylamine	na	14	na	1	1	12	46	46	S4W-1 (RDWC*44)
Phenanthrene	na	18	na	1	3	12	3.1	87	S4W-1 (RDWC*44)
Pyrene	na	18	na	0	1	12	5.5	5.5	S4W-1 (RDWC*44)
Misc. (ug/L)									
Total Organic Carbon	na	na	na	na	10	12	1760	18300	WC1-2 (RDWC*45)
Total Organic Halides	na	na	na	na	12	12	36	232	OMW2 (RDWX*47)
Chloride	na	na	na	na	3	3	30400	53000	OMW2 (RDWX*47)
Nitrate (as N)	na	na	na	na	3	3	1200	33000	S4W-1 (RDWX*48)
Sulfate	na	na	na	na	2	3	16400	146000	OMW2 (RDWX*47)
pH	na	na	na	na	9	9	6.96	7.67	8B (RDWC*47)

3.0 FIELD INVESTIGATION PROGRAM

An additional field sampling event was conducted by Shaw in 2007. This investigation was performed in order to obtain current analytical data for the site to complete the characterization of the site. The data was used to perform human health and ecological risk assessments that serve as the basis for the proposed remediation for the site. Details of the investigation are presented in *Section 3.1*. Samples and chemical analyses performed in support of the investigation are presented in **Table 3-1**. Results from the investigation are discussed in *Section 4.0*.

Table 3-1
2007 RFI Environmental Samples and Analyses

Media	Sampling ID	Depth (ft bgs)	Analytes
2007 RFI - Shaw			
Soil	AOGW02S	33-35	TCL VOCs, SVOCs, and PAHs
	AOGW08S	24-25	TCL VOCs, SVOCs, and PAHs
	AOGW09S	17.5-19.5	TCL VOCs, SVOCs, and PAHs
Surface Water	AOSW01	na	TCL VOCs, SVOCs, and PAHs
	AOSW02	na	TCL VOCs, SVOCs, and PAHs
Sediment	AOSD01	0-0.5	TCL VOCs, SVOCs, and PAHs
	AOSD02	0-0.5	TCL VOCs, SVOCs, and PAHs
Groundwater	8B	na	TCL VOCs, SVOCs, PAHs, alkalinity, chloride, DHC, ethane, ethene, ferrous iron, methane, nitrate, nitrite, pH, sulfate, sulfide, and TOC
	AOGW02	na	TCL VOCs, SVOCs, PAHs, alkalinity, chloride, DHC, ethane, ethene, methane, nitrate, nitrite, pH, sulfate, sulfide, and TOC
	OMW1	na	TCL VOCs, SVOCs, PAHs, alkalinity, chloride, DHC, ethane, ethene, ferrous iron, methane, nitrate, nitrite, pH, sulfate, sulfide, and TOC
	OMW2	na	TCL VOCs, SVOCs, PAHs, alkalinity, chloride, DHC, ethane, ethene, ferrous iron, methane, nitrate, nitrite, pH, sulfate, sulfide, and TOC
	P-1	na	TCL VOCs, SVOCs, PAHs, alkalinity, chloride, DHC, ethane, ethene, methane, nitrate, nitrite, pH, sulfate, sulfide, and TOC
	P-2	na	TCL VOCs, SVOCs, PAHs, alkalinity, chloride, DHC, ethane, ethene, methane, nitrate, nitrite, pH, sulfate, sulfide, and TOC
	P-3	na	TCL VOCs, SVOCs, PAHs, alkalinity, chloride, DHC, ethane, ethene, methane, nitrate, nitrite, pH, sulfate, sulfide, and TOC
	P-4	na	TCL VOCs, SVOCs, PAHs, alkalinity, chloride, DHC, ethane, ethene, ferrous iron, methane, nitrate, nitrite, pH, sulfate, sulfide, and TOC
	S4W-1	na	TCL VOCs, SVOCs, PAHs, alkalinity, chloride, DHC, ethane, ethene, ferrous iron, methane, nitrate, nitrite, pH, sulfate, sulfide, and TOC
	WC1-2	na	TCL VOCs, SVOCs, PAHs, alkalinity, chloride, DHC, nitrate, nitrite, pH, sulfate, sulfide, and TOC

Refer to **Appendix A-1, Table A-1** for the preparation and analytical methodologies used.

3.1 RFI, Shaw, 2007

3.1.1 Soil

As presented in **Table 3-1**, three soil samples (AOGW02S, AOGW08S, and AOGW09S) were collected for chemical analysis; one each from three borings advanced using a truck-mounted direct push rig (**Figure 4-1**). Initially, these borings were intended to be direct push groundwater sampling points. However, refusal was encountered within each of the borings before reaching groundwater. Instead, samples were collected from a 1- to 2-foot depth interval immediately above refusal, where the soil exhibited a strong fuel oil odor. As shown in **Table 3-1**, soil samples were analyzed for target compound list (TCL) VOCs, SVOCs, and PAHs.

3.1.2 Surface Water/Sediment

Two collocated surface water/sediment sample pairs were collected from the drainage ditch where oily water was discharging in the 1980s (**Figure 4-1**). Samples were analyzed for TCL VOCs, TCL SVOCs, and low-level PAHs (**Table 3-1**). The purpose of these samples was to assess whether oil-related constituents were still being transported via groundwater to the drainage ditch, which is acting as a local groundwater discharge point.

3.1.3 Groundwater

Groundwater samples were collected from nine existing monitoring wells (8B, OMW1, OMW2, P-1, P-2, P-3, P-4, S4W-1, and WC1-2) and from one direct push groundwater sampling point (AOGW02). As shown in **Table 3-1**, samples from all of these wells were analyzed for TCL VOCs, SVOCs, PAHs, alkalinity, chloride, nitrate, nitrite, pH, sulfate, sulfide, and TOC. All wells, except for WC1-2, were also analyzed for ethane, ethene, and methane. Finally, wells 8B, OMW1, OMW2, P-4, and S4W-1 were also field screened for ferrous iron.

Groundwater sample AOGW02 was collected from boring AOGW02 – a proposed direct push groundwater sampling point. This temporary groundwater monitoring well was screened from 36 to 46 ft bgs in a void encountered between 37 to 46 ft bgs while advancing this boring. As described above, this groundwater sample was analyzed for TCL VOCs, SVOCs, PAHs, alkalinity, chloride, ethane, ethene, methane, nitrate, nitrite, pH, sulfate, sulfide, and TOC.

Boring logs and well construction diagrams for the existing wells are presented in **Appendix B-1**. The well purging/field water quality measurement forms are included in **Appendix B-2**. Groundwater sample locations are illustrated on **Figure 4-1**.

3.1.4 Global Positioning System Activities

Sample location coordinates and elevations were obtained for surface water/sediment samples AOSW/SD01 and AOSW/SD02 and borings AOGW02, AOGW08, and AOGW09 using a Trimble Geo XH Global Positioning System. The Geo XH system was used to obtain real-time position information with submeter accuracy and elevations at 1.5 to 2 times the horizontal accuracy. Horizontal position information was recorded in the U.S. State [Virginia (South)] Plane Coordinate System (measured in U.S. survey feet) using the North American Datum of 1983. The vertical control was measured in feet using the National Geodetic Vertical Datum of 1988. Position information will be entered into the Environmental Restoration Information System database. Sample location coordinates and elevations are presented in **Appendix C**.

3.1.5 Quality Assurance

The accuracy and integrity of 2007 RFI data were ensured through the implementation of internal quality control (QC) measures in accordance with *MWP Addendum 019* (Shaw, 2007), as approved by USEPA Region III and VDEQ. Quality assurance (QA) and QC activities, including field QC, laboratory QC, data management, and data validation were integrated into the investigation program to meet data quality objectives (DQOs) established for the RFI. The data were evaluated for each of the DQO indicators in **Appendix A-2, Table A-3** and found to meet the pre-established goals. Qualified data did not impact the data quality of the RFI. Complete details of the RFI QA/QC analysis and activities are presented in **Appendix A-2**. Chemical data validation reports and analytical data are provided in **Appendix A-3**.

3.1.6 Modifications to the Sampling Plan

In some cases, modifications to the Work Plan are necessary to adjust for field conditions as they occur during field sampling. Adjustments to *MWP Addendum 019* (Shaw, 2007) were necessary during sampling activities at Area O, as described below.

One of the existing groundwater wells (WC1-1) to be sampled was found to be dry when sampling was attempted. Direct push groundwater sampling points AOGW01 through AOGW10 were not sampled, with the exception of AOGW02. These samples were intended to characterize the groundwater in the overburden, in the area between the source and the ditch where oil water was reportedly discharging in the 1980s. With the exception of AOGW02, groundwater at Area O was only present in the bedrock aquifer, monitored by the existing wells. Although groundwater samples were not collected from the overburden (except AOGW02), the absence of water in these borings provides valuable information about groundwater flow immediately downgradient of the site.

Soil samples from borings AOSB01 through AOSB05 were proposed to be collected adjacent to the AST in the leak area. This area was underneath the concrete secondary containment for the tank and samples were not collected because: 1) the concrete prevents the completion of exposure pathways for human and ecological receptors; and 2) the integrity of the secondary containment for the tank outweighed the importance of the samples.

Three subsurface soil samples (AOGW02S, AOGW08S, and AOGW09S) not proposed in MWP Addendum 019 were collected during the investigation. As described in *Section 3.1.1*, these subsurface soil samples were collected from three of the direct push borings proposed for direct push groundwater sampling. These additional soil samples provide valuable information about the presence/absence of oil-related constituents in the overburden at Area O (see *Section 4.0*).

4.0 NATURE AND EXTENT OF CONTAMINATION

The following sections provide a discussion of the site conditions and the nature and extent of chemicals found in site media at Area O. The sampling locations are illustrated on **Figure 4-1**. A summary of the results from the samples are portrayed on **Figure 4-2**. The distribution and concentrations of chemicals and parameter groups (i.e., VOCs, SVOCs, etc.) are evaluated for source locations, migration pathways, and potential hotspots.

Soil/Sediment Screening. Chemical results from soil and sediment samples are compared to adjusted USEPA Region III industrial and residential soil risk-based concentrations (RBCs) (USEPA, 2007a), as well as facility-wide background inorganic concentrations (IT, 2001), and other regulatory criteria. Industrial and residential RBCs were adjusted downward to a hazard index (HI) of 0.1 for non-carcinogenic compounds to ensure that chemicals with additive effects are not prematurely eliminated during screening.

Current (October 2007) RBC screening values and background 95 percent upper tolerance limits for analytes detected in soil and sediment at Area O are presented for comparison in **Table 4-1** (soil) and **Table 4-2** (sediment). Analytical results for inorganic compounds in soil are indicated in the tables and figures as exceedances when they exceed both the background value and a screening value. Eliminating screening level exceedances in soil that are below the background value allows site-specific constituents to be more clearly indicated in the tables and figures.

Surface Water/Groundwater Screening. Surface water and groundwater sampling results are compared to the 2006 Edition of the Drinking Water Standards and Health Advisories (i.e., MCLs and secondary MCLs) (USEPA, 2006a) and adjusted tw-RBCs (USEPA, 2007a). Analytes detected in Area O surface water and groundwater are presented for comparison against screening criteria in **Table 4-3** (surface water) and **Table 4-4** (groundwater). Soil, groundwater, surface water, and sediment results from the 2007 RFI are presented in *Section 4.1.1*.

4.1 RFI, Shaw, 2007

4.1.1 Soil Analytical Results

Three soil samples (AOGW02S, AOGW08S, and AOGW09S) were collected at the site and analyzed for TCL VOCs, SVOCs, and PAHs. Detected results are presented in **Table 4-1**.

VOCs. One VOC (methylene chloride) was detected in soil sample AOGW09S. The concentration was well below its residential soil screening level (SSL).

PAHs. PAHs were not detected in site soil samples.

SVOCs. SVOCs were not detected in site soil samples.

4.1.2 Sediment Analytical Results

Two sediment samples (AOSD01 and AOSD02) were collocated with surface water samples AOSW01 and AOSW02. Both samples were analyzed for TCL VOCs, SVOCs, and PAHs. Detected sediment results are presented in **Table 4-2**.

VOCs. One VOC (acetone) was detected in sediment sample AOSD02 at a concentration well below its residential screening level. Acetone was not detected in sample AOSD01.

PAHs. PAHs were not detected in site sediment samples.

SVOCs. SVOCs were not detected in site sediment samples.

LEGEND

⊕ Groundwater Sample Location

■ Soil Sample Location

▲ Sediment/Surface Water Sample Location

☐ Area O Boundary

☐ Other SWMU Boundary

Notes:

1) Aerial photo, dated 2005, was obtained from Montgomery County, VA GIS & Planning Services.

N

Scale:

0 75 150 300 Feet

U.S. Army Corps of Engineers

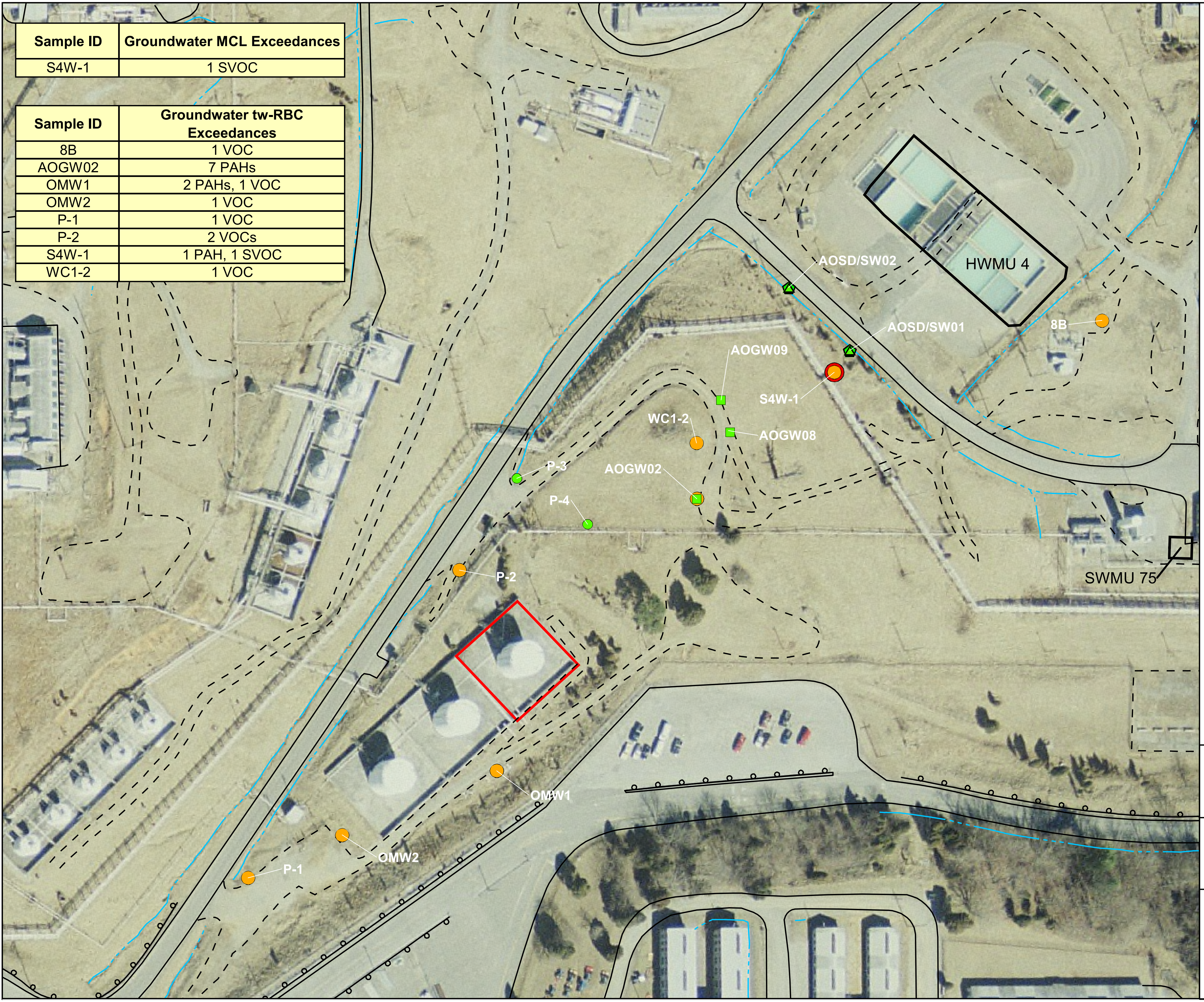
Shaw® Shaw Environmental, Inc.

FIGURE 4-1

2007 Investigation Sample Locations at Area O

Radford Army Ammunition Plant,
Radford, VA

RFAAP_Fig4-1_AREO_2007_Samp_Locations.mxd (joy.pasquarelli) (2/8/2008 4:49:31 PM)



Sample ID	Groundwater MCL Exceedances
S4W-1	1 SVOC

Sample ID	Groundwater tw-RBC Exceedances
8B	1 VOC
AOGW02	7 PAHs
OMW1	2 PAHs, 1 VOC
OMW2	1 VOC
P-1	1 VOC
P-2	2 VOCs
S4W-1	1 PAH, 1 SVOC
WC1-2	1 VOC

LEGEND

▲	Sediment Sample Location Result < r-RBC and i-RBC
⬟	Surface Water Sample Location Result < tw-RBC and < MCL
●	Groundwater Sample Location Result < MCL
●	Groundwater Sample Location Result >= tw-RBC
●	Groundwater Sample Location Result >= MCL
■	Soil Sample Location Result < r-RBC and < i-RBC
—	Water Feature
- -	Dirt Road
—	Paved Road
☐	Area O Boundary
☐	Other SWMU Boundary

Notes:
1) Aerial photo, dated 2005, was obtained from Montgomery County, VA Planning & GIS Services.

Scale: 0 50 100 200 Feet

N

U.S. Army Corps of Engineers

Shaw® Shaw Environmental, Inc.

FIGURE 4-2
Area O 2007 Groundwater,
Surface Water, Sediment, and Soil Results
Radford Army Ammunition Plant,
Radford, VA

ArcGIS File: RFAAP_Fig4-2_AREAO_2007_Samp_Location_Results.mxd (5/22/2008 2:41:57 PM)

Table 4-1
Analytes Detected in 2007
Soil Samples

Analyte			Sample ID	**AOGW02S**					**AOGW08S**					**AOGW09S**				
			Sample Date	**8/16/07**					**8/16/07**					**8/16/07**				
			Sample Depth (ft)	**33-35**					**24-25**					**17.5-19.5**				
	i-RBC	**r-RBC**	**Background**	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL
VOCs (ug/kg)																		
Methylene chloride	380000	85000	na	15	U	UJ	*7.3*	*15*	18	U	UJ	*9.1*	*18*	15.6	J	J	*6.3*	*13*
PAHs (ug/kg)		None detected																
SVOCs (ug/kg)		None detected																

*Refer to legend immediately following this table for a list of definitions and table notes.

Table 4-1
Legend

12	J	Shading and black font indicate an industrial RBC exceedance.
12	J	Bold outline indicates a residential RBC exceedance.
12	**J**	Bold, underlined font indicates a background exceedance.
12	*12*	Shading in the MDL/MRL columns indicates the MDL exceeds a criterion.

RBCs for non-Carcinogenic compounds have been recalculated to an HI of 0.1.

The pyrene RBCs were used for acenaphthylene, benzo(g,h,i)perylene and phenanthrene.

Inorganic results below background UTLs are not indicated as exceedances on the table.

RBC = Risk-Based Concentration (October 2007).

RBC values in table are for the more conservative chromium VI.

RBC values for chromium III are 150,000 (ind) and 12,000 (res), which were not exceeded.

Lead screening values from Technical Review Workgroup for Lead: Guidance Document (April 1999).

mg/kg = milligrams per kilogram (parts per million).

ng/kg = nanograms per kilogram (parts per trillion).

μg/kg = micrograms per kilogram (parts per billion).

NA = not applicable.

NT = analyte not tested.

Lab Q = Lab Data Qualifiers

* = Laboratory duplicate not within control limits.

B = (organics) Blank contamination. Value detected in sample and associated blank.

A (Dioxins) = B = (metals) Value <MRL and >MDL and is considered estimated.

E (metals) = Reported value is estimated because of the presence of interferences.

EMPC (Dioxins) = The ion-abundance ratio between the two characteristic PCDD/PCDF ions was outside accepted ranges. The detected PCDD/PCDF was reported as an estimated maximum possible concentration (EMPC).

J = (organics) Value <MRL and >MDL and is considered estimated.

U = Analyte not-detected at the method reporting limit.

X = (dioxins) Ion abundance ratio outside acceptable range. Value reported is EMPC.

Val Q = Validation Data Qualifiers

B = blank contamination. Value detected in sample and associated blank.

J = estimated concentration.

K = estimated concentration bias high.

L = estimated concentration bias low.

N = presumptive evidence for tentatively identified compounds using a library search.

U = analyte not detected.

UJ = estimated concentration non-detect.

UL = estimated concentration non-detect bias low.

Table 4-2
Analytes Detected in 2007 Sediment Samples

Analyte			Sample ID Sample Date	**AOSD01** **7/18/07**					**AOSD02** **7/18/07**				
	i-RBC	**r-RBC**	**Background**	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL
VOCs (ug/kg)													
Acetone	92000000	7000000	na	110	U	UJ	*53*	*110*	87.7	J	J	*48*	*97*
PAHs (ug/kg)	None detected												
SVOCs (ug/kg)	None detected												

*Refer to legend immediately following this table for a list of definitions and table notes.

Table 4-2
Legend

12	J	Shading and black font indicate an industrial RBC exceedance.
12	J	Bold outline indicates a residential RBC exceedance.
12	**J**	Bold, underlined font indicates a background exceedance.
12	*12*	Shading in the MDL/MRL columns indicates the MDL exceeds a criterion.

RBCs for non-Carcinogenic compounds have been recalculated to an HI of 0.1.
The pyrene RBCs were used for acenaphthylene, benzo(g,h,i)perylene and phenanthrene.
Inorganic results below background UTLs are not indicated as exceedances on the table.
RBC = Risk-Based Concentration (October 2007).
RBC values in table are for the more conservative chromium VI.
RBC values for chromium III are 150,000 (ind) and 12,000 (res), which were not exceeded.
Lead screening values from Technical Review Workgroup for Lead: Guidance Document (April 1999).
mg/kg = milligrams per kilogram (parts per million).
ng/kg = nanograms per kilogram (parts per trillion).
µg/kg = micrograms per kilogram (parts per billion).
NA = not applicable.
NT = analyte not tested.

Lab Q = Lab Data Qualifiers

* = Laboratory duplicate not within control limits.
B = (organics) Blank contamination. Value detected in sample and associated blank.
A (Dioxins) = B = (metals) Value <MRL and >MDL and is considered estimated.
E (metals) = Reported value is estimated because of the presence of interferences.
EMPC (Dioxins) = The ion-abundance ratio between the two characteristic PCDD/PCDF ions was outside accepted ranges. The detected PCDD/PCDF was reported as an estimated maximum possible concentration (EMPC).
J = (organics) Value <MRL and >MDL and is considered estimated.
U = Analyte not-detected at the method reporting limit.
X = (dioxins) Ion abundance ratio outside acceptable range. Value reported is EMPC.

Val Q = Validation Data Qualifiers

B = blank contamination. Value detected in sample and associated blank.
J = estimated concentration.
K = estimated concentration bias high.
L = estimated concentration bias low.
N = presumptive evidence for tentatively identified compounds using a library search.
U = analyte not detected.
UJ = estimated concentration non-detect.
UL = estimated concentration non-detect bias low.

Table 4-3
Analytes Detected in 2007 Surface Water Samples

Analyte	Sample ID Sample Date		**AOSW01** **7/18/07**					**AOSW02** **7/18/07**				
	MCL	**tw-RBC**	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL
VOCs (ug/L)												
Acetone	na	550	25	U		*5*	*25*	7	J	J	*5*	*25*
PAHs (ug/L)												
1-Methylnaphthalene	na	na	4.8			*0.26*	*1*	1.1	U		*0.27*	*1.1*
Acenaphthene	na	36	0.91	J	J	*0.51*	*1*	1.1	U		*0.53*	*1.1*
Fluorene	na	24	1.7			*0.26*	*1*	1.1	U		*0.27*	*1.1*
Phenanthrene	na	18	0.95	J	J	*0.51*	*1*	1.1	U		*0.53*	*1.1*
SVOCs (ug/L)	None detected											

*Refer to legend immediately following this table for a list of definitions and table notes.

Table 4-3
Legend

12	J	Shading and black font indicate an MCL exceedance.
12	J	Bold outline indicates a tw-RBC exceedance.
12	*12*	Shading in the MDL/MRL columns indicates the MDL exceeds a criterion.

tw-RBCs for non-Carcinogenic compounds have been recalculated to an HI of 0.1.
The pyrene tw-RBCs were used for acenaphthylene, benzo(g,h,i)perylene and phenanthrene.
The 2-methylnaphthalene tw-RBC was used for 1-methylnaphthalene.
Secondary MCLs were used for aluminum, iron, manganese, silver, and zinc.
MCL Action Levels were used for copper and lead.
MCL = Maximum Contaminant Level (USEPA, 2006).
tw-RBC = Tap Water Risk-Based Concentration (USEPA, October 2007).
tw-RBC value in table is for the more conservative chromium VI.
    tw-RBC value for chromium III is 5,500, which was not exceeded.
ng/L = nanograms per liter (parts per trillion).
µg/L = micrograms per liter (parts per billion).
NA = not applicable.
NT = analyte not tested.

Lab Q = Lab Data Qualifiers

B = (organics) Blank contamination. Value detected in sample and associated blank.
A (Dioxins) = B = (metals) Value <MRL and >MDL and is considered estimated.
E (metals) = Reported value is estimated because of the presence of interferences.
EMPC (Dioxins) = The ion-abundance ratio between the two characteristic PCDD/PCDF ions was outside accepted ranges. The detected PCDD/PCDF was reported as an estimated maximum possible concentration (EMPC).
J = (organics) Value <MRL and >MDL and is considered estimated.
U = Analyte not-detected at the method reporting limit.
X = (dioxins) Ion abundance ratio outside acceptable range. Value reported is EMPC.

Val Q = Validation Data Qualifiers

B = blank contamination. Value detected in sample and associated blank.
J = estimated concentration.
K = estimated concentration bias high.
L = estimated concentration bias low.
N = presumptive evidence for tentatively identified compounds using a library search.
U = analyte not detected.
UJ = estimated concentration non-detect.
UL = estimated concentration non-detect bias low.

Table 4-4
Analytes Detected in 2007 Groundwater Samples
Page 1 of 4

Analyte	Sample ID Sample Date		8B 8/27/07					AOGW02 8/23/07					OMW1 8/24/07				
	MCL	tw-RBC	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL
VOCs (ug/L)																	
Chloroform	80	0.15	1	U		0.21	1	1	U		0.21	1	0.42	JB	B	0.21	1
Tetrachloroethene	5	0.1	0.61	J	J	0.25	1	1	U		0.25	1	1	U		0.25	1
PAHs (ug/L)																	
1-Methylnaphthalene	na	na	1.1	U		0.28	1.1	414		L	5	20	32.4			0.25	0.98
2-Methylnaphthalene	na	2.4	1.1	U		0.28	1.1	180		L	5	20	16			0.25	0.98
Acenaphthene	na	36	1.1	U		0.56	1.1	47.1			9.9	20	2.2			0.49	0.98
Acenaphthylene	na	18	1.1	U		0.56	1.1	18.2	J	J	9.9	20	0.98	U		0.49	0.98
Fluorene	na	24	1.1	U		0.28	1.1	101			5	20	3.7			0.25	0.98
Naphthalene	na	0.65	1.1	U		0.28	1.1	50.7			5	20	27.5			0.25	0.98
Phenanthrene	na	18	1.1	U		0.56	1.1	163			9.9	20	1.7			0.49	0.98
Pyrene	na	18	1.1	U		0.28	1.1	18.9	J	J	5	20	0.98	U		0.25	0.98
SVOCs (ug/L)																	
bis(2-Ethylhexyl)phthalate	6	4.8	5.6	U		2.2	5.6	79	U		32	79	4.9	U		2	4.9
Carbazole	na	3.3	5.6	U		1.1	5.6	79	U		16	79	1.7	J	J	0.98	4.9

* Refer to legend immediately folowing this table for a list of definitions and table notes.

Table 4-4
Analytes Detected in 2007 Groundwater Samples
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Analyte		Sample ID Sample Date	**OMW2** **8/24/07**					**P-1** **8/23/07**					**P-2** **8/23/07**				
	MCL	**tw-RBC**	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL
VOCs (ug/L)																	
Chloroform	80	0.15	14.2	B		0.21	1	11.5	B		0.21	1	10.3	B		0.21	1
Tetrachloroethene	5	0.1	1	U		0.25	1	1	U		0.25	1	0.3	J	J	0.25	1
PAHs (ug/L)																	
1-Methylnaphthalene	na	na	1	U	UL	0.26	1	0.98	U	UL	0.25	0.98	1	U	UL	0.25	1
2-Methylnaphthalene	na	2.4	1	U	UL	0.26	1	0.98	U	UL	0.25	0.98	1	U	UL	0.25	1
Acenaphthene	na	36	1	U	UL	0.51	1	0.98	U		0.49	0.98	1	U		0.5	1
Acenaphthylene	na	18	1	U	UL	0.51	1	0.98	U		0.49	0.98	1	U		0.5	1
Fluorene	na	24	1	U		0.26	1	0.98	U		0.25	0.98	1	U		0.25	1
Naphthalene	na	0.65	1	U	UL	0.26	1	0.98	U		0.25	0.98	1	U		0.25	1
Phenanthrene	na	18	1	U	UL	0.51	1	0.98	U		0.49	0.98	1	U		0.5	1
Pyrene	na	18	1	U	UL	0.26	1	0.98	U		0.25	0.98	1	U		0.25	1
SVOCs (ug/L)																	
bis(2-Ethylhexyl)phthalate	6	4.8	5.1	U		2	5.1	4.9	U		2	4.9	5	U		2	5
Carbazole	na	3.3	5.1	U		1	5.1	4.9	U		0.98	4.9	5	U		1	5

* Refer to legend immediately folowing this table for a list of definitions and table notes.

Table 4-4
Analytes Detected in 2007 Groundwater Samples
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Analyte	Sample ID Sample Date		**P-3** **8/23/07**					**P-4** **8/27/07**				
	MCL	**tw-RBC**	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL
VOCs (ug/L)												
Chloroform	80	0.15	1	U		*0.21*	*1*	1	U		*0.21*	*1*
Tetrachloroethene	5	0.1	1	U		*0.25*	*1*	1	U		*0.25*	*1*
PAHs (ug/L)												
1-Methylnaphthalene	na	na	0.97	U	UL	*0.24*	*0.97*	0.98	U		*0.25*	*0.98*
2-Methylnaphthalene	na	2.4	0.97	U	UL	*0.24*	*0.97*	0.98	U		*0.25*	*0.98*
Acenaphthene	na	36	0.97	U	UL	*0.49*	*0.97*	0.98	U		*0.49*	*0.98*
Acenaphthylene	na	18	0.97	U	UL	*0.49*	*0.97*	0.98	U		*0.49*	*0.98*
Fluorene	na	24	0.97	U		*0.24*	*0.97*	0.98	U		*0.25*	*0.98*
Naphthalene	na	0.65	0.97	U	UL	*0.24*	*0.97*	0.98	U		*0.25*	*0.98*
Phenanthrene	na	18	0.97	U		*0.49*	*0.97*	0.98	U		*0.49*	*0.98*
Pyrene	na	18	0.97	U	UL	*0.24*	*0.97*	0.98	U		*0.25*	*0.98*
SVOCs (ug/L)												
bis(2-Ethylhexyl)phthalate	6	4.8	4.9	U		*1.9*	*4.9*	4.9	U		*2*	*4.9*
Carbazole	na	3.3	4.9	U		*0.97*	*4.9*	4.9	U		*0.98*	*4.9*

* Refer to legend immediately folowing this table for a list of definitions and table notes.

Table 4-4
Analytes Detected in 2007 Groundwater Samples
Page 4 of 4

Analyte	Sample ID Sample Date		S4W-1 8/27/07					WC1-2 8/28/07				
	MCL	**tw-RBC**	Result	Lab Q	Val Q	MDL	MRL	Result	Lab Q	Val Q	MDL	MRL
VOCs (ug/L)												
Chloroform	80	0.15	1	U		*0.21*	*1*	1.7			*0.21*	*1*
Tetrachloroethene	5	0.1	1	U		*0.25*	*1*	1	U		*0.25*	*1*
PAHs (ug/L)												
1-Methylnaphthalene	na	na	7.6			*0.25*	*0.99*	0.91	U		*0.23*	*0.91*
2-Methylnaphthalene	na	2.4	2			*0.25*	*0.99*	0.91	U		*0.23*	*0.91*
Acenaphthene	na	36	1.5			*0.5*	*0.99*	0.91	U		*0.45*	*0.91*
Acenaphthylene	na	18	0.99	U		*0.5*	*0.99*	0.91	U		*0.45*	*0.91*
Fluorene	na	24	2.9			*0.25*	*0.99*	0.91	U		*0.23*	*0.91*
Naphthalene	na	0.65	1			*0.25*	*0.99*	0.91	U	UL	*0.23*	*0.91*
Phenanthrene	na	18	1.5			*0.5*	*0.99*	0.91	U	UL	*0.45*	*0.91*
Pyrene	na	18	0.99	U		*0.25*	*0.99*	0.91	U	UL	*0.23*	*0.91*
SVOCs (ug/L)												
bis(2-Ethylhexyl)phthalate	6	4.8	23.1			*2*	*5*	4.5	U		*1.8*	*4.5*
Carbazole	na	3.3	5	U		*0.99*	*5*	4.5	U		*0.91*	*4.5*

* Refer to legend immediately folowing this table for a list of definitions and table notes.

Table 4-4
Legend

12	J	Shading and black font indicate an MCL exceedance.
12	J	Bold outline indicates a tw-RBC exceedance.
12	*12*	Shading in the MDL/MRL columns indicates the MDL exceeds a criterion.

tw-RBCs for non-Carcinogenic compounds have been recalculated to an HI of 0.1.
The pyrene tw-RBCs were used for acenaphthylene, benzo(g,h,i)perylene and phenanthrene.
The 2-methylnaphthalene tw-RBC was used for 1-methylnaphthalene.
Secondary MCLs were used for aluminum, iron, manganese, silver, and zinc.
MCL Action Levels were used for copper and lead.
MCL = Maximum Contaminant Level (USEPA, 2006).
tw-RBC = Tap Water Risk-Based Concentration (USEPA, October 2007).
tw-RBC value in table is for the more conservative chromium VI.
tw-RBC value for chromium III is 5,500, which was not exceeded.
ng/L = nanograms per liter (parts per trillion).
µg/L = micrograms per liter (parts per billion).
NA = not applicable.
NT = analyte not tested.

Lab Q = Lab Data Qualifiers

B = (organics) Blank contamination. Value detected in sample and associated blank.
A (Dioxins) = B = (metals) Value <MRL and >MDL and is considered estimated.
E (metals) = Reported value is estimated because of the presence of interferences.
EMPC (Dioxins) = The ion-abundance ratio between the two characteristic PCDD/PCDF ions was outside accepted ranges. The detected PCDD/PCDF was reported as an estimated maximum possible concentration (EMPC).
J = (organics) Value <MRL and >MDL and is considered estimated.
U = Analyte not-detected at the method reporting limit.
X = (dioxins) Ion abundance ratio outside acceptable range. Value reported is EMPC.

Val Q = Validation Data Qualifiers

B = blank contamination. Value detected in sample and associated blank.
J = estimated concentration.
K = estimated concentration bias high.
L = estimated concentration bias low.
N = presumptive evidence for tentatively identified compounds using a library search.
U = analyte not detected.
UJ = estimated concentration non-detect.
UL = estimated concentration non-detect bias low.

4.1.3 Surface Water Analytical Results

Two surface water samples (AOSW01 and AOSW02) were collected in the drainage ditch northeast of the site where groundwater was discharging to the surface. Both samples were analyzed for TCL VOCs, SVOCs, and PAHs. Detected surface water results are presented in **Table 4-3**.

VOCs. One VOC (acetone) was detected in sample AOSW02 at a concentration below its tw-RBC. An MCL does not exist for acetone.

PAHs. Four PAHs (1-methylnaphthalene, acenaphthene, fluorene, and phenanthrene) were detected in sample AOSW01 at concentrations below applicable aqueous screening levels. PAHs were not detected in sample AOSW02.

SVOCs. Non-PAH SVOCs were not detected in either surface water samples.

4.1.4 Groundwater Analytical Results

Groundwater samples were collected from nine existing wells and one direct push groundwater sampling point for chemical analysis (**Table 3-1**). Detected groundwater results are presented in **Table 4-4** and summarized in **Table 4-5**.

VOCs. Two VOCs [chloroform and tetrachloroethene (PCE)] were detected at concentrations exceeding their tw-RBCs in Area O groundwater samples. Chloroform exceeded its tw-RBC in five of the samples (OMW1, OMW2, P-1, P-2, and WC1-2). Chloroform concentrations ranged from 0.42 to 14.2 µg/L, below the MCL of 80 µg/L. PCE exceeded its tw-RBC (0.10 µg/L) in two (8B and P-2) of the ten samples.

PAHs. Eight PAHs were detected in Area O groundwater samples. Of these (1-methylnaphthalene, 2-methylnaphthalene, acenaphthene, acenaphthylene, fluorene, naphthalene, phenanthrene, and pyrene) exceeded their respective tw-RBCs. 1-methylnaphthalene does not have an associated tw-RBC. In addition, none of the detected PAHs have an associated MCL.

SVOCs. Two non-PAH SVOCs [bis(2-ethylhexyl)phthalate and carbazole] were detected in site groundwater. Bis(2-ethylhexyl)phthalate exceeded its tw-RBC and MCL in well S4W-1. It was undetected in the remaining nine samples. Carbazole was only detected in well OMW1 at a concentration below its tw-RBC. Carbazole does not have an MCL.

4.1.5 SSL Comparison

Table 4-6 presents the chemical results from the 1992 and 1993 soil sampling compared with the current (October, 2007) USEPA Region III SSL soil transfer to groundwater values, using a dilution attenuation factor of 20 (USEPA, 2007a). One compound, methylene chloride, was detected in one of the 2007 samples. The only detection was in sample AOGW09S, at a concentration of 15.6 micrograms per kilogram (µg/kg), below its SSL of 19 µg/kg.

As shown in the table, one VOC (chloroform) and two PAHs (2-methylnaphthalene and naphthalene) were found to exceed SSLs in the 1992/1993 samples. These three constituents were also detected in groundwater at Area O.

Chloroform was detected in one of 17 soil samples at a concentration of 2.4 µg/kg, exceeding the SSL of 0.91 µg/kg. Chloroform was detected in five groundwater samples during the 2007 sampling, but four of the detections were flagged with a “B” during data validation, indicating that chloroform was also detected in laboratory blanks associated with these samples. The single

Table 4-5
Summary of Analytes Detected in 2007 Groundwater Samples

Analyte	MCL	tw-RBC	# of MCL Exceedances	# of tw-RBC Exceedances	# of Detections	# of Samples	Minimum Concentration	Maximum Concentration	Location of Maximum
VOCs (ug/L)									
Chloroform	80	0.15	0	5	5	10	0.42	14.2	OMW2
Tetrachloroethene	5	0.1	0	2	2	10	0.3	0.61	8B
PAHs (ug/L)									
1-Methylnaphthalene	na	na	na	na	3	10	7.6	414	AOGW02
2-Methylnaphthalene	na	2.4	na	2	3	10	2	180	AOGW02
Acenaphthene	na	36	na	1	3	10	1.5	47.1	AOGW02
Acenaphthylene	na	18	na	1	1	10	18.2	18.2	AOGW02
Fluorene	na	24	na	1	3	10	2.9	101	AOGW02
Naphthalene	na	0.65	na	3	3	10	1	50.7	AOGW02
Phenanthrene	na	18	na	1	3	10	1.5	163	AOGW02
Pyrene	na	18	na	1	1	10	18.9	18.9	AOGW02
SVOCs (ug/L)									
bis(2-Ethylhexyl)phthalate	6	4.8	1	1	1	10	23.1	23.1	S4W-1
Carbazole	na	3.3	na	0	1	10	1.7	1.7	OMW1

Table 4-6
Summary of SSL Transfer Exceedances in Soil at Area O

Analyte	SSL Transfer	# of SSL Transfer Exceedances	# of Detections	# of Samples	Minimum Concentration	Maximum Concentration	Location of Maximum
VOCs (ug/kg)							
Acetone	22000	0	1	17	28	28	OSB10 (RFIS*101)
Chloroform	0.91	1	1	17	2.4	2.4	OSB2 (RFIS*88)
Ethylbenzene	15000	0	1	17	3.3	3.3	OSB10 (RFIS*104)
Methylene chloride	19	0	1	17	15.6	15.6	AOGW09S
PAHs (ug/kg)	***None detected***						
SVOCs (ug/kg)							
2-Chlorophenol	na	na	1	26	190	190	OSB12 (RDSX*43)
2-Methylnaphthalene	4400	2	5	26	140	30000	OSB4 (RFIS*92)
Acenaphthene	100000	0	1	26	2300	2300	OSB4 (RFIS*92)
Acenaphthylene	680000	0	1	26	180	180	OSB10 (RFIS*104)
Anthracene	470000	0	1	26	810	810	OSB4 (RFIS*92)
bis(2-Ethylhexyl)phthalate	2900000	0	1	26	2200	2200	OSB15 (RDSX*46)
Dibenzofuran	3800	0	2	26	420	990	OSB4 (RFIS*92)
Di-n-butylphthalate	5000000	0	3	26	130	520	OSB20 (RDSX*51)
Fluorene	140000	0	6	26	87	3100	OSB4 (RFIS*92)
Naphthalene	150	3	3	26	210	2200	OSB4 (RFIS*92)
Phenanthrene	680000	0	6	26	200	4700	OSB4 (RFIS*92)
Pyrene	680000	0	2	26	120	400	OSB4 (RFIS*92)

chloroform detection that was not “B” flagged was found in well WC1-2 at a concentration of 1.4 µg/L, above the tw-RBC of 0.15, but well below the MCL of 80 µg/L (Note: 80 µg/L is the MCL for total trihalomethanes).

The two PAHs are fuel-related constituents and their presence is likely the result of the fuel oil leak at Area O. 2-Methylnaphthalene was detected in five of the 17 soil samples and exceeded the SSL in two of the samples. Naphthalene was detected in three of the 17 soil samples and exceeded the SSL in each of the samples where it was detected. Two samples (OSB4 and OSB10) had exceedances of both compounds. Concentrations in soil were below the industrial and residential RBCs. In groundwater, 2-methylnaphthalene was detected in three of the ten groundwater samples and exceeded its tw-RBC in two samples. Naphthalene was detected in three of the ten groundwater samples and exceeded its tw-RBC in all three samples. Neither compound has an MCL.

Based on SSL and groundwater screening results, chloroform, 2-methylnaphthalene, and naphthalene were the only constituents found to exceed both SSLs and groundwater screening criteria.

4.2 Nature and Extent Summary and Conclusions

4.2.1 Soil

The soil at Area O was investigated during the 1991/1992 and 1993 sampling events in support of the 1994 RFI and then again during the 2007 RFI. The combined data set from these investigations indicates that PAHs and SVOCs were detected in previous investigation soil samples collected for this site. However, none of the detected concentrations exceeded residential or industrial SSLs. In 2007, PAHs and SVOCs were not detected in any of the soil samples. Only one VOC (methylene chloride) was detected in 2007 in one sample (AOGW09S). However, it did not exceed residential or industrial screening levels.

Results from the investigations at Area O indicate that any negative impacts resulting from the underground fuel oil leak have been mitigated during the twenty years since the leaking pipe was replaced.

4.2.2 Surface Water/Sediment

Surface water and sediment in the drainage ditch on the northeast side of Area O was investigated during the 1994 and 2007 RFIs. A comparison between the 1994 and 2007 results indicates that PAH concentrations in sediment have decreased to the point that they are no longer detectable.

Surface water/sediment results from the more recent 2007 RFI indicated that no SVOCs, VOCs, or PAHs were present above current screening levels in either of the samples collected from the ditch. Similarly, to the soil, results from the surface water and sediment indicate that removal of the leaking pipe, and the passage of twenty years have mitigated the impacts of the leak on the ditch. Qualitatively, the fact that oily water has not been seen discharging to the ditch from the hillside supports this conclusion as well.

4.2.3 Groundwater

Groundwater at Area O, including samples from wells at downgradient HWMU 4, was investigated during the 2007 RFI. Although groundwater samples were also collected during the 1994 RFI, the more recent data from the 2007 RFI was used to assess potential impacts to groundwater as a result of the underground fuel oil leak at Area O. The 1994 data was used to assess trends in concentrations over time.

Groundwater results from the 2007 RFI indicated that two VOCs (chloroform and PCE), one SVOC [bis(2-ethylhexyl)phthalate], and seven PAHs (2-methylnaphthalene, acenaphthene, acenaphthylene, fluorene, naphthalene, phenanthrene, and pyrene) were present at the time of the investigation above current groundwater screening levels in the study area. The PAHs are potentially fuel-related constituents. The highest PAH concentrations in 1994 were found in well S4W-1. A comparison in concentration between the 1994 and 2007 results from this indicate that the majority of the PAHs have either:

- Migrated further downgradient and the plume has detached from the source area; or
- Been broken down through natural processes.

The other constituents detected above screening levels in groundwater [chloroform, PCE and bis(2-ethylhexyl)phthalate] are not fuel-related constituents and are not likely to have originated at the site.

PCE was detected in two wells (8B and P-2) at concentrations above the tw-RBC, but well below the MCL. Well 8B is located at HWMU 4 and is the farthest downgradient well. PCE was not detected in any of the wells located between Area O and 8B. Well P-2 is located cross-gradient from the site. The distribution of PCE does not suggest that Area O is the source of this chemical in groundwater.

Although chloroform was present at concentrations exceeding the tw-RBC in five wells (P-1, OMW1, OMW2, P-2, and WC1-2) in the study area, all the detected concentrations were below its MCL. This compound was also detected in wells that were upgradient of Area O; therefore, it is unlikely that exceedances of chloroform are a result of the underground oil leak at Area O. The detections of chloroform were flagged with a “B” during data validation, indicating that this compound was also detected in associated laboratory control samples and may be the result of blank contamination.

In addition to suspected blank contamination, the presence of chloroform is likely due to water leaks in the nearby aging water supply lines. According to RFAAP Sewer and Water Line Drawing #23, there is a 12-inch water line that traverses the crest of the hill between Area O and HWMU 4 and another 6-inch water line along the road parallel to the fuel oil tanks. In an Alternate Source Demonstration for Hazardous Waste Post-Closure Care Permit for HWMU 7, Alliant TechSystems (ATK) demonstrated that the aging and leaking water supply lines at HWMU 7 were likely the source of chloroform contamination in groundwater at HWMU 7. ATK indicated that the drinking water samples collected from RFAAP in 2004 and 2005 contained detectable concentrations of chloroform ranging from 13.4 µg/L to as high as 120 µg/L.

There is no history of use for chloroform at Area O, and chloroform is not a constituent of fuel oil. Based on the aforementioned conclusions, chloroform is not considered a concern in groundwater at Area O.

Bis(2-ethylhexyl)phthalate was detected in one of the ten 2007 samples and exceeded its tw-RBC and MCL in that sample. Bis(2-ethylhexyl)phthalate is a constituent that is primarily used in plastics and may be a contaminant resulting from the well construction, sampling, and/or the laboratory. Its isolated detection suggests that it is not a concern at the site. Further details regarding the origin and use of bis(2-ethylhexyl)phthalate is presented in *Section 5.2.3*.

5.0 CONTAMINANT FATE AND TRANSPORT

This section presents a discussion of the fate and transport mechanisms for chemicals of potential concern (COPCs) at Area O. Physical and chemical properties of the impacted media and of the contaminant(s) affect the fate and persistence of contamination in the environment (Rosenblatt et al., 1975). A general discussion of the physical properties and mechanisms which may govern the fate of contaminants in the environment, and a discussion of contaminant transport is presented in **Appendix D**. A discussion of the physical and chemical properties affecting soil conditions at Area O is presented as *Section 5.1*.

No constituents were detected at concentrations greater than their respective residential screening level in soil samples collected at Area O. A generalized fate and transport discussion for those constituents identified as risk drivers in the HHRA are presented in *Section 5.2*. A discussion of the fate of risk drivers by natural attenuation factors is presented in *Section 5.3*.

5.1 Soil Properties Affecting Fate and Transport

Chemical and physical properties of soil influence the fate and transport of constituents through the environment. Grain size distribution, pH, and TOC are commonly used to assess these chemical and physical characteristics of the soil. A summary of each follows.

Grain Size Distribution. The grain size distribution measures the amount of clay, silt, sand, and gravel in a sample based on the diameter of the material. Soil particles less than 0.002 millimeters are classified as clay and have a very large specific surface area, allowing them a significant capacity to adsorb water and other substances. Clay composition greatly influences soil fertility and the physical conditions of the soil. Clay directly affects the permeability and the plasticity of soil by generally lowering the soil's permeability and increasing the plasticity. Because pores between clay particles are very small and convoluted, movement of both water and air is very slow. Fate and transport of chemical compounds are hindered when passing through a soil with a high composition of clay due to clay's ability to adsorb cat-ions and to retain soil moisture. The site soil at Area O has a high percentage of clay, is a low permeability zone, and therefore it is more difficult for constituents to pass through the soil. The grain size distribution is also used to assess the permeability of soil. Well-sorted sands and gravels have a smaller distribution of grain size and a higher permeability. Poorly sorted, clayey sands and gravels have a large range in grain size and lower permeability because the smaller clay and silt particles fill in the void spaces between the sand and gravel.

Soil pH. Soil pH is a measure of acidity or alkalinity and is an important chemical property because it is an indication of soil reaction potential. Soil reaction influences the fate of many pollutants, affecting their breakdown and potential movement. For example, hydrolysis is the reaction of a compound with water. It usually involves the introduction of a hydroxyl (-OH) group into an organic compound, usually at a point of unbalanced charge distribution. The hydrolysis reaction can displace halogens and may be catalyzed by the presence of acids, bases, or metal ions. Therefore, the rate of hydrolysis is pH and metal-ion concentration dependent. The transport of some contaminants is also affected by pH. This is less significant for neutral and slightly polarized organic compounds, which are somewhat affected by pH, but is significant for chemicals that tend to ionize (Lyman et al., 1990). When the pH of the groundwater is approximately 1.0 to 1.5 units above the negative log of the acid dissociation constant (pK_a), adsorption becomes significant, retarding transport rates. pH also affects the rate of biodegradation that may occur at a site. Most bacteria find the optimum pH range to be 6.5 to 7.5 and are not able to survive at pH values greater than 9.5 or below 4.0 (Knox et al., 1993).

Soil at RFAAP generally ranges in pH from slightly less than 4.0 to slightly more than 9.61. A review of pH results during the *Facility-Wide Background Study Report* (IT, 2001) across soil types at the MMA did not yield outstanding trends. Higher soil pH results were generally associated with limestone and shale parent material (IT, 2001).

pH groundwater measurements were taken at Area O wells in August 2007. Those measurements ranged between 6.5 and 7.1. This means that the site groundwater has the optimum pH for bacteria to thrive and degradation to occur.

TOC. Organic matter content is expressed as a percentage, by weight, of the soil material that is a composition of plant and animal residues in the soil at various stages of decomposition. Available water capacity and infiltration rate are affected by organic matter content. Sorption and desorption are two major mechanisms affecting the fate of contaminants in the subsurface. Sorption is the process by which a compound is retained onto a solid particle rather than remaining dissolved in solution. The sorption of contaminants to the soil matrix is an important factor affecting their transport in terrestrial environments. Hydrophobic contaminants will accumulate at an interface or partition into a nonpolar phase (e.g., associate with the organic content of the subsurface medium) rather than partition into the water phase. For nonionic organic chemicals and aquifer materials, sorption is largely controlled by the clay and organic carbon content of the soil. The subsurface soil at this site is composed of yellowish-red sticky and plastic clay, and the substratum is red sandy clay loam. So, there is a large percentage of clay in the soil, and therefore the permeability and sorption is low. In addition, this means that the amount of TOC present in the soil matrix has a large affect on the fate of both organic and inorganic compounds. The degree to which TOC affects the fate of a chemical varies dependent on the properties of the chemical itself. Soil TOC concentrations at RFAAP range from 0.075 to 30.4 percent, with a median value of 0.5 percent.

5.2 Fate and Transport of Analytes Detected Above Screening Levels

As discussed in *Section 4.0*, no analytes were detected above screening levels in soil, surface water, or sediment at Area O. Constituents detected at concentrations exceeding groundwater levels of concern in 2007 included two VOCs (chloroform and PCE) and seven PAHs (2-methylnaphthalene, acenaphthene, acenaphthylene, fluorene, naphthalene, phenanthrene, and pyrene), and one SVOC [bis(2-ethylhexyl)phthalate]. Of these exceedances, only chloroform, PCE, and bis(2-ethylhexyl)phthalate were identified as risk drivers in the HHRA (*Section 6.0*). Specific characteristics of these risk drivers are discussed in more detail in the following sections.

5.2.1 Chloroform

During the 2007 sampling event, detected chloroform exceeded its tw-RBC (0.15 µg/L) in five Area O monitoring wells (OMW1, OMW2, P-1, P-2, and WC1-2). Detected concentrations ranged from 0.42 µg/L to 14.2 µg/L. These concentrations were well below the MCL of 80 µg/L.

Chloroform is a colorless liquid with a pleasant, nonirritating odor and a slightly sweet taste. It will burn only when it reaches very high temperatures. In the past, chloroform was used as an inhaled anesthetic during surgery, but it is not used that way today. Today, chloroform is used to make other chemicals and can also be formed in small amounts when chlorine is added to water. Other names for chloroform are trichloromethane and methyl trichloride.

Chloroform evaporates easily into the air. Most of the chloroform in air breaks down eventually, but it is a slow process. The breakdown products in air include phosgene and hydrogen chloride, which are both toxic. It does not stick to soil very well and can travel through soil to groundwater. Chloroform dissolves easily in water and some of it may break down to other chemicals. Chloroform lasts a long time in groundwater [Agency for Toxic Substances Disease Registry (ATSDR), 1997a].

5.2.2 PCE

During the 2007 sampling event, PCE exceeded its tw-RBC (0.1 µg/L) in two monitoring wells 8B and P-2 at concentrations of 0.61 and 0.3 µg/L, respectively. However, concentrations were below its MCL (5 µg/L).

PCE is a manufactured chemical used for dry cleaning and metal degreasing. Other names for tetrachloroethene include perchloroethylene, PCE, and tetrachloroethylene. It is a nonflammable liquid at room temperature. It evaporates easily into the air and has a sharp, sweet odor. Most people can smell PCE when it is present in the air at a level of 1 part PCE per million parts of air (1 ppm) or more, although some can smell it at even lower levels (ATSDR, 1997b).

5.2.3 Bis(2-ethylhexyl)phthalate

Bis(2-ethylhexyl)phthalate was only detected in well S4W-1 in 2007 RFI groundwater samples. It was detected above its tw-RBC of 4.8 µg/L and MCL of 6, at a concentration of 23.1 µg/L.

Bis(2-ethylhexyl)phthalate is a manufactured chemical that is commonly added to plastics to make them flexible. It is a colorless liquid with almost no odor. Bis(2-ethylhexyl)phthalate is present in plastic products such as wall coverings, tablecloths, floor tiles, furniture upholstery, shower curtains, garden hoses, swimming pool liners, rainwear, baby pants, dolls, some toys, shoes, automobile upholstery and tops, packaging film and sheets, sheathing for wire and cable, medical tubing, and blood storage bags (ATSDR, 2002).

Exposure to bis(2-ethylhexyl)phthalate is generally very low. Increased exposures may come from intravenous fluids delivered through plastic tubing, and from ingesting contaminated foods or water. It is not toxic at the low levels usually present in the environment. In animals, high levels of bis(2-ethylhexyl)phthalate damaged the liver and kidney and affected the ability to reproduce. Bis(2-ethylhexyl)phthalate has been found in at least 733 of the 1,613 National Priorities List sites identified by the USEPA (ATSDR, 2002).

Bis(2-ethylhexyl)phthalate is everywhere in the environment because of its use in plastics, but it does not evaporate easily or dissolve in water easily. It can be released in small amounts to indoor air from plastic materials, coatings, and flooring. It dissolves faster in water if gas, oil, or paint removers are present. Bis(2-ethylhexyl)phthalate attaches strongly to soil particles. In soil or water, bis(2-ethylhexyl)phthalate can be broken down by microorganisms into harmless compounds. Bis(2-ethylhexyl)phthalate does not break down easily when it is deep in the soil or at the bottom of lakes or rivers. It is in plants, fish, and other animals, but animals high on the food chain are able to break down this SVOC, so tissue levels are usually low (ATSDR, 2002).

5.3 Natural Attenuation Parameters Affecting the Fate of Risk Drivers

Groundwater samples collected at Area O were analyzed for natural attenuation parameters to assess whether groundwater conditions are conducive for the biological degradation and natural attenuation of risk drivers (discussed in *Section 6.0*) identified in groundwater at the site.

During aerobic biological attenuation, electron acceptors are required by the microorganisms for respiration. Dissolved oxygen (DO) is the most favored electron acceptor used in the biodegradation of fuel-related compounds. DO levels measured at Area O were above 0.5 milligrams per liter (mg/L) during the most recent sampling event in August 2007 (**Table 9-1**), with the exception of wells 8B and S4W-1. The elevated levels of DO in Area O groundwater indicate that aerobic conditions exist, which are favorable for the reduction of fuel-related constituents.

Anaerobic degradation can also occur in aquifers. Conditions favorable for anaerobic degradation were found in one well (8B) where PCE was also observed. This is favorable because anaerobic groundwater conditions are conducive to the reduction of chlorinated ethenes, like PCE. In monitoring well S4W-1, the only risk driver detected in groundwater above the tw-RBC was bis(2-ethylhexyl)phthalate, which may be attributed to well construction or other plastic products. Therefore, the DO levels suggest that natural attenuation is creating favorable conditions for the reduction of risk drivers in Area O groundwater.

Oxidation-reduction potential (ORP) levels often coincide with DO values. ORP values greater than 50 millivolts (mV) indicate aerobic and oxidizing conditions exist. The ORP levels in Area O groundwater were above 50 mV in most wells during the August 2007 sampling event. Elevated levels ranged from 83 mV at monitoring well OMW2 to 144 mV at monitoring well P-4. As expected, due to anaerobic DO conditions in wells 8B and S4W-1, lower ORP levels were observed at -52 and -187 mV, respectively. At well OMW1, a lower ORP level and an elevated DO level were observed during the August 2007 sampling event. These levels also indicate that natural attenuation is creating conditions favorable for the reduction of risk drivers in Area O groundwater.

At Area O, most of the biological natural attenuation processes taking place are via aerobic biodegradation, which requires oxygen. Levels of lesser energy potential electron acceptors may not be required to degrade groundwater risk drivers. However, the lesser electron acceptors were evaluated to determine the geochemical properties that can effect degradation of risk drivers in Area O groundwater. After oxygen is depleted, nitrate will be used as an electron acceptor. Nitrate concentrations ranged from below the detection limit of 0.05 mg/L at S4W-1 and AOGW02 to 4.0 mg/L at OMW2 (**Table 9-1**). Ferrous iron is a product of ferric iron reduction, created during anaerobic microbial activity. Elevated levels of ferrous iron were observed in wells 8B and S4W-1 at 4.0 and 2.2 mg/L, respectively. The elevated levels in these two wells were expected as anaerobic conditions exist and are favorable for the biodegradation of a chlorinated ethene (PCE) observed in well 8B. After ferric iron has been depleted, sulfate will be used as an electron acceptor during anaerobic biological degradation. Sulfate concentrations in Area O groundwater ranged from 9.1 mg/L at AOGW02 to 50 mg/L at OMW2 during August 2007, where aerobic conditions exist in both wells. Sulfate concentrations in well S4W-1, where anaerobic conditions exist, were 10.2 mg/L in August 2007. As the other electron acceptors are depleted, carbon dioxide is then used, and methane is produced. Dissolved methane concentrations were measured to determine if methanogenic (anaerobic) conditions were established in Area O groundwater. Elevated levels of methane were detected in wells OMW1, S4W-1, and 8B, which also coincided with negative ORP levels (**Table 9-1**). In monitoring wells OMW1, S4W-1, and 8B, methane levels were detected at concentrations of 6,900, 1,020, and 1.4 µg/L (respectively) in August 2007. The evaluation of the electron acceptors suggests that natural attenuation is creating favorable conditions for the reduction of risk drivers through both aerobic and anaerobic biodegradation.

TOC was analyzed in Area O groundwater samples to determine the amount of carbon that is available for biological consumption as an energy source. Many of the risk drivers can also be used as a carbon substrate for the microbes. The TOC concentrations correlate to the amount of fuel-related constituents detected in most wells. TOC concentrations ranged from below the detection limit of 0.5 to 38 mg/L in Area O wells (**Table 9-1**).

Elevated concentrations of ethene and ethane were not observed during the August 2007 sampling event. The presence of ethene or ethane was not expected until PCE has been biologically reduced to trichloroethene, cis-1,2-dichloroethene, vinyl chloride, and then undergone reductive dechlorination to ethene. PCE was detected in two wells (8B and P-2) in August 2007 (below the MCL), and no biological degradation products have been observed.

pH is the measure of the acidity or basicity of a solution. The pH levels in Area O groundwater ranged from 7.0 in wells 8B and S4W-1 to 7.3 in well P-4 during the August 2007 sampling event. These observed pH levels are conducive for microbial growth, which should aid in natural attenuation processes.

Alkalinity is a measure of the ability of a solution to neutralize acids and therefore retain a neutral pH. At Area O, alkalinity concentrations in groundwater ranged from 168 mg/L in well S4W-1 to 478 mg/L in sample AOGW02 (**Table 9-1**). These alkalinity levels indicate that the pH of the groundwater at Area O will remain neutral.

The only known species able to completely reduce chlorinated ethenes to the harmless product ethene is the anaerobic bacterium *Dehalococcoides* sp. (DHC). All Area O groundwater samples were analyzed to determine if this bacterium was present in Area O groundwater. Elevated levels were observed in wells 8B, OMW1, AOGW02, P-1, P-2, and P-3. Only one chlorinated ethene (PCE) was observed in two wells (8B and P-2) during August 2007. At these wells, DHC was detected at 130,000 (8B) and 4,900 (P-2) cells per milliliter (cells/mL). In general, concentrations greater than 3,000 cells/mL are adequate to reduce chlorinated ethenes. At OMW1, reducing conditions were also observed which would favor the growth of these microorganisms. The presence of DHC in Area O groundwater suggests that the reduction of chlorinated ethenes has occurred and concentrations are able to be further reduced in groundwater at this site.

The presence of natural attenuation parameters in Area O indicates that groundwater conditions are conducive for the biological and abiotic reduction of risk drivers in groundwater. The primary constituents identified in Area O groundwater are fuel-related, and elevated DO and carbon sources are available at the site for the aerobic degradation of these compounds.

In addition, the areas of anaerobic conditions present in groundwater at the site are conducive to the degradation of PCE. The presence of ferrous iron in Area O groundwater is also beneficial for the degradation of PCE. The evaluation of the electron acceptors suggests that natural attenuation is creating favorable conditions for the reduction of risk drivers through both aerobic and anaerobic biodegradation. The high presence of the anaerobic bacterium DHC supports the degradation of PCE to a harmless byproduct.

In conclusion, natural attenuation processes are occurring and should continue to aid in the reduction of risk drivers at Area O. Both aerobic degradation and anaerobic reductive dechlorination are occurring in groundwater at Area O. Areas where fuel-related constituents are present have aerobic conditions that are favorable for the degradation of these chemicals. The areas where chlorinated solvents are present (8B, S4W-1) have lower DO and ORP values indicative of reductive chlorination. These wells also had higher concentrations of DHC, which also indicates that reductive dechlorination is occurring in groundwater at these locations.

6.0 HUMAN HEALTH RISK ASSESSMENT

This HHRA evaluates the probability and magnitude of potential adverse effects on human health associated with exposure to site-related chemicals in site media at Area O. The HHRA was conducted for the site consistent with guidance included in EPA's *Interim Final Risk Assessment Guidance for Superfund (RAGS)* (USEPA, 1989a) and other current USEPA/USEPA Region III resources and guidance documents as noted on the RAGS Part D tables provided in **Appendix E-1**. Additional information regarding site background can be found in *Section 2.0*.

This HHRA consists of the following six sections:

- **Section 6.1: Data Summary and Selection of COPCs:** Relevant site data are gathered, examined, and discussed. Basic constituent statistics and screening levels are summarized. COPCs are identified by comparison to screening criteria as discussed in *Section 6.1.2*.
- **Section 6.2: Exposure Assessment:** Potentially exposed populations (e.g., receptors) and exposure routes are identified, and exposure point concentrations (EPCs) are calculated for COPCs. Standard exposure factors and health-protective assumptions are used to assess the magnitude, frequency, and duration of exposure for each exposure route and intakes are calculated.
- **Section 6.3: Toxicity Assessment:** Toxicity criteria for COPCs are gathered and presented.
- **Section 6.4: Risk Characterization:** Quantitative risks and hazards are estimated and summarized by combining toxicity criteria with intakes for each exposure route.
- **Section 6.5: Uncertainties Analysis:** Uncertainties, "including uncertainties in the physical setting definition for the site, in the models used, in the exposure parameters, and in the toxicity assessment" (USEPA, 1989a) are discussed.
- **Section 6.6: Summary and Conclusions:** The results of the HHRA are summarized.

As previously stated, the tabulated risk assessment results are presented in accordance with USEPA guidance described in *RAGS: Volume I – Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments)* (USEPA, 2001a). RAGS D requires the risk assessment results to be presented in a series of standardized tables, which are presented in **Appendix E-1**.

6.1 Data Summary and Selection of COPCs

6.1.1 Data Summary

Table 6-1 identifies the soil, groundwater, surface water, and sediment samples used in the HHRA for Area O. The complete data tables for detected analytes for each media are provided in *Section 4.0*. Additional information regarding the data used in the HHRAs is summarized below:

- If a constituent was measured by two methods, results from the more sensitive analytical method were used. For example, PAHs were analyzed as part of the SVOC method, as well as by a PAH-specific method. Results from the specific method were used.

Table 6-1
Sample Group

SUBSURFACE SOIL		
OSB1 (RFIS*66) 14-16 ft bgs	OSB9 (RFIS*100) 10-12 ft bgs	OSB17 (RDSX*48) 10.5-12.5 ft bgs
OSB2 (RFIS*88) 14-16 ft bgs	OSB10 (RFIS*104) 14-16 ft bgs	OSB18 (RDSX*49) 10-12 ft bgs
OSB5 (RFIS*94) 5-7 ft bgs	OSB11 (RFIS*102) 11-13 ft bgs	
SURFACE WATER		
AOSD01	AOSW02	TMSW01
SEDIMENT		
AOSD01	AOSD02	
GROUNDWATER		
AOGW02	P-4	OMW1
P-1	TM-2	OMW2
P-2	S4W-1	TMMW1
P-3	WC1-2	8B

Because the secondary containment for the AST covers most of Area O, no surface soil samples were collected.

- J-flagged data (estimated concentration) are considered detections and are used without modification.
- The qualification and validation of the analytical data included a comparison of the site data to corresponding blank (laboratory, equipment rinse, field, and trip) concentration data. If the detected concentration in a site sample was less than ten times (for common laboratory contaminants) or five times (for other compounds) the concentration in the corresponding blank sample, the sample was qualified with a “B.” According to USEPA Region III guidance (USEPA, 1995a, 2000b), it cannot be unequivocally stated that the result is not “non-detected” at that concentration. Therefore, B-qualified data are typically eliminated from the data set. Data sets for this HHRA were evaluated for B-qualified data on an “analyte-by-analyte” basis.
- Rejected results (R-flagged) are not used.
- Data from duplicate sample pairs are averaged and treated as one result. If an analyte is detected in one of the sample pair, one-half the detection limit of the non-detect is averaged with the detected result, and the result is considered detected.

Additional information regarding specific soil and water samples used in the HHRA is provided in *Sections 6.1.1.1 and 6.1.1.2*.

6.1.1.1 Soil

Soil samples collected during sampling events in 1991 and 1993 were used for the COPC screenings. No surface soil samples were collected because the AST is sitting on a large concrete, bermed area that prevents contact with surface soil at the tank. As presented in **Table**

6-1, the subsurface soil samples used in this risk assessment for Area O were collected from 5 to 16 ft bgs. A total of eight subsurface soil samples were used for the HHRA. Sample OSB5 was collected in duplicate and the detected concentrations of each analyte were averaged. The samples were analyzed for VOCs and SVOCs (which included pesticides and polychlorinated biphenyls).

6.1.1.2 Groundwater

Groundwater samples collected during the 2007 sampling event were used for the COPC screenings. A total of twelve samples were collected. The samples were analyzed for VOCs, SVOCs, and PAHs. Sampling locations are listed in **Table 6-1**.

6.1.1.3 Surface Water

Surface water samples collected during the 2007 sampling event were used for the COPC screenings. A total of three samples were collected. These samples were collected from the drainage ditch at the base of the scarp. The samples were analyzed for VOCs, SVOCs, and PAHs. Sampling locations are listed in **Table 6-1**.

6.1.1.4 Sediment

Sediment samples collected during the 2007 sampling event were used for the COPC screenings. A total of two samples were collected from 0 to 0.5 ft. These samples were collected from the drainage ditch at the base of the scarp. The samples were analyzed for VOCs, SVOCs, and PAHs. Sampling locations are listed in **Table 6-1**.

6.1.2 Identification of COPCs

COPCs were identified for the sites by comparing the maximum detected concentration (MDC) to the following screening levels for each media: USEPA Region III residential risk-based concentrations (r-RBCs) (soil) and USEPA tw-RBCs (groundwater) as presented in the October 2007 USEPA Region III RBC and Alternate RBC Tables (USEPA, 2007a). In accordance with USEPA Region III guidance, RBCs for non-carcinogenic chemicals were adjusted downward to a hazard quotient (HQ) of 0.1 to ensure that chemicals with additive effects were not prematurely eliminated during screening.

Because RBCs are not available for sediment, chemicals present in sediment were compared with USEPA Region III soil r-RBCs corresponding to a carcinogenic risk of $1x10^{-6}$ or adjusted to reflect one-tenth (0.1) of the HI for non-carcinogenic effects. The r-RBCs were then increased by one order of magnitude to represent the types of exposures that are more likely to occur for this medium.

Because RBCs are not available for surface water, chemicals present in surface water were compared to USEPA Region III tw-RBCs corresponding to a carcinogenic risk of $1x10^{-6}$ or adjusted to reflect one-tenth (0.1) of the HI for non-carcinogenic effects. The tw-RBCs were then increased by one order of magnitude to represent the types of exposures that are more likely to occur for this medium.

Although current and future land uses at Area O are most likely to be industrial in nature, residential (rather than industrial) soil RBCs were used for comparisons to soil concentrations. Because the resident scenario was evaluated for this HHRA, residential soil RBCs were used to screen chemicals in soil as a conservative measure.

Analytes detected at a maximum concentration greater than the corresponding adjusted RBC or screening values identified above (or those for which no screening criteria exists) were selected as COPCs. COPC screening tables for each medium are presented in **Appendix E-1**, **Tables E.1-2** (COPC Determination Detects-Subsurface Soil), **E.1-4** (COPC Determination Detects-Sediment), **E.1-6** (COPC Determination Detects-Surface Water), and **E.1-8** (COPC Determination Detects-Groundwater). As shown in these tables, COPCs were identified in Area O groundwater. There were no COPCs identified for subsurface soil, sediment, or surface water.

Similarly, the reporting limits for those constituents that were not detected were compared with RBCs for each medium. Chemicals that were not detected in at least one medium have not been included in the HHRA. The reporting limits for the non-detected constituents were screened against the RBCs to ensure that the range of reporting limits was generally low enough to detect constituents that would exceed RBCs. The maximum reporting limits for these constituents were compared to RBCs. The results of these comparisons are shown in **Appendix E-1, Tables E.1-3** (Non-Detect Screening-Subsurface Soil), **E.1-5** (Non-Detect Screening-Sediments), **E.1-7** (Non-Detect Screening-Surface Water), and **E.1-9** (Non-Detect Screening-Groundwater).

6.2 Exposure Assessment

The objective of the exposure assessment is to estimate "the type and magnitude of exposures to chemicals of potential concern" (USEPA, 1989a). When combined with chemical-specific toxicity information (summarized in the toxicity assessment), these exposures produce estimations of potential risks.

6.2.1 Conceptual Site Model/Receptor Characterization

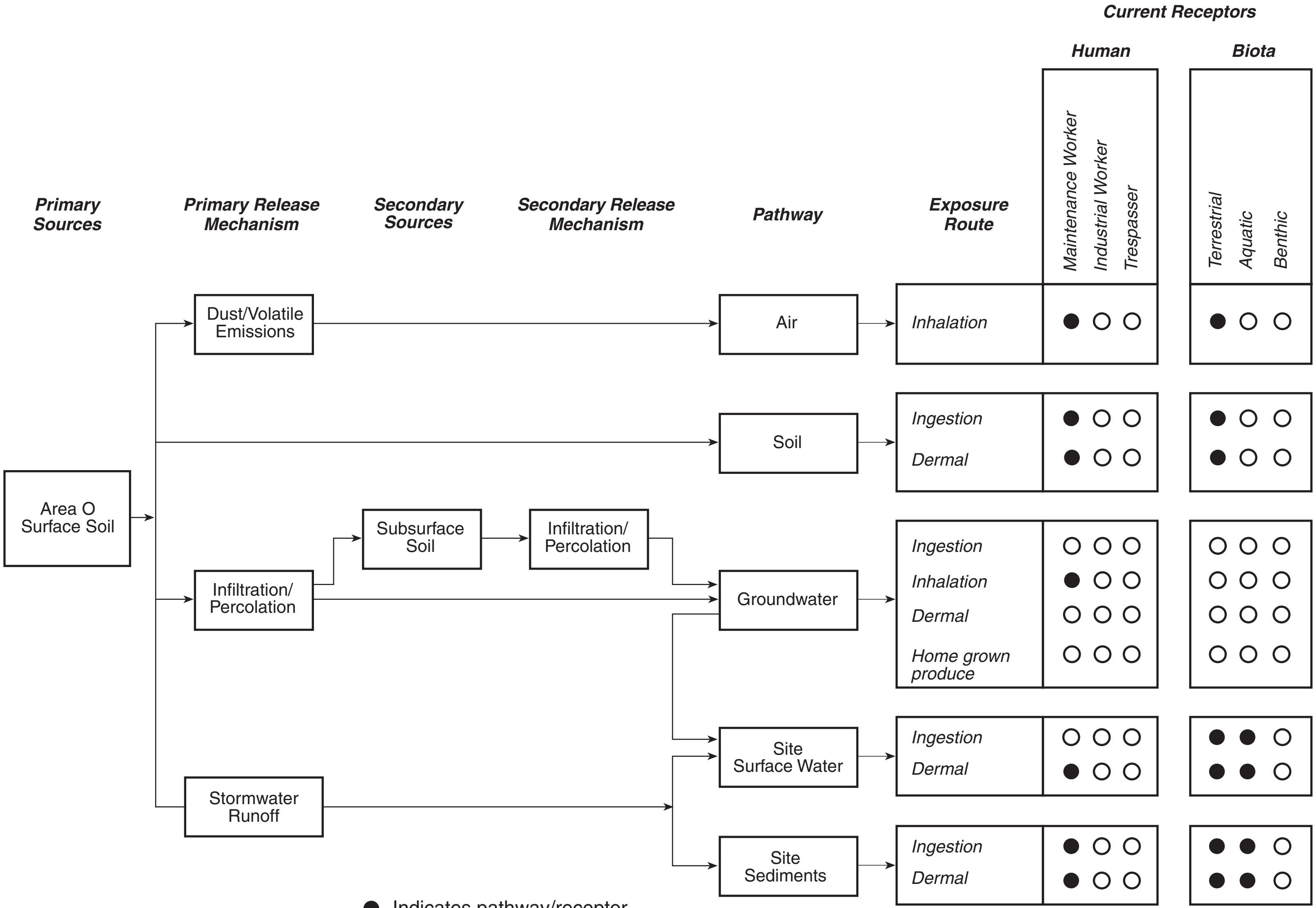
Refined CSMs for Area O are presented on **Figures 6-1 and 6-2** for current and future exposure scenarios, respectively. Area O consists of approximately one 269,000-gallon fuel oil AST that is situated on a concrete base and surrounded by a concrete secondary containment system (Shaw, 2007). The southeast side of the valley remains relatively level for 300 ft north of the tanks. The ground surface drops more abruptly at that point and the scarp in the hillside has a 30-foot drop over approximately 150 ft. A road cuts across the valley at the base of this scarp, and there is a drainage ditch along the road where oily water reportedly discharged from the hillside in the 1980s.

An Oil Audit was conducted by USACE in 1982. This audit noted fuel leakage of an underground pipeline connecting a filling station to the fuel tank at approximately 3,000 gallons.

Land use around Area O is industrial. Area O is not currently in use. The area immediately surrounding the tank is covered by concrete and surrounded by a concrete containment system. The nearest residences are a few miles away. It is expected that Area O and surrounding vicinity will remain industrial into the foreseeable future.

Although the site is not currently used, it was conservatively assumed that maintenance workers are the most likely receptors at the site. Due to Installation security, it is unlikely that trespassers could gain access to Area O; however, risks associated with the maintenance worker are considered protective of the limited exposure experienced by the trespasser.

If future development occurs, maintenance workers, industrial/commercial workers, and excavation workers could be exposed to subsurface soil as a result of disturbing soil during construction/excavation activities. Therefore, maintenance worker, industrial worker, and excavation worker exposures at Area O were evaluated for subsurface soil in the HHRA.



		Current Receptors					
		Human			Biota		
Pathway	Exposure Route	Maintenance Worker	Industrial Worker	Trespasser	Terrestrial	Aquatic	Benthic
Air	Inhalation	●	○	○	●	○	○
Soil	Ingestion	●	○	○	●	○	○
	Dermal	●	○	○	●	○	○
Groundwater	Ingestion	○	○	○	○	○	○
	Inhalation	●	○	○	○	○	○
	Dermal	○	○	○	○	○	○
	Home grown produce	○	○	○	○	○	○
Site Surface Water	Ingestion	○	○	○	●	●	○
	Dermal	●	○	○	●	●	○
Site Sediments	Ingestion	●	○	○	●	●	○
	Dermal	●	○	○	●	●	○

● Indicates pathway/receptor combinations to be evaluated

○ Indicates pathway/receptor combinations incomplete or no source

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Figure 6-1. Current Land Use Conceptual Site Model for Area O Radford Army Ammunition Plant, Virginia

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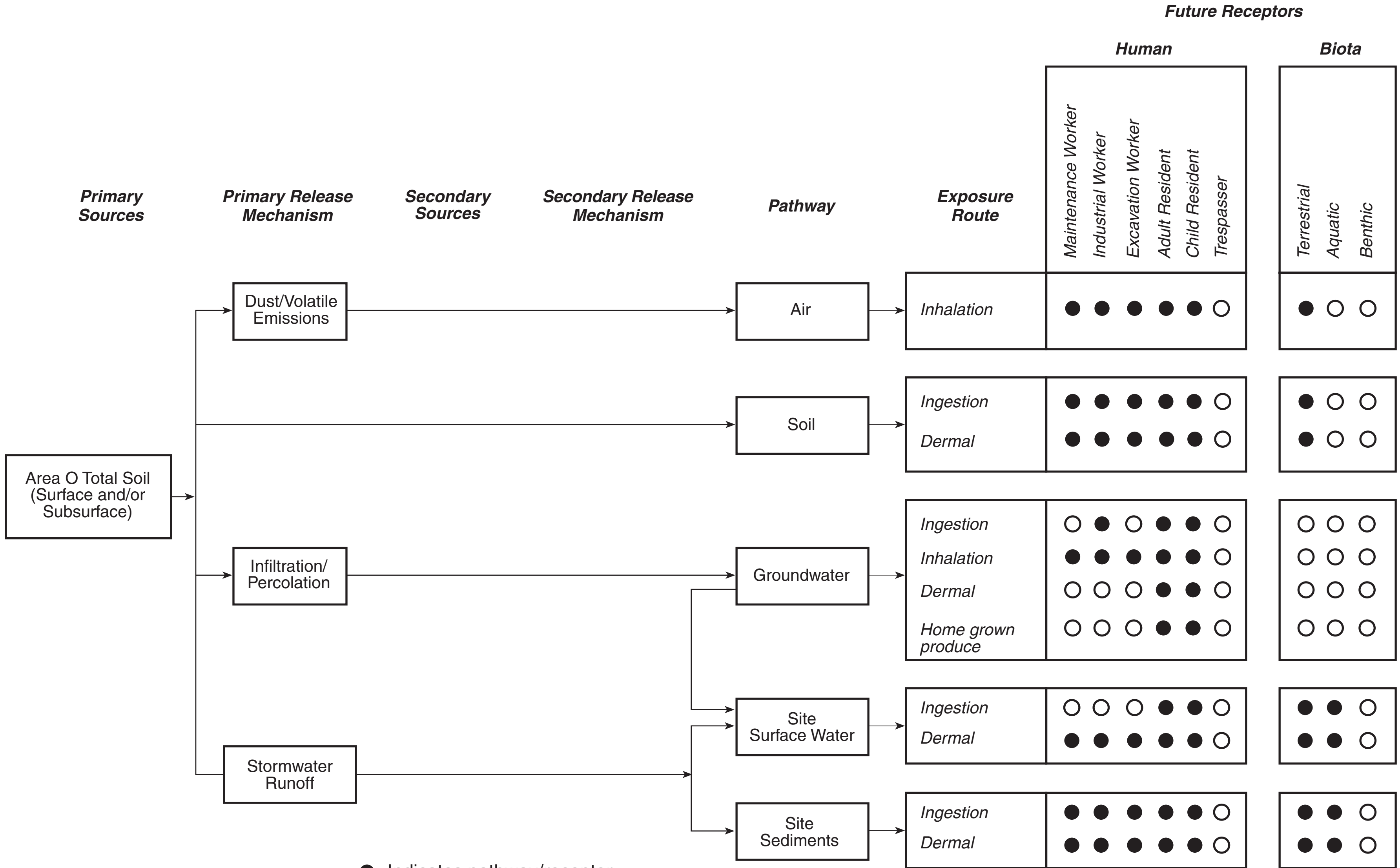

Pathway	Exposure Route	Maintenance Worker	Industrial Worker	Excavation Worker	Adult Resident	Child Resident	Trespasser	Terrestrial	Aquatic	Benthic
Air	Inhalation	●	●	●	●	●	○	●	○	○
Soil	Ingestion	●	●	●	●	●	○	●	○	○
	Dermal	●	●	●	●	●	○	●	○	○
Groundwater	Ingestion	○	●	○	●	●	○	○	○	○
	Inhalation	●	●	●	●	●	○	○	○	○
	Dermal	○	○	○	●	●	○	○	○	○
	Home grown produce	○	○	○	●	●	○	○	○	○
Site Surface Water	Ingestion	○	○	○	●	●	○	●	●	○
	Dermal	●	●	●	●	●	○	●	●	○
Site Sediments	Ingestion	●	●	●	●	●	○	●	●	○
	Dermal	●	●	●	●	●	○	●	●	○

● Indicates pathway/receptor combinations to be evaluated

○ Indicates pathway/receptor combinations incomplete or no source

Figure 6-2. Future Land Use Conceptual Site Model for Area O Radford Army Ammunition Plant, Virginia

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DRAWING BY	JIS, III	CHECKED BY	CH	3/17/08	DRAWING NO.
	4/26/07	APPROVED BY	CH	3/17/08	S-123461-1/07-w

RFAAP is likely to remain a military installation; therefore, a residential scenario is considered unlikely. However, the residential scenario was evaluated for Area O to assess clean closeout requirements under RCRA.

6.2.2 Identification of Exposure Pathways

The potential receptors identified for Area O include maintenance workers, industrial workers, excavation workers, child residents, adult residents, and lifetime residents. An excavation worker is an individual who would be engaged in excavation work as well as other site construction activities. In **Appendix E-1, Table E.1-1** summarizes the selection of exposure pathways for each receptor listing the rationale for the inclusion or exclusion of each pathway. Conceptual site diagrams for the site are presented on **Figures 6-1 and 6-2**.

6.2.3 Calculation of EPCs

EPCs were not calculated for groundwater. Because the data set represents the most current sampling event, the MDC for COPCs identified for groundwater were conservatively used in the risk assessment. The EPC values for groundwater are shown in **Appendix E-1, Table E.1-10**.

6.2.4 Quantification of Exposure: Calculation of Daily Intakes

For each receptor and pathway, chronic daily intake (CDI, expressed as milligrams of COPC per kilogram body weight per day) for each COPC is estimated by combining the EPC with exposure parameters such as ingestion rate, frequency of contact, duration, and frequency of exposure. In addition, intake parameters are selected so the combination of intake variables results in an estimate of the reasonable maximum exposure for that pathway (USEPA, 1989a).

Intake formulas, exposure parameters, and chemical-specific parameters for each of the receptors for Area O are provided in **Appendix E-1, Tables E.1-11 and E.1-12**.

For exposures to groundwater via dermal contact, the amount of chemical in water absorbed through the skin must be estimated in order to calculate the dose used in the intake formula. The dose absorbed per unit area per event (DA) is a function of chemical concentration in water, the permeability coefficient for that chemical from water through the skin, and exposure time. Following USEPA (2004a) guidance, receptor-specific DA values were calculated using USEPA's worksheet (2001b) and chemical-specific parameters described in **Appendix E-1, Table E.1-13**.

To evaluate inhalation of VOCs from groundwater, EPCs were calculated for VOCs in air using the models depicted in the following sections and provided in **Appendix E-1, Tables E.1-14 through E.1-17**. For this scenario, the volatilization model outlined in American Society for Testing and Materials (ASTM) Risk-Based Corrective Action Guidance (ASTM, 1995) for volatilization from groundwater to ambient air was used. In this case, chemical intake is a result of inhalation of outdoor vapors that originate from dissolved hydrocarbons in groundwater located somewhere below ground surface. The equations used to calculate the volatilization factor to ambient air for VOCs in Area O groundwater are presented in **Appendix E-1, Table E.1-14**.

The Johnson and Ettinger model (USEPA, 2004b) is used to estimate indoor air concentrations of volatiles migrating from groundwater through the groundwater and into a structure. The worksheet for this model was used to estimate air concentrations of VOCs in office buildings and residences for this HHRA (USEPA, 2004c). The worksheets are found in **Appendix E-2**, and the results are given in **Appendix E-1, Table E.1-15**.

In the event that excavation work is performed on site, the worker may be exposed to volatile emissions from groundwater below the bottom of the trench. While USEPA does not have a standardized model for estimating concentrations of airborne VOCs in a trench or a pit, the VDEQ provides such a model on their Voluntary Remediation Program website (VDEQ, 2007). The equation and parameters are given in **Appendix E-1, Table E.1-16**.

EPCs of VOCs in air due to volatilization from groundwater were estimated for a showering scenario, applicable to the adult resident, using the Foster-Chrostowski (1987) shower room model. The model is described in **Appendix E-1, Table E.1-17**.

6.3 Toxicity Assessment

The methodology used for classifying health effects from exposure to chemicals is recommended by USEPA (2007b). The health effects analysis considers chronic (long-term) exposures. Using the following hierarchy (USEPA, 2003a), the chronic toxicity criteria were obtained from:

- Tier 1 – Integrated Risk Information System (IRIS) (USEPA, 2007b).
- Tier 2 – Provisional Peer Reviewed Toxicity Values (PPRTVs) – as developed on a chemical-specific basis by the Office of Research and Development/National Center for Environmental Assessment/Superfund Health Risk Technical Support Center (USEPA, 2003a). Because access to PPRTVs is limited, these values were obtained directly from USEPA Region III's RBC table (USEPA, 2007a).
- Tier 3 – Other Toxicity Values – including additional USEPA and non-USEPA sources of toxicity information. This tier includes the Health Effects Assessment Summary Tables (USEPA, 1997a).

Toxicity criteria used to quantify non-carcinogenic hazards (risk reference doses - RfDs) and carcinogenic risks (e.g., slope factors - CSFs) are presented in **Appendix E-1, Tables E.1-18 through E.1-21**.

6.4 Risk Characterization

Quantitative risks and hazards due to exposure to COPCs are estimated and summarized by combining toxicity criteria (presented in the Toxicity Assessment) with CDIs (calculated in the Exposure Assessment). Methods used to calculate risks and hazards are taken from USEPA (1989a).

For exposures to potential carcinogens, the individual upper-bound excess lifetime cancer risk was calculated by multiplying the estimated CDI by the CSF. In order to assess the individual excess lifetime cancer risks associated with simultaneous exposure to COPCs, the risks derived from the individual chemicals are summed within each exposure pathway. For the residential scenario, carcinogenic risk was evaluated for the lifetime resident.

Non-carcinogenic adverse health effects are calculated by dividing the CDI of each COPC by its RfD, forming an HQ. HQs greater than 1 indicate the potential for adverse health effects. To estimate non-carcinogenic adverse health effects due to simultaneous exposure to several COPCs, HQs for individual COPCs are summed within each exposure pathway to form an HI. As with HQs, HIs that are greater than 1 indicate potential adverse health effects. In such cases, COPCs are divided into categories based on the target organ affected (e.g., liver, kidney) and target organ-specific HIs are recalculated. Non-carcinogenic hazards were evaluated for both child and adult residents independently.

Excess lifetime cancer risks derived in this report are compared to USEPA's target risk range for Superfund sites of 1E-06 to 1E-04 (USEPA, 1989a). In addition, USEPA's Office of Solid Waste and Emergency Response has issued a directive (USEPA, 1991a) clarifying the role of HHRA in the Superfund process. The directive states that, if the cumulative carcinogenic risk to a receptor (based on reasonable maximum exposure for both current and future land use) is less than 1E-04 and the non-carcinogenic HI is equal to or less than 1, action generally is not warranted unless adverse environmental effects are likely.

Calculation of risks and hazards due to exposure to COPCs are presented in **Appendix E-1, Tables E.1-22 through E.1-43**. Summaries of the risk and hazard calculations are provided in **Appendix E-l, Tables E.1-44 through E.1-53** and summarized in **Table 6-2**. A refinement of the HIs based on target organs is conducted by calculating HIs on a target organ-specific basis. In addition, **Appendices E.1, Tables E.1-54 through E.1-63** summarize risks and hazards for risk/HI drivers (i.e., those COPCs contributing to a total risk greater than 1.E-06 or a total target organ hazard greater than 1).

6.5 Uncertainties

Risk assessments involve the use of assumptions, judgments, and incomplete data to varying degrees that contribute to the uncertainty of the final estimates of risk. Uncertainties result both from the use of assumptions or models in lieu of actual data and from the error inherent in the estimation of risk related parameters and may cause risk to be over-estimated or underestimated. Based on the uncertainties described below, this risk assessment should not be construed as presenting an absolute estimate of risk to persons potentially exposed to COPCs.

Consideration of the uncertainty attached to various aspects of the risk assessment allows better interpretation of the risk assessment results and understanding of the potential adverse effects on human health. In general, the primary sources of uncertainty are associated with environmental sampling and analysis, selection of chemicals for evaluation, toxicological data, and exposure assessment. The effects of these uncertainties on the risk estimates are discussed below.

6.5.1 Environmental Sampling and Analysis

If the samples do not adequately represent media at Area O, hazard/risk estimates could be over-estimated or underestimated. The sampling and analysis plan was designed to investigate anticipated areas of contamination and delineate area(s) of concern. Therefore, there is less chance that the hazard/risk estimates are biased low. Also, if the analytical methods used do not apply to some chemicals that are present at each area, risk could be underestimated. Because the analytical methods at the site were selected to address all chemicals that are known or suspected to be present on the basis of the history of each area, the potential for not identifying a COPC is reduced.

Uncertainty in environmental chemical analysis can stem from several sources including errors inherent in the sampling or analytical procedures. Analytical accuracy errors or sampling errors can result in rejection of data, which decreases the available data for use in the HHRA, or in the qualification of data, which increases the uncertainty in the detected chemical concentrations. There is uncertainty associated with chemicals reported in samples at concentrations below the

Table 6-2
Risk Summary

Timeframe/Receptor	**Risk**	**HI**	**Risk Drivers**	**Target Organ Segregation HI>1[a]**
Future maintenance worker	1E-11	8E-07	None	N/A
Future industrial worker	2E-6	**1E+00**	**Groundwater** Bis(2-ethylhexyl) phthalate; PCE	**Respiratory Tract** (1.3) - Groundwater [1-Methylnapthalene - Ing (0.9); 2-Methylnaphthalene - Ing (0.4)]
Future excavation worker	2E-08	6E-03	None	N/A
Future adult resident	N/A	**2E+01**	N/A	**Respiratory Tract** (16.5) - Groundwater [1-Methylnapthalene - Ing (2.8) and Derm (4.4); 2-Methylnaphthalene - Ing (1.2) and Derm (1.6); Naphthalene - Inh (6.4)]
Future child resident	8E-06	**3E+01**	**Groundwater** Bis(2-ethylhexyl) phthalate; PCE	**Respiratory Tract** (24) - Groundwater [1-Methylnapthalene - Ing (6.6) and Derm (11); 2-Methylnaphthalene - Ing (2.9) and Derm (3.9)] **Kidney** (1.6) - Groundwater [Phenanthrene - Ing (0.4) and Derm (0.9); Pyrene - Derm (0.2)]
Future lifetime resident	8E-05	N/A	**Groundwater** Bis(2-ethylhexyl) phthalate; PCE; chloroform	N/A
Future off-site adult resident	N/A	**2E+01**	N/A	**Respiratory Tract** (16.5) - Groundwater [1-Methylnapthalene - Ing (2.8) and Derm (4.4); 2-Methylnaphthalene - Ing (1.2) and Derm (1.6); Naphthalene - Inh (6.4)]
Future off-site child resident	8E-06	**3E+01**	**Groundwater** Bis(2-ethylhexyl) phthalate; PCE	**Respiratory Tract** (24) - Groundwater [1-Methylnapthalene - Ing (6.6) and Derm (11); 2-Methylnaphthalene - Ing (2.9) and Derm (3.9)] **Kidney** (1.6) - Groundwater [Phenanthrene - Ing (0.4) and Derm (0.9); Pyrene - Derm (0.2)]
Future off-site lifetime resident	8E-05	N/A	**Groundwater** Bis(2-ethylhexyl) phthalate; PCE; chloroform	N/A
Future off-site maintenance worker	1E-11	8E-07	None	N/A
Future off-site industrial worker	2E-06	**1E+00**	**Groundwater** Bis(2-ethylhexyl) phthalate; PCE	**Respiratory Tract** (1.3) - Groundwater [1-Methylnapthalene - Ing (0.9); 2-Methylnaphthalene - Ing (0.4)]
Future off-site excavation worker	2.0E-08	6E-03	None	N/A

N/A = Not Applicable HI = Hazard Index HQ = Hazard Quotient

Ing = Ingestion; Inh = Inhalation; Derm = Dermal

Bold = Exceeds USEPA Risk or Hazard Range

a) Cumulative HIs and individual HQs are rounded to the nearest tenth. HIs > 1 and HQs > 0.1 are listed.

method reporting limit but still included in data analysis and with those chemicals qualified “J” indicating that the concentrations are estimated.

Another uncertainty associated with sampling and analysis concerns the inclusion of chemicals that are potentially present in the environment due to anthropogenic sources. For example, dioxins are considered ubiquitous in soil from anthropogenic sources such as combustion and incineration of municipal waste, coal, wood, and fuel. If such chemicals are not site-related, or if contributions from the ambient conditions are significant, then the risks associated with the site may be over-estimated. This uncertainty may have a low-to-moderate effect on overestimating risks.

6.5.2 Selection of Chemicals for Evaluation

A comparison of maximum detected chemical concentrations to USEPA Region III RBCs was conducted for soil, sediment, surface water, and groundwater. Chemicals whose maximum concentrations were below their respective RBCs were not carried through the assessment. It is unlikely that this risk-based screening excluded chemicals that should be included, based on the conservative exposure assumptions and conservatively derived toxicity criteria that are the basis of the RBCs. Although following this methodology does not provide a quantitative risk estimate for every chemical, it focuses the assessment on the chemicals accounting for the greatest risks (i.e., chemicals whose maximum concentrations exceed their respective RBCs), and the cumulative risk estimates would not be expected to be significantly greater. As presented on the non-detect method detection limit (MDL) screening tables in **Appendix E-1, Tables E.1-3, E.1-5, E.1-7, and E.1-9**, the maximum MDL exceeded the adjusted RBCs for several chemicals in soil and groundwater; therefore, the site-related risks and hazards could be underestimated for the risk assessments due to inadequate detection limits.

Reporting limits in subsurface soil (**Appendix E-1, Table E.1-3**) exceeded RBCs for 19 out of 123 constituents (15 percent): 3,3’-dichlorobenzidine, aldrin, alpha-BHC, Aroclor 1016, Aroclor 1221, Aroclor 1232, Aroclor 1242, Aroclor 1248, Aroclor 1254, Aroclor 1260, benzidine, benzo(a)pyrene, dibenz(a,h)anthracene, dieldrin, heptachlor epoxide, indeno(1,2,3-cd)pyrene, n-nitrosodimethylamine, n-nitroso-di-n-propylamine, and toxaphene. Of these, benzo(a)pyrene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene are of most interest because they are carcinogenic PAHs. Although the most sensitive analytical method was employed, these constituents were not detected using the 8270C Selective Ion Monitoring (SIM) method. While these PAHs may be present in fuel oils, they are not considered to be predominant components. For example, Fuel Oil No. 2, is chiefly composed of unbranched paraffins (HSDB, 2008). Typical analysis also includes naphthalenes, phenanthrenes, and methylnaphthalenes. Fuel oils consist of approximately 80 to 90 percent aliphatic alkanes (paraffins) and cycloalkanes (naphthalenes) (ATSDR, 1995), 10 to 20 percent aromatics (such as benzene) and olefins (such as styrene), and less than 5 percent PAHs. As shown in **Appendix E-1, Table E.1-2**, predominant components of fuel oil (2-methylnaphthalene, naphthalene, and phenanthrene) were detected in subsurface soil at Area O, but were not selected as COPCs. There is no evidence that the remaining chemicals have been used at Area O. Furthermore, none of these constituents have been detected in other media at Area O. Although these chemicals, if present, could contribute additional risk and hazard, they would not be expected to change the overall conclusions of the risk assessment.

Reporting limits in surface water (**Appendix E-1, Table E.1-7**) exceeded tw-RBCs for 15 of 96 constituents (16 percent): 1,1,2,2-tetrachloroethane, 1,4-dichlorobenzene, 2,4-dinitrotoluene, 2,6-dinitrotoluene, 3,3'-dichlorobenzidine, benzo(a)pyrene, bis(2-chloroethyl)ether, bis(2-chloroisopropyl)ether, dibenz(a,h)anthracene, hexachlorobenzene, nitrobenzene, n-nitroso-di-n-propylamine, pentachlorophenol, trichloroethene, and vinyl chloride. Of these, benzo(a)pyrene and dibenz(a,h)anthracene are of most interest because they are carcinogenic PAHs. Although the most sensitive analytical method was employed, these constituents were not detected using the 8270C SIM method. As discussed above for subsurface soil, these PAHs may be present in fuel oils, but they are not considered to be predominant components. As shown in **Appendix E-1, Table E.1-6**, predominant components of fuel oil (1-methylnaphthalene and phenanthrene) were detected in surface water at Area O, but were not selected as COPCs. There is no evidence that the remaining chemicals have been used at Area O. Furthermore, none of these constituents have been detected in other media at Area O. In addition, surface water exposures at Area O involve limited exposure frequency and exposure duration (e.g., through maintenance activities or wading). Although these chemicals, if present, could contribute additional risk and hazard, they would not be expected to change the overall conclusions of the risk assessment.

Groundwater data sets had the highest percentage of exceedances. Reporting limits in groundwater (**Appendix E-1, Table E.1-9**) exceeded tw-RBCs for 46 of 90 constituents (51 percent): 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, 1,2-dichloroethane, 1,3-dichoropropane, 1,3-dichlorobenzene, 1,4-dichlorobenzene, 2,4,6-trichlorophenol, 2,4-dichlorophenol, 2,4-dimethylphenol, 2,4-dinitrophenol, 2,4-dinitrotoluene, 2,6-dinitrotoluene, 2-chloronaphthalene, 2-chlorophenol, 3&4-methylphenol, 3,3'-dichlorobenzidine, benzene, benzoic(a)anthracite, benzoic(a)preen, benzoic(b)fluoranthene, benzo(k)fluoranthene, bis(2-chloroethyl)ether, bis(2-chloroisopropyl) ether, bromodichloromethane, bromomethane, carbon tetrachloride, chrysene, dibenz(a,h)anthracene, dibenzofuran, dibromochloromethane, hexachlorobenzene, hexachlorobutadiene, hexachlorocyclopentadiene, hexachloroethane, indeno(1,2,3-cd)pyrene, isophorone, methylene chloride, nitrobenzene, n-nitroso-di-n-propylamine, n-nitrosodiphenylamine, p-chloroaniline, pentachlorophenol, trichloroethene, and vinyl chloride. Of these, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene are of most interest because they are carcinogenic PAHs. Although the most sensitive analytical method was employed, these constituents were not detected using the 8270C SIM method. As discussed above for subsurface soil, these PAHs may be present in fuel oils, but they are not considered to be predominant components. As shown in **Appendix E-1, Table E.1-8**, predominant components of fuel oil (1-methylnaphthalene, 2-methylnaphthalene, naphthalene, and phenanthrene) were detected in groundwater at Area O, but were not selected as COPCs. There is no evidence that the remaining chemicals have been used at Area O. None of these constituents have been detected in other media at Area O. It is assumed that groundwater exposures at Area O involve limited exposure frequency and exposure duration for maintenance, industrial, and excavation workers. In addition, while a residential scenario has been included for completeness, it is unlikely that Area O groundwater will be used for residential purposes in the future. Although these chemicals, if present, could contribute additional risk and hazard, they would not be expected to change the overall conclusions of the risk assessment.

6.5.3 Exposure Assessment

The primary areas of uncertainty affecting exposure parameter estimation involve the assumptions regarding exposure pathways, the estimation of EPCs, and the exposure parameters used to estimate chemical doses.

An underlying assumption in the HHRA is that individuals at the site would engage in activities that result in exposures via each selected pathway. For example, it was assumed that maintenance workers engage in regular activities (once a week) under current and future land use conditions resulting in exposure to COPCs. This assumption is conservative, in that it is more likely that the activity patterns occur only occasionally.

The excavation worker evaluation was based on site-specific and default assumptions for the calculation, which include that active excavation activities will occur for 125 days over a 6-month period (5-day workweeks) with 8-hour workdays. While future construction has not been planned at Area O, the small size of the site would seemingly dictate that the duration of any heavy construction on site would likely be 6 months or less. Furthermore, it is unlikely that an excavation worker at Area O would spend 4 hours per day working in a trench over a 6-month period. There is generally a higher level of uncertainty associated with the use of modeled concentrations (i.e., volatilization factor calculated using the trench model) than in the use of measured concentrations if valid measurement data are available for the exposure medium and exposure location. However, the inhalation cancer risk/non-cancer hazard estimates are likely to be over-estimated in the HHRA.

In establishing EPCs, the concentrations of chemicals in the media evaluated are assumed to remain constant over time. Depending on the properties of the chemical and the media in which it was detected, this assumption could over-estimate risks, depending on the degree of chemical transport to other media or the rate and extent a chemical degrades over time. Future risks and hazards are likely to be over-estimated by this HHRA based on evidence that concentrations of COPCs in groundwater have been decreasing between 1991 and 2007. In addition, off-site migration of COPCs in groundwater was not modeled for this RFI. Instead, the on-site concentrations of COPCs in groundwater were conservatively used to represent off-site exposures. Hypothetical future off-site exposure to COPC concentrations on site that have migrated off site with no attenuation is possible, however, very unlikely. The COPC concentrations in the aquifer would be expected to decline as they migrate along the groundwater flow path. Therefore, risks and hazards associated with off-site exposures to groundwater are likely to be over-estimated.

Because the groundwater data set was based on the most recent sampling event, the MDC was conservatively used to represent the EPC. Using a value that is based on one sampling location (i.e., the maximum) has associated uncertainty and likely adds a high (conservative) bias to the estimate of exposure and associated risks.

The exposure parameters, used to describe the extent, frequency, and duration of exposure, introduce uncertainties. Actual risks for individuals within an exposed population may differ from those predicted, depending upon their actual intake rates (e.g., soil ingestion rates), nutritional status, or body weight. Exposure assumptions were selected to produce an upper bound estimate of exposure in accordance with USEPA guidelines regarding evaluation of potential exposures at Superfund sites (e.g., exposures were assumed to occur for 25 years for workers). In addition, many USEPA (1991b) default exposure parameters are highly conservative and are based on risk management interpretations of limited data.

Evaluation of the dermal absorption exposure pathway (**Appendix E-1, Table E.1-13**) is affected by uncertainties in dermal exposure parameters. For exposures to COPCs in groundwater via dermal absorption, the USEPA's dermal guidance (USEPA, 2004a) cautions that the procedures for estimating dermal dose from water contact are very new. The dermal permeability estimates are probably the most uncertain of the parameters in the dermal dose equation. The equation used to calculate the term, DA_{event}, is based on a regression model that predicts the water permeability coefficient for organics. Statistical analysis of the regression equation provides the range of octanol/water partition coefficients (K_{ow}) and molecular weights (MW) where this regression model could be used to predict permeability coefficients (Effective Prediction Domain or EPD). For example, based on its K_{ow} and MW, phenanthrene is outside the EPD. As a result, it is possible that the permeability constant for phenanthrene is over-estimated.

For chemicals outside the EPD, a model for predicting the fraction absorbed dose (FA) is proposed for chemicals with a high K_{ow}, taking into account the balance between the increased lag time of these chemicals in the stratum corneum and the desquamation of skin during the absorption process. The consequence is a net decrease in total systemic absorption. Several COPCs in groundwater at Area O were added to USEPA's dermal absorption worksheet for this HHRA (2001b). Permeability coefficients (K_p) values were calculated for 1-methylnaphthalene, 2-methylnaphthalene, acenaphthene, acenaphthylene, fluorene, and pyrene using K_{ow} and MW values. Because no FA values were available for these COPCs, the FA values were conservatively assumed to be 1.0. As a result, it is possible that the K_p values for some of the COPCs are over-estimated.

Based on USEPA's dermal absorption worksheet (2001b), dermal exposures are also considered relative to drinking water exposures. In cases where dermal exposure for a chemical is less than 10 percent of the drinking water exposure, USEPA recommends against quantifying exposure and risk in the body of the risk assessment (USEPA, 2004a). Based on this recommendation, dermal risk and hazard were not quantified for chloroform.

For the halogenated chemicals, such as PCE, K_p values could be underestimated. The data set upon which the equation for K_p was derived consisted primarily of hydrocarbons with a relatively constant ratio of molar volume to MW (USEPA, 2004a). Because halogenated compounds have a lower ratio of molar volume relative to their MW than hydrocarbons, the K_p correlation based on the MW of hydrocarbons will tend to underestimate the K_p for halogenated organic chemicals. Therefore, the risks and hazards calculated for PCE via the dermal pathway may be underestimated.

Finally, the bioavailability of a chemical in water is dependent on the ionization state of that chemical with the non-ionized forms more readily available that the ionized forms. The DA_{event} values for this risk assessment are based on the concentrations of the COPCs in groundwater provided in the laboratory report. The values presented in the report represent the total concentrations of ionized and non-ionized species and therefore do not provide the information necessary to calculate separate DA_{event} values. Finally, for scenarios involving showering, exposure to volatile COPCs is more apt to be due to inhalation than dermal absorption.

Several models were used to estimate air concentrations that would be expected to result from volatilization of COPCs from groundwater into air. These models included the ASTM model for ambient air (**Appendix E-1, Table E.1-14**), Johnson and Ettinger model for indoor air (**Appendix E-1, Table E.1-15**), the VDEQ model for construction trench air (**Appendix E-1, Table E.1-16**), and the Foster-Chrostowski model for shower air (**Appendix E-1, Table E.1-17**). For the ASTM model, the relationship between outdoor air and COPCs dissolved in groundwater is represented by the volatilization factor, VF_{amb} (ASTM, 1995). It is based on the following assumptions:

- A constant dissolved chemical concentration in groundwater.
- Linear equilibrium partitioning between dissolved chemicals in groundwater and chemical vapors at the groundwater table.
- Steady-state vapor-and liquid-phase diffusion through the capillary fringe and vadose zones to ground surface.
- No loss of chemical as it diffuses toward ground surface (i.e., no biodegradation).
- Steady, well-mixed atmospheric dispersion of the emanating vapors within the breathing zones modeled by a “box model” for air dispersion.

The model assumes that the COPC concentrations are constant and that there is no degradation of the chemical over time. Also, because several of the inputs to the model are not collected during a typical site characterization, conservative inputs have to be estimated or inferred from available data and other non-site-specific sources of information. For example, the soil properties (e.g., soil dry bulk density soil total porosity, and soil water-filled porosity) were based on the “lookup” table for the Johnson and Ettinger model (see **Appendix E-1, Table E.1-15** and discussion below). This table provides values for the soil properties based on soil type. Another source of uncertainty is using meteorological data from the National Oceanic and Atmospheric Administration (NOAA) rather than site-specific measurements. Although the input concentrations for the model are likely to result in an over-estimate of risk and hazard, the overall effect of all of the other variables is not known.

The Johnson and Ettinger model was developed for use as a screening level model and is based on a number of simplifying assumptions. Limitations and assumptions associated with the model are described in the user’s guide (USEPA, 2004b). These include:

- Contaminant vapors enter the structure primarily through cracks and openings in the walls and foundation.
- Convective transport occurs primarily within the building zone of influence and vapor velocities decrease rapidly with increasing distance from the structure.
- Diffusion dominates vapor transport between the source of contamination and the building zone of influence.
- All vapors originating from below the building will enter the building unless the floors and walls are perfect vapor barriers.
- All soil properties in any horizontal plane are homogeneous.
- The contaminant is homogeneously distributed within the zone of contamination.

- The areal extent of the contamination is greater than that of the building floor in contact with the soil.
- Vapor transport occurs in the absence of convective water movement within the soil column (i.e., evaporation or infiltration) and in the absence of mechanical dispersion.
- The model does not account for transformation processes (e.g., biodegradation, hydrolysis).
- The soil layer is in contact with the structure floor and walls are isotropic with respect to permeability.
- Both the building ventilation rate and the difference in dynamic pressure between the interior of the structure and the soil surface are constant values.

Some of the uncertainty in the model results is associated with the input concentrations. Although the model allows for use of the average groundwater concentration, the MDC was used as the EPC as a conservative measure. Furthermore, it is assumed that the concentration does not decrease over time due to biodegradation. Because the model is based on long-term exposures to indoor air, risk and hazards are likely to be over- estimated.

The depth to groundwater was based on the average depth across the site and may not be representative of the entire exposure area or reflect fluctuations in the water table. The actual impact of this uncertainty on the results is not known. It is anticipated that impacts would be balanced by the over-estimation introduced by other variables such as use of MDCs as the EPCs. As stated above, most of the inputs to the model are not collected during a typical site characterization. For example, the soil properties (e.g., soil dry bulk density, soil total porosity, and soil water-filled porosity) were based on the “lookup” table for the Johnson and Ettinger model. In addition, there are currently no occupied structures at Area O. Future construction plans are unknown. Therefore, default values were used to represent the characteristics of hypothetical buildings. It is also noted in the Johnson and Ettinger model user’s guide (USEPA, 2004b) that use of measured soil gas concentrations directly beneath a building floor instead of calculated concentrations would reduce uncertainty in the estimation of indoor air concentrations.

The VDEQ trench model is based upon the combination of a vadose zone model to estimate volatilization of gases from contaminated groundwater into a construction trench and a “box model” to estimate dispersion of contaminants from air inside the trench into the above-ground atmosphere (VDEQ, 2007). The parameters for chemical/physical properties and environmental conditions were provided by VDEQ for the trench model. Site-specific information was applied, if possible.

Uncertainties associated with the trench model for the construction/utility worker (VDEQ, 2007) include:

- The maximum concentration of each COPC in Area O groundwater was used to estimate long-term exposures to VOCs in ambient air in construction/utility trenches which can over-estimate risks.
- It is assumed that the trench is 3 ft wide by 8 ft long by 15 ft deep. Although utility work may be performed in trenches with these dimensions, excavation for other types of projects (e.g., construction of a structure or re-grading of the area) would be expected to

be larger. The trench model is likely to over-estimate risk and hazards for other types of projects that could occur at Area O.

- The default value for air changes per hour (2 per hour) is based upon measured ventilation rates of buildings, which could over-estimate the air exchange in an outdoor setting.
- The depth of the trench was set at the average depth to groundwater at Area O (610 ft). This value may not be representative of groundwater depth across the entire site.
- The trench model assumes that a construction/utility worker would work in the trench for 4 hours each day for a period of 6 months. It is unlikely that excavation/construction projects at Area O would require a worker to spend this amount of time in a trench.

Because the nature of future excavation/construction work at Area O is unknown and the assumptions for the trench model are very conservative, it is likely that potential risks and hazards to excavation workers is over-estimated.

Air concentrations of VOCs inhaled during showering were modeled using the Foster-Chrostowski shower model (Foster and Chrostowski, 1987). This model takes into account many of the variable factors that influence the release of VOCs from water and their subsequent buildup in shower room air. It essentially predicts that indoor air levels increase as water concentrations increase, air exchange rates decrease, and water temperatures increase. Inherent in the equations is the assumption that shower water is immediately disaggregated into droplets of equal size and that volatilization occurs from the droplet only between the time it is released from the shower head until it impacts the bottom of the shower. The model does not take into account volatilization from water running down nearby surfaces and the showering individual and draining from the shower bottom. Therefore, the model is likely to underestimate indoor VOC air concentrations and exposures. Another uncertainty is due to the assumption that the shower room air mixes instantaneously and there is no chemical decay of VOCs once they are released into the indoor air. It is likely, however, that air concentrations of VOCs will be higher immediately adjacent to the shower spray (i.e., within the individual’s breathing zone) than in the rest of the shower room. Therefore, the model may underestimate inhalation exposures during showering by assuming a completely mixed indoor air environment.

6.5.4 Toxicological Data

The HHRA relies on USEPA-derived dose response criteria. These health effects criteria are conservative and are designed to be protective of sensitive subpopulations. The health criteria used to evaluate long-term exposures, such as RfDs or CSFs, are based on concepts and assumptions that bias an evaluation in the direction of overestimation of health risk. As USEPA notes in its *Guidelines for Carcinogenic Risk Assessment* (USEPA, 1986), there are major uncertainties in extrapolating both from animals to humans and from high to low doses. There are important species differences in uptake, metabolism, and organ distribution of carcinogens, as well as species and strain differences in target site susceptibility, human populations are variable with respect to genetic constitution, diet, occupational and home environment, activity patterns, and other cultural factors.

These uncertainties are compensated for in the derivation of CSFs by using the 95 percent upper bound of the dose-response curve, which is extrapolated from relatively high experimental doses to the lower dose ranges typical in environmental exposure scenarios. For non-carcinogens, an

RfD is typically derived based on an experimental or estimated no-observed-adverse-effect level to which one or more uncertainty factors has been introduced; the uncertainty factors for the Area O COPCs are up to three orders of magnitude. The assumptions used here provide a rough but plausible estimate of the upper limit of toxicity; in other words, it is not likely that the actual toxicity would be much more than the estimated toxicity, but it could very well be considerably lower, even approaching zero. Thus, the use of CSFs and RfDs add a conservative bias to the estimate of cancer and non-cancer risks. More refined modeling in the area of dose response calculation (e.g., using maximum likelihood dose response values rather than the 95 percent upper bound) would be expected to substantially lower the final risk.

For dermal absorption exposure pathways, the absence of dermal toxicity criteria necessitates the use of oral toxicity data. To calculate risk estimates for the dermal absorption pathway, absorbed dermal absorption doses are combined with oral toxicity values (also discussed above in *Section 6.3*). Oral toxicity values, which are typically expressed in terms of potential (or administered) doses, should be adjusted when assessing dermal absorption doses, which are expressed as internal (or absorbed) doses. In this assessment, absolute oral absorption factors that reflect the toxicity study conditions were used to modify the oral toxicity criteria. For those chemicals lacking sufficient information, a default oral absorption factor of 1.0 was used. The exposure estimates for the dermal absorption pathways may be over-estimated or underestimated, depending on how the values used in the HHRA reflect the difference between the oral and dermal routes, which may introduce an associated high bias or low bias to the risk results associated with this pathway.

Inhalation toxicity criteria are unavailable for many of the COPCs. This HHRA does not use oral-based toxicity criteria to estimate risks from inhalation exposure because of the following uncertainties associated with such a substitution:

- Many contaminants show portal-of-entry toxicity - that is, adverse health effects occur primarily at the tissue site at which the chemical is introduced into the body (e.g., GI tract, lung, or skin).
- Physiological and anatomical differences between the GI tract and respiratory systems invalidate a cross-route quantitative risk extrapolation. The small intestine of humans contains a very large surface area that readily absorbs most compounds by passive diffusion (Klaasen et al., 1986). The oral absorption of a few compounds, such as iron, is an energy-dependent (active-transport) process; wherein, the absorption rate is proportional to the body’s current need for iron.
- The rate and extent of pulmonary absorption are much more complex and depend on such factors as particle size distribution of the airborne toxicant and blood-gas solubility of the toxicant (Klaasen et al., 1986). Particles with median aerodynamic diameters of approximately 1 micrometer or less are absorbed by the alveolar region of the human lung. Larger particles deposit in the tracheobronchial or nasopharyngeal regions where they are cleared by mucociliary mechanisms and subsequently swallowed or physically removed and exhaled. Therefore, pulmonary absorption is more highly dependent on the physiochemical properties of the material than oral absorption.
- Because highly soluble gases (e.g., chloroform) are more rapidly absorbed into the blood than poorly soluble gases (e.g., ethylene), they take much longer to reach equilibrium.

Thus, the inhalation absorption rate of a gas is more dependent on blood solubility than the oral absorption rate of the same substance administered as a liquid.

- Human inhalation risk estimates based on oral toxicity data in subhuman species are distorted by both route-to-route extrapolation and interspecies extrapolation. For example, the rodent GI tract, which includes a structurally unique fore stomach, is anatomically and functionally distinct from the human lung, which contains a very large alveolar surface area for extensive absorption. The rate and extent of absorption across these distinct physiological systems are not alike.

In addition, for inhalation exposure to substances present as dusts, vapors, gases, or airborne particulate matter, dose extrapolation is far more complex and therefore associated with uncertainty. The major confounding factors that prohibit a direct dose extrapolation of an inhaled toxicant are the following:

- Over 40 functionally different cell types in the lung - the distribution, consequent metabolic reactions, and air exchange rates vary widely across species.
- Differential concentration and activity of the detoxifying protein glutathione.
- Interspecies and intraspecies differences in the ability to repair pulmonary cell damage, and to clear toxic contaminants and immune complexes from the respiratory tract. For example, species vary in the ability to activate macrophages - nonspecific immune cells that can both protect the inner lining of the respiratory system and, at high concentrations, damage healthy tissues.
- Anatomical variations in the respiratory pathway, which affect both absorption rates and time to reach steady-state blood levels.
- Sensitivity to solubility and concentration variables; because of metabolic saturation (i.e., the exhaustion of normal metabolic activity caused by exposure to high concentrations), highly soluble contaminants deviate from first-order kinetics - which makes it difficult to predict the rates and extent of biotransformation and detoxification reactions. Furthermore, intermittent inhalation exposure to highly blood-soluble chemicals results in bioaccumulation in fat tissue because of the insufficient time between exposure sessions for complete clearance of the contaminant. Such slow release from the fat compartment to other body tissues can result in toxicological and metabolic effects that are difficult to assess and vary across species.

For chemicals without IRIS toxicity criteria, provisional toxicity criteria were used where available (**Appendix E-1, Tables E.1-18 through E.1-21**). Provisional toxicity criteria present a source of uncertainty, because USEPA has evaluated the compound, but consensus has not been established on the toxicity criteria. Provisional values developed by USEPA’s National Center for Environmental Assessment were used for PCE (oral CSF and inhalation CSF) and chloroform (inhalation RfD). The inhalation RfD for PCE is based on a Minimum Risk Level developed by the ATSDR (USEPA, 2007a). In addition, there were no toxicity values for 1-methylnaphthalene and phenanthrene. Due to similarity in structure, the toxicity values for 2-methylnaphthalene were used for 1-methylnaphthalene. Because phenanthrene is a non-carcinogenic PAH, toxicity values for pyrene were used for phenanthrene. For this assessment, use of provisional or surrogate toxicity criteria was preferable to not evaluating the chemical in order to limit data gaps. However, because these toxicity criteria have not been formally accepted by USEPA, there is uncertainty with these values and, therefore, with the risks calculated using these toxicity criteria. In particular, 1-methylnaphthalene and phenanthrene are drivers for non-cancer hazard. Although these chemicals are similar to their surrogates, it is not known whether the hazard is over- or underestimated.

For some chemicals, toxicity criteria were unavailable (**Appendix E-1, Tables E.1-18 through E.1-21**). Although lack of published toxicity data could result in an underestimation of risk, this uncertainty is likely to be balanced by the conservative nature of the verified toxicity values that were available for use.

It is noted that the Supplemental SSL Guidance (USEPA, 2002) recommends that toxicity values for subchronic exposures be used to calculate the HQs for the excavation worker pathway. Although subchronic values for some chemicals are included in USEPA’s database of PPRTVs, this website cannot be accessed without authorization. Because the VDEQ compiles subchronic toxicity values, however, the website for the VDEQ Voluntary Remediation Program was consulted for subchronic values (VDEQ, 2007). While toxicity values based on subchronic exposures were available for some COPCs at Area O, the subchronic values did not differ from the chronic values. The overall lack of subchronic toxicity values for the COPCs at these sites contributes to the uncertainty of the cancer risk estimates and the HIs. Typically, subchronic toxicity values are ten-fold greater than chronic toxicity values. Because chronic toxicity values were used for all COPCs, the calculated risks and hazards are likely to be over-estimated for the excavation worker.

6.5.5 Risk Characterization

Minor uncertainty is associated with rounding of the risk and hazard estimates. Thus, the actual risk or hazard may be slightly greater or less than the presented values. A related issue is that rounding causes or differences between summed risk and hazard values, depending on how the summing is performed. For example, the RAGS Table 7 spreadsheets in **Appendix E-1** present risks and hazards that are summed for exposure route, exposure point, exposure medium, and medium total. Only for the first (exposure route) are the individual chemical-specific risks and hazards summed to derive the total. For the subsequent summations (exposure point, exposure medium, and medium total), each is the summation of the preceding sums. For this reason, there can also be rounding-related differences between the ‘same’ values presented in RAGS Table 9 and 10 spreadsheets in **Appendix E-1**.

6.6 HHRA Summary and Conclusions

This HHRA was performed to evaluate the potential human health effects associated with previous activities at Area O. Receptors included current/future maintenance worker, future industrial worker, future excavation worker, future adult resident, future child resident, and lifetime resident. Off-site adult and child residents, maintenance workers, industrial workers, and excavation workers were also evaluated for potential exposures to groundwater in the event that groundwater migrates off site in the future.

As presented in *Section 6.4*, the total cancer risk for future maintenance worker exposures to groundwater (1E-11) was below the target risk range of 1E-06 to 1E-04. The total HI (8E-07) was below 1.

For future industrial worker exposures to groundwater, the total cancer risk (2E-06) was within the target risk range of 1E-06 to 1E-04, primarily due to bis(2-ethylhexyl)phthalate and PCE.

The total HI (1E+00) was equal to 1. None of the HIs for individual COPCs exceeded 1. When recalculated by target organ, the HI for the respiratory tract (1.3) exceeded 1.

For the future excavation worker, the total cancer risk associated with groundwater (2E-08) was below the target risk range of 1E-06 to 1E-04. The total HI (6E-03) was below 1.

For the future lifetime resident, the total cancer risk associated with groundwater (8E-05) was within the target risk range of 1E-06 to 1E-04, due to bis(2-ethylhexyl)phthalate, PCE, and chloroform. For future adult resident exposures, the total HI (HI = 2E+01) was above 1, primarily due to 1-methylnaphthalene (7.3), 2-methylnaphthalene (2.8), and naphthalene (6.4). When recalculated by target organ, the HI for the respiratory tract (16.5) exceeded 1.

For the future child resident, the total cancer risk associated with groundwater (8E-06) was within the target risk range of 1E-06 to 1E-04, due to bis(2-ethylhexyl)phthalate and PCE. The total HI (HI = 3E+01) was above 1, primarily due to 1-methylnaphthalene (17), 2-methylnaphthalene (6.8), and phenanthrene (1.3). When recalculated by target organ, the following target organs exceeded 1: respiratory tract (24) and kidney (1.6).

Off-site residents were evaluated to address potential future migration of COPCs in groundwater. For the future off-site lifetime resident, the total cancer risk associated with groundwater (8E-05) was within the target risk range of 1E-06 to 1E-04, due to bis(2-ethylhexyl)phthalate, PCE, and chloroform. For future adult resident exposures, the total HI (HI = 2E+01) was above 1, primarily due to 1-methylnaphthalene (7.3), 2-methylnaphthalene (2.8), and naphthalene (6.4). When recalculated by target organ, the HI for the respiratory tract (16.5) exceeded 1.

For the future off-site child resident, the total cancer risk associated with groundwater (8E-06) was within the target risk range of 1E-06 to 1E-04, due to bis(2-ethylhexyl)phthalate and PCE. The total HI (HI = 3E+01) was above 1, primarily due to 1-methylnaphthalene (17), 2-methylnaphthalene (6.8), and phenanthrene (1.3). When recalculated by target organ, the following target organs exceeded 1: respiratory tract (24) and kidney (1.6).

For the future maintenance worker exposures to groundwater (1E-11), the total cancer risk was below the target risk range of 1E-06 to 1E-04. The total HI was below 1 (8E-07).

For future industrial worker exposures to groundwater, the total cancer risk (2E-06) was within the target risk range of 1E-06 to 1E-04, primarily due to bis(2-ethylhexyl)phthalate and PCE. The total HI (1E+00) was equal to 1. None of the HIs for individual COPCs exceeded 1. When recalculated by target organ, the HI for the respiratory tract exceeded 1.

For the future excavation worker, the total cancer risk associated with groundwater (2E-08) was below the target risk range of 1E-06 to 1E-04. The total HI (6E-03) was below 1.

7.0 ECOLOGICAL RISK ASSESSMENT

A SLERA was performed to provide an estimate of current and future ecological risk associated with potential hazardous substance releases at Area O. The results of the SLERA contribute to the overall characterization of the site and the scientific/management decision point reached from the SLERA includes one of the following:

- There is adequate information to conclude that ecological risks are negligible and, therefore, there is no need for further action at the site on the basis of ecological risk.
- The information is not adequate to make a decision at this point and further refinement of data is needed to augment the ecological risk screening.
- The information collected and presented indicates that a more thorough assessment is warranted.

The SLERA was performed following the *RFAAP Final MWP* (URS, 2003), the *RFAAP Site Screening Process* (USEPA, 2001c and URS, 2007), the *Tri-Service Procedural Guidelines for Ecological Risk Assessments* (Wentsel et al., 1996), and Steps 1, 2, and 3a of the *Ecological RAGS: Process for Designing and Conducting Ecological Risk Assessments* (USEPA, 1997b). Steps 1, 2, and 3a were completed as part of the SLERA. The addition of Step 3a focuses the outcome of the SLERA, streamlines the review process, and allows one assessment to function as the initial forum for ecological risk management decision making at the site.

The primary objective of the SLERA is to assess whether there is enough information to state that there is the potential for unacceptable risks to ecological receptors as a result of potential hazardous substance releases. Characterizing the ecological communities in the vicinity of Area O, assessing the particular hazardous substances being released, identifying pathways for receptor exposure, and estimating the magnitude and likelihood of potential risk to identified receptors meets this objective. The SLERA addresses the potential for adverse effects to vegetation, the soil invertebrate community, wildlife, endangered and threatened species, and wetlands or other sensitive habitats that may be associated with Area O.

Concentrations of chemicals were measured in subsurface soil (5 to 16 ft), surface water, and sediment. Due to the nature of the underground release, there is no expected surface soil exposure pathway for ecological receptors at this site. In addition, most of the site is covered with secondary containment that functions as an impermeable barrier and precludes the presence of exposed surface soil. Using available concentration data, a SLERA was performed by following Steps 1 and 2 of USEPA (1997b). Step 1 includes a screening-level problem formulation and ecological effects evaluation, and Step 2 includes a screening level preliminary exposure estimate and risk calculation. The SLERA is organized as follows: Site Characterization (*Section 7.1*); Identification of Chemicals of Potential Ecological Concern (COPECs) and Concentration Statistics (*Section 7.2*); Identification of Exposure Pathways and Potential Receptors for Analysis (*Section 7.3*); Risk Characterization (*Section 7.4*); Uncertainty Analysis (*Section 7.5*); and, Results and Conclusions (*Section 7.6*).

7.1 Site Characterization

The Area O site characterization section includes a general discussion of Area O, vegetative communities, a species inventory, and a discussion on threatened and endangered species.

Area O consists of one 269,000-gallon fuel oil AST situated on a concrete base, surrounded by a concrete secondary containment system (**Figure 2-1**). The site is located in the east section of the MMA, southwest of the Inert Gas Plant, located on the southeast side of a northeastward sloping drainage valley. Elevations range from 1,775 ft msl near well P-1 (at the southwest end of the site) to 1,740 ft msl at the asphalt road northeast of the tanks. The base of the tank containment structure has an elevation of 1,771 ft msl. The southeast side of the valley remains relatively level for 300 ft north of the tanks. The ground surface drops more abruptly at that point, and the scarp in the hillside has a 30-foot drop over approximately 150 ft. An asphalt road cuts across the valley at the base of this scarp, and there is a drainage ditch along the road where oily water reportedly discharged from the hillside in the 1980s.

There are two additional 269,000-gallon ASTs that are situated adjacent to Area O. The tank immediately to the southwest of Area O also contained fuel oil. The tank immediately to the southwest of that tank contained alcohol. An Oil Audit, performed by USACE in 1982, reported a fuel leakage of approximately 3,000 gallons originating from an underground pipeline connecting a filling station to one of the fuel tanks. In 1983, four monitoring wells were installed to characterize groundwater flow and quality at the site. A Facility Visit by plant personnel in 1990 indicated that the leaking line was not a fuel line connected to the filling station as described in 1982, but instead was a discharge line connecting the northeastern-most fuel tank to a pumping station. After this discovery, the discharge line was replaced with an above-ground line. In 1992, an RFI was performed that involved a soil gas survey, and the collection of soil, groundwater, surface water, and sediment samples. In 1994, during Phase II of the RFI, additional soil and groundwater samples were collected from the site. These data, however, were deemed unrepresentative of current conditions and new sample analytical results were used in the SLERA.

7.1.1 General Installation Background

The Virginia Department of Game and Inland Fisheries (1999) conducted the most recent Installation-wide biological survey at RFAAP. Major objectives of this survey were to sample flora and fauna, identify and delineate the major habitat community types, and provide management recommendations for both community types and threatened, endangered or species of concern. Eight community types were identified at RFAAP:

- Bottomland forest.
- Calcareous forest.
- Cliffs.
- Grasslands.
- Oak forest.
- Pine plantation.
- Successional forest.
- Water.

Endangered plants or animals were not observed at Area O during the Installation-wide biological survey of 1999. Five state-listed rare plants were observed at RFAAP during this survey: *Clematis coattails, Cystoptris tennesseensis, Hasteola suaveolens, Sagittaria rigida,* and

Eleocharis intermedia. State threatened animals located at RFAAP include the invertebrate *Speyeria idalia* and the birds *Ammodramus henslowii* (Henslow's sparrow) and *Lanius ludovicianus* (loggerhead shrike).

An earlier comprehensive inventory of the mammals, birds, reptiles, aquatic invertebrates, trees, and plants found on the Installation, and of fish inhabiting the New River where it flows through the Installation, was conducted in 1976 during the *RFAAP Installation Assessment* (USATHAMA, 1976). Information from that assessment was summarized in previous documents (Dames and Moore, 1992). The summarized information was updated for the RFI through personal communication with RFAAP biologists and is presented in the following paragraphs (from URS, 2003).

Many of the reptiles, mammals, and birds listed in the assessment (USATHAMA, 1976) are believed to breed on the Installation. Migratory waterfowl are found throughout the spring and winter near the New River because the Installation is on the Atlantic Flyway. Public fishing occurs in the New River where it flows through RFAAP.

The Virginia Department of Game and Inland Fisheries identified the following terrestrial flora and fauna as endangered or threatened for Pulaski and Montgomery Counties:

- Plant species – six endangered, three threatened.
- Insect species – one endangered, four threatened.
- Bird species – three endangered.
- The locally endangered mountain lion.

In addition, a fish, salamander, four additional bird species, and the river otter are identified as species of concern in the two counties in which RFAAP is located.

Tree species at RFAAP include the shortleaf pine, loblolly pine, eastern white pine, yellow poplar, and black walnut. There are 2,537 acres of managed woodland on site (personal communication with T. Thompson, RFAAP Conservation Specialist 1995, as cited in URS, 2003).

RFAAP is located at the boundary of the central Appalachian Ridges and Valleys Ecoregion and the central Appalachian Ecoregion (Omernik, 1986). These two Ecoregions are characterized in **Table 7-1**.

Table 7-1
Ecoregions of RFAAP

Ecoregion	Land Surface Form	Potential Natural Vegetation	Land Use
Central Appalachian Ridges and Valleys	Open low hills to open low mountains	Appalachian oak in undisturbed areas	Mosaic of cropland and pasture with some woodland and forest
Central Appalachian	Open low to high hills, open mountains	Mixed mesophytic forest[1], Appalachian oak, northern hardwoods[2]	Forest and woodland mostly ungrazed

[1] maple, buckeye, beech, tuliptree, oak, linden
[2] maple, birch, beech, hemlock

A Shaw ecologist performed site reconnaissance activities in 2007. Prior to the reconnaissance, relevant information was obtained, including topographic maps, township, county, or other appropriate maps. This information was used to identify the location of potential ecological units such as streams, creeks, ponds, grasslands, forest, and wetlands on or near many of the RFAAP solid waste management units and areas of concern. Additionally, the Virginia Department of Game and Inland Fisheries (1999) Installation-Wide Biological Survey, which identifies the locations of threatened and endangered species at RFAAP, was reviewed. The location of known or potential contaminant sources and the probable gradient of the pathway by which contaminants may be released to the surrounding environment were identified. The reconnaissance was used to evaluate more subtle clues of potential effects from contaminant releases.

7.1.2 Surface Water

A ditch alongside of the roadway downgradient from the site is the only surface water source at Area O. The ditch was created during when the water table was intercepted during road construction. The ditch is, at the widest, 2½ ft and is bordered along one side by a paved road and a steep hillside on the other. There is up to approximately 6 inches of water in the ditch due to seepage of groundwater. It joins a series of other ditches that eventually flow into Stroubles Creek approximately 1 mile from Area O. Stroubles Creek eventually flows into the New River north of the site.

7.1.3 Wetlands

According to the information presented in the Virginia Department of Game and Inland Fisheries (1999) Installation-Wide Biological Survey, and confirmed during the site reconnaissance, there are no designated wetlands at Area O.

7.1.4 Vegetative Communities

Vegetative communities at the site, as presented in the Virginia Department of Game and Inland Fisheries (1999) Installation-Wide Biological Survey, were verified during the reconnaissance. The area surrounding Area O is primarily maintained grass, roadways, industrial buildings, and paved areas (**Figure 2-1**). The grass area is mowed on an infrequent basis to eliminate woody plants. No signs of vegetative stress were observed during the site reconnaissance.

This habitat type can be expected to support relatively few wildlife species assemblages. Some species may spend some time within the area for foraging and resting activities, typically near the perimeter of the site where some vegetation occurs.

7.1.5 Species Inventory

As presented in the Virginia Department of Game and Inland Fisheries (1999) Installation-Wide Biological Survey, six different taxa and several species were recorded during the survey. **Table 7-2** presents the numbers of species recorded at RFAAP associated with the grassland community type including surface water within the grassland areas.

Table 7-2
Species Inventory within RFAAP's Grassland Community Type

Taxa	Number of Species	Typical Examples
Plants	24	little bluestem, broomsedge, panic grass, orchard grass, foxtail, timothy, thistle, fireweed, hawkweed
Invertebrates	~250 in 17 taxonomic orders	millipedes, beetles, flies, springtails, seed bugs, bees, ants, moths, butterflies, dragonflies, mantis, caddisflies, isopods, pill bugs, amphipods
Reptiles and amphibians	24	salamanders, toads, frogs, turtles, snakes
Birds	83	robin, swift, dove, sparrow, warbler, wren, hawk
Mammals	13	red fox, white-tailed deer, shrew, meadow vole

7.1.6 Threatened, Rare and Endangered Species Information

Threatened, rare, or endangered species found within the grassland community type at RFAAP include those presented in **Table 7-3** [Virginia Department of Game and Inland Fisheries (1999) Installation-Wide Biological Survey]. Given the grassland community type at the site, it is possible these species could also occur at the site; however, as mentioned in *Section 7.1.1*, no threatened, rare, or endangered species have been documented at Area O.

Table 7-3
Threatened, Rare, and Endangered Species in RFAAP's Grassland Community

Common Name	Scientific Name	Federal Status	State Status
Midland sedge	*Carex mescochorea*	not available	Watchlist
Shaggy false gromwell	*Onosmodium hispidissimum*	not available	Watchlist
Regal fritillary butterfly	*Speyeria idalia*	not available	State threatened
Henslow's sparrow	*Ammodramus henslowii*	not available	State threatened
Loggerhead shrike	*Lanius ludovicianus*	not available	State threatened

Although a unique community type (calcareous fen) exists within the RFAAP grassland community type, it is not found at or near Area O.

7.2 Identification of COPECs and Concentration Statistics

A list of samples used in the SLERA is presented in **Table 7-4**. COPECs are selected in **Tables 7-5 and 7-6**, and the COPEC selection process is described in more detail in the following subsections. A discussion of non-detected constituent concentrations compared with ecotoxicity screening values is presented in the Uncertainty Analysis section *(Section 7.8)*.

Table 7-4
Samples Used in the Area O SLERA

Surface Water	Sediment
AOSW01	AOSD01
TMSW01 (duplicate)	AOSD02
AOSW02	

Table 7-5
Occurrence, Distribution, and Selection of Chemicals of Potential Ecological Concern for Surface Water Direct Contact Exposure at Area O

Scenario Timeframe: Current/Future
Medium: Surface Water
Exposure Medium: Surface Water

Exposure Point	CAS Number	Chemical	Minimum Concentration (Qualifier)	Maximum Concentration (Qualifier)	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Direct Contact COPEC (Y/N)	Rationale for Selection or Deletion
Surface Water	90-12-0	1-Methylnaphthalene	4.10E-03	4.10E-03	mg/L	AOSW01	1/2	1.10E-03 - 1.10E-03	Yes	DET
	83-32-9	Acenaphthene	8.30E-04 J	8.30E-04 J	mg/L	AOSW01	1/2	1.10E-03 - 1.10E-03	Yes	DET
	67-64-1	Acetone	7.00E-03 J	7.00E-03 J	mg/L	AOSW02	1/2	2.50E-02 - 2.50E-02	Yes	DET
	86-73-7	Fluorene	1.50E-03	1.50E-03	mg/L	AOSW01	1/2	1.10E-03 - 1.10E-03	Yes	DET
	85-01-8	Phenanthrene	7.35E-04 J	7.35E-04 J	mg/L	AOSW01	1/2	1.10E-03 - 1.10E-03	Yes	DET

COPEC Selection Rationale Codes

Selection Reason: Detected constiuent (DET)
Deletion Reason: ----

Notes/Definitions:

N/A = Not Applicable or Not Available
COPEC = Chemical of Potential Ecological Concern
J = Estimated Value
mg/L = milligrams per liter

Table 7-6
Occurrence, Distribution, and Selection of Chemicals of Potential Ecological Concern for Sediment Direct Contact Exposure at Area O

Scenario Timeframe: Current/Future
Medium: Sediment
Exposure Medium: Sediment

Exposure Point	CAS Number	Chemical	Minimum Concentration (Qualifier)	Maximum Concentration (Qualifier)	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Direct Contact COPEC (Y/N)	Rationale for Selection or Deletion
Sediment	67-64-1	Acetone	8.77E-02 J	8.77E-02 J	mg/kg	AOSD02	1/2	1.10E-01 - 1.10E-01	Yes	DET

COPEC Selection Rationale Codes

Selection Reason: Detected constiuent (DET)
Deletion Reason: ----

Notes/Definitions:

N/A = Not Applicable or Not Available
COPEC = Chemical of Potential Ecological Concern
J = Estimated Value
mg/kg = milligrams per kilogram

7.2.1 Data Organization

Sediment and surface water measurements are the only data available for Area O that are relevant to ecological exposures.

Chemicals that were not detected at least once in a medium have not been included in the risk assessment, but are presented in **Appendix F, Tables F-1 and F-2**.

The analytical data may have qualifiers from the analytical laboratory QC or from the data validation process that reflect the level of confidence in the data. Some of the more common qualifiers and their meanings are from USEPA (1989a). Besides taking into account the ecological depth of interest, the methodology for data summary was identical for the SLERA and the HHRA.

7.2.2 Descriptive Statistical Calculations

Due to the uncertainty associated with characterizing contamination in environmental media, the 95 percent upper confidence limit (UCL) of the mean is typically estimated for chemicals selected as COPECs and used as the EPC. However, since there were only two samples collected for each medium, the MDC was used as the EPC (**Tables 7-9 and 7-10**).

7.2.3 Frequency of Detection

Chemicals that are detected infrequently may be artifacts in the data that may not reflect site-related activity or disposal practices. These chemicals, however, have been included in the risk evaluation and a low frequency of detection was not used to deselect COPECs.

7.2.4 Natural Site Constituents (Essential Nutrients)

There was no analytical data for essential nutrients (e.g., calcium, magnesium, potassium, and sodium); therefore, they were not assessed in the SLERA.

7.2.5 Selection of COPECs

COPECs were selected as shown in **Tables 7-5 through 7-8**. In general, COPECs were selected as a concern for the direct contact exposure pathway if the constituent was detected in an environmental medium (**Tables 7-5 and 7-6**). For food chain exposure pathways, detected COPECs were selected if they are important bioaccumulative constituents (NIBC; USEPA, 2000c) (**Tables 7-7 and 7-8**).

Dioxin-like compounds, if they were detected, would be treated according to procedures provided by USEPA and the World Health Organization (WHO) (Van den Berg et al., 2006; USEPA, 1989b, 1994b; WHO, 1998). Dioxin-like compounds (PCDDs and PCDFs) are present in the environmental media as complex mixtures. However, due to the nature of the chemical release, dioxin-like compounds are not expected COPECs at Area O and were not analyzed for.

7.2.6 Summary of COPEC Selection

Tables 7-5 through 7-8 have been prepared for detected constituents in surface water and sediment with the following information:

- CAS number.
- Chemical name.
- Range of detected concentrations, and associated qualifiers.

Table 7-7
Occurrence, Distribution, and Selection of Chemicals of Potential Ecological Concern for Surface Water Food Chain Exposure at Area O

Scenario Timeframe: Current/Future
Medium: Surface Water
Exposure Medium: Surface Water

Exposure Point	CAS Number	Chemical	Minimum Concentration (Qualifier)	Maximum Concentration (Qualifier)	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Food Chain COPEC (Y/N)	Rationale for Selection or Deletion
Surface Water	90-12-0	1-Methylnaphthalene	4.10E-03	4.10E-03	mg/l	AOSW01	1/2	1.10E-03 - 1.10E-03	No	NIBC
	83-32-9	Acenaphthene	8.30E-04 J	8.30E-04 J	mg/l	AOSW01	1/2	1.10E-03 - 1.10E-03	Yes	IBC
	67-64-1	Acetone	7.00E-03 J	7.00E-03 J	mg/l	AOSW02	1/2	2.50E-02 - 2.50E-02	No	NIBC
	86-73-7	Fluorene	1.50E-03	1.50E-03	mg/l	AOSW01	1/2	1.10E-03 - 1.10E-03	Yes	IBC
	85-01-8	Phenanthrene	7.35E-04 J	7.35E-04 J	mg/l	AOSW01	1/2	1.10E-03 - 1.10E-03	Yes	IBC

COPEC Selection Rationale Codes

Selection Reason: Important Bioaccumulative Compounds (IBC) [as defined in Table 4-2, of USEPA 823-R-00-001, February 2000]

Deletion Reason: Not Important Bioaccumulative Compound (NIBC)

Notes/Definitions

N/A = Not Applicable or Not Available
COPEC = Chemical of Potential Ecological Concern
J = Estimated Value
mg/L = milligrams per liter

NOTE: Even though these chemicals are important bioaccumulative compounds, the only bioaccumulative exposure pathway that would be evaluated would be surface water to fish. Since fish are not present in the drainage e ditch, this exposure pathway is incomplete and no food chain exposure model is needed for Area O.

Table 7-8
Occurrence, Distribution, and Selection of Chemicals of Potential Ecological Concern for Sediment Food Chain Exposure at Area O

Scenario Timeframe: Current/Future
Medium: Sediment
Exposure Medium: Sediment

Exposure Point	CAS Number	Chemical	Minimum Concentration (Qualifier)	Maximum Concentration (Qualifier)	Units	Location of Maximum Concentration	Detection Frequency	Range of Detection Limits	Food Chain COPEC (Y/N)	Rationale for Selection or Deletion
Sediment	67-64-1	Acetone	8.77E-02 J	8.77E-02 J	mg/kg	AOSD02	1/2	1.10E-01 - 1.10E-01	No	NIBC

COPEC Selection Rationale Codes

Selection Reason: Important Bioaccumulative Compounds (IBC) [as defined in Table 4-2, of USEPA 823-R-00-001, February 2000]

Deletion Reason: Not Important Bioaccumulative Compound (NIBC)

Notes/Definitions

N/A = Not Applicable or Not Available
COPEC = Chemical of Potential Ecological Concern
J = Estimated Value

Table 7-9
Medium-Specific Exposure Point Concentration Summary for Area O

Scenario Timeframe: Current/Future
Medium: Surface Water
Exposure Medium: Surface Water

Exposure Point	Chemical of Potential Concern	Units	Arithmetic Mean of Detects	Multiple Detection Limits? (Yes/No) [1]	95% UCL (Distribution) [2]	Maximum Concentration	Exposure Point Concentration			
							Value	Units	Statistic [3]	Rationale [4]
Surface Water	1-Methylnaphthalene	mg/L	2.33E-03	N/A	N/A	4.10E-03	4.10E-03	mg/L	Max	Test (7)
	Acenaphthylene	mg/L	6.65E-04	N/A	N/A	8.30E-04	8.30E-04	mg/L	Max	Test (7)
	Anthracene	mg/L	9.75E-03	N/A	N/A	7.00E-03	7.00E-03	mg/L	Max	Test (7)
	Fluorene	mg/L	1.03E-03	N/A	N/A	1.50E-03	1.50E-03	mg/L	Max	Test (7)
	Phenanthrene	mg/L	6.43E-04	N/A	N/A	7.35E-04	7.35E-04	mg/L	Max	Test (7)

Notes: N/A = Not applicable

[1] ProUCL software (version 4.0, USEPA, 2007) recommends use of Kaplan-Meier method if there are multiple detection limits.

[2] Statistical Distribution and 95% UCL as determined by ProUCL (unless otherwise noted): (G) the data were determined to follow gamma distribution; (L) the data were determined to follow lognormal distribution; (NP) the data were determined to be non-parametric; (N) the data were determined to be normally distributed.

[3] Statistic: Maximum Detected Value (Max); 95% KM Chebyshev (95% KM-Cheby); 97.5% KM Chebyshev (97.5% KM-Cheby); 99% KM Chebyshev (99% KM-Cheby); 95% KM Percentile Bootstrap (95% KM-% Btstrp); 95% KM-t (95% KM-t); 95% KM-BCA (95% KM-BCA); 95% H-UCL (95% H-UCL); 95% Chebyshev -Mean, SD- UCL (95% Cheby, Mean, SD); 97.5% Chebyshev -Mean, SD- UCL (97.5% Cheby, Mean, SD); 99% Chebyshev -Mean, SD- UCL (99% Cheby, Mean, SD); 95% UCL of Log-transformed Data (95% UCL-T) 95% Student's-t (95% Student's-t); 95% Modified-t (95% Modified-t); 95% UCL based on bootstrap statistic (95% UCL-Bst); 95% Approximate Gamma UCL (95% Approx. Gamma).

[4] Unless otherwise noted (see footnote 5), ProUCL EPC selection rationale based on, detection limit values, distribution, standard deviation, and sample size (see ProUCL output in appendix for further details):

Test (1): Kaplan-Meier method recommended by ProUCL due to multiple detection limits.
Test (2): 95% UCL recommended by ProUCL exceeds maximum detected concentration, therefore, maximum concentration used for EPC.
Test (3): Shapiro-Wilk W test, Kolmogorov-Smirnov (K-S), and Anderson-Darling (A-D) tests, indicate data follow nonparametric distribution.
Test (4): Shapiro-Wilk W test indicates data are normally distributed.
Test (5): Shapiro-Wilk W test indicates data are log-normally distributed.
Test (6): Kolmogorov-Smirnov (K-S) and/or Anderson-Darling (A-D) tests indicate data follow gamma distribution.
Test (7): Sample size is less than or equal to 5, therefore, maximum concentration used for EPC.

[5] Infrequent detection resulted in ProUCL modeling error for this constituent, therefore distribution, average, and UCL determined using non-ProUCL bootstrap method with random numbers for NDs (see text for details).

Table 7-10
Medium-Specific Exposure Point Concentration Summary for Area O

Scenario Timeframe: Current/Future
Medium: Sediment
Exposure Medium: Sediment

Exposure Point	Chemical of Potential Concern	Units	Arithmetic Mean of Detects	Multiple Detection Limits? (Yes/No) [1]	95% UCL (Distribution) [2]	Maximum Concentration	Exposure Point Concentration			
							Value	Units	Statistic [3]	Rationale [4]
Sediment	Acetone	mg/kg	7.14E-02	No	N/A	8.77E-02	8.77E-02	mg/kg	Max	Test (7)

Notes: N/A = Not applicable

[1] ProUCL software (version 4.0, USEPA, 2007) recommends use of Kaplan-Meier method if there are multiple detection limits.

[2] Statistical Distribution and 95% UCL as determined by ProUCL (unless otherwise noted): (G) the data were determined to follow gamma distribution; (L) the data were determined to follow lognormal distribution; (NP) the data were determined to be non-parametric; (N) the data were determined to be normally distributed.

[3] Statistic: Maximum Detected Value (Max); 95% KM Chebyshev (95% KM-Cheby); 97.5% KM Chebyshev (97.5% KM-Cheby); 99% KM Chebyshev (99% KM-Cheby); 95% KM Percentile Bootstrap (95% KM-% Btstrp); 95% KM-t (95% KM-t); 95% KM-BCA (95% KM-BCA); 95% H-UCL (95% H-UCL); 95% Chebyshev -Mean, SD- UCL (95% Cheby, Mean, SD); 97.5% Chebyshev -Mean, SD- UCL (97.5% Cheby, Mean, SD); 99% Chebyshev -Mean, SD- UCL (99% Cheby, Mean, SD); 95% UCL of Log-transformed Data (95% UCL-T) 95% Student's-t (95% Student's-t); 95% Modified-t (95% Modified-t); 95% UCL based on bootstrap statistic (95% UCL-Bst); 95% Approximate Gamma UCL (95% Approx. Gamma).

[4] Unless otherwise noted (see footnote 5), ProUCL EPC selection rationale based on, detection limit values, distribution, standard deviation, and sample size (see ProUCL output in appendix for further details):

Test (1): Kaplan-Meier method recommended by ProUCL due to multiple detection limits.
Test (2): 95% UCL recommended by ProUCL exceeds maximum detected concentration, therefore, maximum concentration used for EPC.
Test (3): Shapiro-Wilk W test, Kolmogorov-Smirnov (K-S), and Anderson-Darling (A-D) tests, indicate data follow nonparametric distribution.
Test (4): Shapiro-Wilk W test indicates data are normally distributed.
Test (5): Shapiro-Wilk W test indicates data are log-normally distributed.
Test (6): Kolmogorov-Smirnov (K-S) and/or Anderson-Darling (A-D) tests indicate data follow gamma distribution.
Test (7): Sample size is less than or equal to 5, therefore, maximum concentration used for EPC.

[5] Infrequent detection resulted in ProUCL modeling error for this constituent, therefore distribution, average, and UCL determined using non-ProUCL bootstrap method with random numbers for NDs (see text for details).

- Concentration units.
- Location of MDC.
- Frequency of detection.
- Range of detection limits.
- COPEC selection conclusion: YES or NO.
- Rationale for selection or rejection of the COPEC.

Footnotes in the tables provide the rationale for selecting or rejecting a chemical as a COPEC.

Five COPECs (1-methylnaphthalene, acenaphthene, acetone, fluorene, and phenanthrene) have been selected for surface water direct contact exposure (**Table 7-5**).

Only one COPEC (acetone) has been selected for sediment direct contact exposure (**Table 7-6**).

Three COPECs (acenaphthene, fluorene, and phenanthrene) have been selected for surface water food chain exposure (**Table 7-7**) because they were detected important bioaccumulative compounds (USEPA, 2000c). However, even though these chemicals are important bioaccumulative compounds, the only bioaccumulative exposure pathway that would be evaluated would be surface water to fish. Since fish are not present in the drainage ditch, this exposure pathway is incomplete and no food chain exposure model is needed for Area O.

No COPECs have been selected for sediment for food chain exposure (**Table 7-8**) because chemicals that are important bioaccumulative compounds (USEPA, 2000c) were not detected.

EPCs based on the statistical procedures discussed in *HHRA Section 6.2.3* are presented in **Tables 7-9 and 7-10**. Arithmetic mean concentrations are presented for informational purposes.

7.3 Identification of Exposure Pathways and Potential Receptors for Analysis

In general, RFAAP terrestrial and aquatic wildlife may be exposed to COPECs by several pathways, including: (1) the ingestion of impacted soil, sediment, surface water, or food while foraging; (2) dermal absorption of chemicals from soil, sediment, or surface water; and, (3) inhalation of chemicals that have been wind-eroded from soil or have volatilized from soil or water. Among these potential exposure pathways, the greatest potential for exposure to chemicals is likely to result from the ingestion of chemicals in food and surface water. The incidental ingestion of impacted soil or sediment (while foraging) is a less important exposure route. The ingestion of food, soil, sediment, and surface water, however, are viable exposure pathways and were considered in the SLERAs, if relevant. Receptor-specific exposures via inhalation or dermal absorption were not selected for further evaluation because of a lack of appropriate exposure data and the expectation that these pathways would be insignificant in comparison to the other exposure pathways quantified. Inhalation exposure would be expected to be minimal due to dilution of airborne COPECs in ambient air. Dermal exposure would also be expected to be minimal due to the expectation that wildlife fur or feathers would act to impede the transport the COPECs to the dermal layer.

At Area O, the food chain pathway was deemed not relevant (*Section 7.2.6*); therefore, only aquatic receptors for direct contact with surface water and sediment were evaluated.

7.4 Risk Characterization

The risk characterization phase integrates information on exposure, exposure-effects relationships, and defined or presumed target populations. The result is a determination of the likelihood, severity, and characteristics of adverse effects to environmental stressors present at a site. Qualitative and semi-quantitative approaches have been taken to estimate the likelihood of adverse effects occurring as a result of exposure of the selected site receptors to COPECs.

7.4.1 Terrestrial Plant Impact Assessment

Since sediment and surface water were the only media of concern at Area O, impacts to terrestrial plants were not assessed.

7.4.2 Predictive Risk Estimation for Terrestrial Wildlife and Aquatic Wildlife

Due to the lack of food chain related COPECs or complete exposure pathways at Area O (*Section 7.2.6*), there are no expected impacts to terrestrial and aquatic faunal receptors via the food chain pathway. Therefore, the risk is based solely upon direct contact with the COPECs.

7.4.3 Approach for the Evaluation of Direct Contact Toxicity

To evaluate direct contact exposure, for those organisms that live within an environmental medium, COPEC media concentrations are compared with Biological Technical Assistance Group (BTAG) direct contact screening values, and a variety of additional appropriate direct contact benchmarks. The results are summarized in **Tables 7-11 and 7-12**.

7.4.3.1 Surface Water

For aquatic organisms potentially exposed to COPECs in surface water collected from Area O, comparison of the EPC to promulgated water quality criteria or a weight-of-evidence approach (for constituents without promulgated criteria) was used. The results are summarized in **Table 7-11**. It should be noted that because of the nature of various benchmark sources, promulgated water quality criteria [e.g., National Ambient Water Quality Criteria (AWQC) and Virginia Criteria for Water] were determined to be more critical during the evaluation than non-promulgated benchmarks. As some aquatic biota are relatively non-mobile, maximum detected surface water concentrations were used as the EPC in all cases (there were too few samples [n = 2] to calculate a 95 percent UCL). Surface water benchmarks used to assess direct contact exposure include the following:

- Region III BTAG Screening Values (USEPA, 2006b).
- National AWQC (USEPA, 2006b).
- Virginia Criteria for Surface Water (VAC, 2007).
- Tier II Secondary Values (Suter and Tsao, 1996).
- Lowest Chronic Effect Values for Fish, Daphnids, Nondaphnids, and Aquatic Plants (Suter and Tsao, 1996).
- USEPA Region 4 Screening Values (Suter and Tsao, 1996).

USEPA's National AWQCs are ecotoxicologically-based benchmarks developed under the Clean Water Act Section 304 (USEPA, 1999; 1996; 1985). At least eight acute toxicity tests from eight different families and three chronic tests are required to develop a criterion for a chemical (USEPA, 1996). To arrive at the chronic AWQC, the final acute value, which is the

Table 7-11
Surface Water Direct Contact Assessment at Area O

COPEC	MDC (ug/L)	EPC (ug/L)	USEPA Region 3 BTAG (ug/L) [a]	NAWQC (ug/L) [b]		Virginia WQC (ug/L) [c]		Tier II Secondary Values (ug/L) [d]		Lowest Chronic Values (ug/L) [d]				USEPA Region 4 Benchmark Screening Values (ug/L) [e]	Weight of Evidence Exceedence	
				Acute	Chronic	Acute	Chronic	Acute	Chronic	Fish	Daphnids	Non-Daphnids	Aquatic Plants		Using MDC	Using EPC
1-Methylnaphthalene	4.10E+00	4.10E+00	2.10E+00	---	---	---	---	3.70E+01	2.10E+00	5.26E+02	---	---	---	---	3 / 4	3 / 4
Acenaphthene	8.30E-01	8.30E-01	5.80E+00	6.70E+02	9.90E+02	---	---	---	---	7.40E+01	6.65E+03	2.27E+02	5.20E+02	---	0 / 7	0 / 7
Acetone	7.00E+00	7.00E+00	1.50E+03	---	---	---	---	2.80E+04	1.50E+03	5.08E+05	1.56E+03	---	---	---	0 / 5	0 / 5
Fluorene	1.50E+00	1.50E+00	3.00E+00	1.10E+03	5.30E+03	---	---	7.00E+01	3.90E+00	---	---	---	---	---	0 / 5	0 / 5
Phenanthrene	7.35E-01	7.35E-01	4.00E-01	---	---	---	---	---	---	---	2.00E+02	---	---	---	1 / 2	1 / 2

--- No Value Available

COPEC = Chemical of potential ecological concern

EPC = Exposure point concentration. Maximum value is EPC.

MDC = Maximum detected concentration

NAWQC = National Ambient Water Qualtiy Criteria

[a] Values from USEPA Region 3 BTAG Screening Levels, 2006. Values are for freshwater.

[b] Values from USEPA, 2006. National Recommended Water Quality Criteria.

[c] Values from Virginia Criteria for Surface Water, 9 VAC 25-260, September 11, 2007.

[d] Values from Suter, G.W., and Tsao, C.L. 1996. Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision, ES/ER/TM-96/R2.

[e] Values from USEPA Region 4 Ecological Benchmark Screening Values for Surface Water (2000).

Table 7-12
Sediment Direct Contact Assessment at Area O

COPEC	MDC (mg/kg)	EPC (mg/kg)	USEPA Region 3 BTAG (mg/kg)[a]	USEPA Region 5 RCRA (mg/kg)[b]	ARCS[c]			SQB (mg/kg)[d]			Canadian ISQG (mg/kg)[e]	Canadian PEL (mg/kg)[e]	NOAA[c]		NOAA SQuiRT[f]	FDEP[c]		Weight of Evidence Exceedence	
					TEC (mg/kg)	PEC (mg/kg)	NEC (mg/kg)	Fish	Daphnid	Non-daphnid Invertebrate			ER-L (mg/kg)	ER-M (mg/kg)	(mg/kg)	TEL (mg/kg)	PEL (mg/kg)	Using MDC	Using EPC
Acetone	8.77E-02	8.77E-02	---	9.90E-03	---	---	---	3.00E+00	9.10E-03	---	---	---	---	---	---	---	---	2 / 3	2 / 3

--- No Value Available
ARCS = Assessment and Remediation of Contaminated Sediment
COPEC = Chemical of Potential Ecological Concern.
EPC = Exposure Point Concentration. The 95% upper confidence limit concentration was selected as the EPC unless it exceeded the maximum detected concentration, in which case the MDC was chosen as the EPC.
ER-L = Effects Range-Low
ER-M = Effects Range-Median
FDEP = Florida Department of Environmental Protection
ISQG = Interim Sediment Quality Guideline
MDC = Maximum detected concentration.
NEC = High No Effect Concentration
NOAA = National Oceanic and Atmospheric Administration
PEC = Probable Effect Concentration
PEL = Probably Effect Level
SQB = Sediment Quality Benchmark
TEC = Threshold Effect Concentration
TEL = Threshold Effect Level

ARCS, SQB, and Canadian values for freshwater environments.
NOAA and FDEP values for estuarine and marine environments, but may be used for screening purposes.

[a] Screening toxicity values from BTAG (2006).

[b] Ecological Screening Levels from Region 5 RCRA, August 2003.

[c] Values from Jones, D.S and Suter, G.W., 1997. Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Sediment-Associated Biota: 1997 Revision. ES/ER/TM-95/R4.

[d] Eq P-derived sediment quality benchmarks presented in Jones, D.S and Suter, G.W., 1997. Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Sediment-Associated Biota: 1997 Revision. ES/ER/TM-95/R4. is presented here (assumed TOC of 1%)

[e] Values from Canadian Council of Ministers of the Environment (CCME), 2003. Canadian Environmental Quality Guidelines. Summary Table December 2003.

[f] Most conservative NOAA SQuiRT values from Buchman, 1999.

fifth percentile of the distribution of 48- to 96-hour acute toxicity test values, is divided by the final acute-chronic ratio. The final acute-chronic ratio is the geometric mean of quotients of at least three median lethal concentration (LC50) tests divided by chronic value ratios from tests of different families of aquatic organisms. Standard chronic tests include measures of growth, reproduction, and lethality, as well as observations of deformities. Chronic AWQC are intended to prevent significant toxic effects in chronic exposures (Suter and Tsao, 1996).

Virginia Criteria for Water (VAC, 2007) are developed using a methodology similar to the National AWQC methodology, but take into account state-specific concerns related to the protection of aquatic biota.

Tier II values (Suter and Tsao, 1996) are used as water quality benchmarks because AWQCs have only been developed for a limited number of constituents (USEPA, 1996). Note: these Tier II values have no direct relation to the Tier 2 assessment approach utilized in the Area O SLERA. The methodology used for the Tier II values is from the Great Lakes Water Quality Initiative (USEPA, 1995b). It incorporates statistically derived “adjustment factors” for the effects threshold to be calculated with less toxicity data than is required for AWQC. The methodology is described in 40 CFR 132. Values for some of the chemicals were calculated by the EPA Office of Water (USEPA, 1995c) and others by Suter and Mabrey (1994). Differences between the USEPA (1995c) and Suter and Mabrey (1994) methodologies include an alternate calculation when no LC_{50} value for a daphnid is available, and the use of nonstandard LC_{50} and median effective concentration (EC_{50}) values in the Suter and Mabrey (1994) methods. These alterations allowed for Tier II values for screening purposes to be calculated for additional chemicals (Suter and Tsao, 1996).

Lowest chronic effect values for fish, daphnids (water fleas), nondaphnids (other aquatic invertebrates excluding water fleas), and aquatic plants (Suter and Tsao, 1996) represent the lowest available toxicity thresholds in the literature for adverse impacts to these four general classes of aquatic biota. These thresholds are useful in estimating potential adverse impacts to these general types of freshwater aquatic receptors.

The USEPA Region 4 Screening Values (Suter and Tsao, 1996) represent additional screening values available from USEPA Region 4.

The results of the weight of evidence screening step are as follows:

- The 1-methylnaphthalene MDC exceeded the BTAG screening value, as well as the acute and chronic Tier II values.
- The acenaphthene MDC did not exceed any of the available benchmarks, and no further action is recommended for this COPEC.
- The acetone MDC did not exceed any of the available benchmarks, and no further action is recommended for this COPEC.
- The fluorene MDC did not exceed any of the available benchmarks, and no further action is recommended for this COPEC.
- The phenanthrene MDC exceeded one of two available benchmarks.

These results suggest that direct contact toxicity in surface water is a potential concern for the following two COPECs:

- 1-Methylnaphthalene.
- Phenanthrene.

7.4.3.2 Sediment

There are no promulgated sediment screening criteria, so for aquatic organisms potentially exposed to COPECs in sediment collected from Area O, a weight-of-evidence approach was used, where the more sediment benchmarks exceeded by the COPEC concentration, the greater the potential for adverse effects. The results are summarized in **Table 7-12**. As most sediment-dwelling aquatic biota are relatively non-mobile, maximum detected sediment concentrations are used. In addition, an EPC more representative of potential community-level effects is also used in the evaluation, expressed as the 95 percent UCL (the MDC was used as the EPC in all cases because there were too few samples collected [n = 2] to calculate a 95 percent UCL). Sediment benchmarks used to assess direct contact exposure include the following:

- Region III BTAG Screening Values (USEPA, 2006b).
- Region 5 RCRA Ecological Screening Levels (USEPA, 2003b).
- Threshold Effect Concentrations (TECs) from Assessment and Remediation of Contaminated Sediments (ARCS) program (Jones et al., 1997).
- Probable Effect Concentrations (PECs) from ARCS program (Jones et al., 1997).
- No Effect Concentrations (NECs) from ARCS program (Jones et al., 1997).
- Sediment Quality Benchmarks (SQBs) (Jones et al., 1997).
- Canadian Interim Sediment Quality Guidelines (ISQGs) [Canadian Council of Ministers of the Environment (CCME), 2003a].
- Canadian Probable Effects Levels (PELs) (CCME, 2003b).
- NOAA Effects Range – Low (ER-L) values (Jones et al., 1997).
- NOAA Effects Range – Median (ER-M) (Jones et al., 1997).
- NOAA SQuiRT values (Buchman, 1999).
- Florida Department of Environmental Protection (FDEP) Threshold Effect Levels (TELs) (Jones et al., 1997).
- FDEP PEL (Jones et al., 1997).

Several government organizations have developed guidelines for acceptable sediment concentrations for screening purposes, sometimes with considerable variation among the approaches. A brief discussion of each of the sediment benchmarks used in the SLERAs is presented in the following subsections.

TECs, PECs, and NECs (as reported in Jones et al., 1997) were developed for the ARCS program (Ingersoll et al., 1996). These values were based on sediment-effect concentrations, using laboratory data on the toxicity of constituents associated with field-collected sediment (predominantly freshwater) to the amphipod *Hyalella azteca* and the midge *Chironomus* *riparius*. Sediment-effect concentrations were calculated from the results of 14-day tests on *C. riparius*, and 14- and 28-day tests on *H. azteca*. The *H. azteca* endpoints were survival, growth (as length), or sexual maturation. The *C. riparius* endpoints were survival and growth.

SQBs from Jones et al. (1997) are based on the sediment/water equilibrium partitioning (EqP) approach, where the prediction of a bulk sediment chemical concentration criterion is a function of the sediment organic carbon and an associated AWQC. Sediment TOC concentrations of 1 percent are assumed for these SQBs. The EqP approach applies specifically to non-ionic organic contaminants; while variations of the equation have been developed for use with polar and ionic organic chemicals.

ISQGs and PELs (CCME, 2003b) represent Canadian Environmental Quality Guidelines initially published by CCME (1995), and include provisional lowest effect levels for some constituents (Persaud et al., 1993). These guidelines are numerical limits recommended to support and maintain aquatic life associated with bed sediments and were developed from the available scientific literature on the biological effects of sediment-associated chemicals. The methodology used in the development of these numerical limits included the modified National Status and Trends Program approach and the Spiked-Sediment Toxicity Test approach.

The methodology used by NOAA (Long et al., 1995; Long and Morgan, 1990) for their NOAA ER-M and ER-L thresholds, and the methodology used by the FDEP (MacDonald, 1994) for their TEL and PEL values are very similar, and utilize data obtained from several approaches, including:

- Background Approach: use of reference background values from various geographic areas, against which site contaminant levels are screened.
- Sediment/Water EqP Approach: prediction of a bulk sediment chemical concentration criterion as a function of the sediment organic carbon and an associated AWQC.

Both the NOAA and FDEP benchmarks are based primarily on estuarine and marine data, but may be used for screening purposes in freshwater environments (Jones et al., 1997). The NOAA ER-L is the lower 10th percentile of the screened data; as such, the ER-L represents the low end of the range for which effects were observed or predicted. The NOAA ER-M is the 50th percentile of the screening data, and represents a median effect level.

The FDEP (MacDonald, 1994) used the updated and revised data set by Long et al. (1995) to calculate TELs. The FDEP methodology differs from the NOAA methodology in that the TELs also incorporate chemical concentrations associated with no adverse biological effects (no-effects data). The TEL is calculated as the geometric mean of the 15th percentile of the effects data set and the 50th percentile of the no-effects data set, thus representing the upper limit of the range of sediment concentrations dominated by no-effects data (Jones et al., 1997). The FDEP TELs are derived from marine and estuarine data.

The results of the sediment direct contact assessment show that, for acetone, two of the available three screening criteria were exceeded. Therefore, direct contact toxicity is a concern for acetone.

7.4.4 Background Metals Considerations

There was no background analysis conducted at Area O, as no background surface water or sediment data were available.

7.5 Uncertainty Analysis

The results of the SLERA are influenced to some degree by variability and uncertainty. In theory, investigators might reduce variability by increasing sample size of the media or species sampled. Alternatively, uncertainty within the risk analysis can be reduced by using species-specific and site-specific data (i.e., to better quantify contamination of media, vegetation, and prey through: direct field measurements, toxicity testing of site-specific media, and field studies using site-specific receptor species). Detailed media, prey, and receptor field studies are costly; thus, the preliminary analyses of risk have been conducted to limit the potential use of these resource-intensive techniques to those COPECs that continue to show a relatively high potential for ecological risk. Since assessment criteria were developed based on conservative assumptions, the result of the assessment errs on the side of conservatism. This has the effect of maximizing the likelihood of accepting a false positive (Type I error: the rejection of a true null hypothesis) and simultaneously minimizing the likelihood of accepting a true negative (Type II error: the acceptance of a false null hypothesis).

A number of factors contribute to the overall variability and uncertainty inherent in ecological risk assessments. Variability is due primarily to measurement error; laboratory media analyses and receptor study design are the major sources of this kind of error. Uncertainty, on the other hand, is associated primarily with deficiency or irrelevancy of effects, exposure, or habitat data to actual ecological conditions at the site. Calculating an estimated value based on a large number of assumptions is often the alternative to the accurate (but costly) method of direct field or laboratory observation, measurement, or testing.

There were 96 chemical constituents not detected in surface water analytical samples. **Appendix F, Table F-1** evaluates the uncertainty associated with these constituents' detection limits by presenting a comparison of the maximum detection limit for each non-detect constituent with the Region III BTAG Surface Water Benchmarks (USEPA, 2006b).

Sixteen of the 96 non-detect constituents had maximum detection limits that exceeded the BTAG surface water benchmarks. This finding is not unexpected, given the conservative and numerically low screening values.

There were 101 chemical constituents not detected in sediment analytical samples. **Appendix F, Table F-2** evaluates the uncertainty associated with these constituents' detection limits by presenting a comparison of the maximum detection limit for each non-detect constituent with the Region III BTAG Sediment Benchmarks (USEPA, 2006b).

Thirty of the 101 non-detect constituents had maximum detection limits that exceeded the BTAG sediment benchmarks. This finding is not unexpected, given the conservative and numerically low benchmark values.

The uncertainty analysis is presented in **Table 7-13** and lists some of the major assumptions made for the SLERA; the direction of bias caused by each assumption (i.e., if the uncertainty results in an over-estimate or underestimate of risk); the likely magnitude of impact [quantitative (percent difference), or qualitative (high, medium, low, or unknown)]; if possible, a description of recommendations for minimizing the identified uncertainties if the SLERA progresses to higher level assessment phases; and the ease of implementing the recommendation (USEPA, 1997b).

Table 7-13. Uncertainty Analysis

Component	Bias	Magnitude	Ways to Minimize Uncertainty	Additional Comments
Small sample size may not fully characterize the site.	Underestimates Risk	Medium	Collect additional samples.	Most analytes were non-detected in the collected samples, so additional samples may not provide any benefit.
Discounting of dermal and inhalation exposure routes.	Underestimates Risk	Low	Include dermal and inhalation routes of exposure.	Would be difficult to quantify these routes of exposure.
Incomplete exposure pathway for surface water to fish.	Underestimates Risk	Low	Quantify pathway.	As fish are not expected in the drainage ditch, the importance of the surface water to fish bioaccumulation pathway is minor.
Direct contact assessment for aquatic organisms	Over-estimates Risk	Medium	Perform field survey on drainage ditch aquatic organisms.	The assessment assumes aquatic organisms are present in the drainage ditch. However, due to lack of suitable habitat, it is unlikely that resident populations of aquatic organisms exist.

The uncertainty analysis identifies and, if possible, quantifies the uncertainty in the individual preliminary scoping assessment, problem formulation, exposure and effects assessment, and risk characterization phases of this SLERA. Based on this uncertainty analysis, the most important biases that may result in an overestimation or underestimation of risk include the following:

- Small sample size may underestimate risk.
- Assumptions of the presence of viable populations of aquatic organisms in the drainage ditch may over-estimate risk for the direct contact exposure pathway.

7.6 SLERA Results and Conclusions

The data, results, and conclusions of the SLERA evaluated risks to ecological populations inhabiting Area O. Conclusions are derived from the risk assessment. Surface water and sediment direct contact exposure results for aquatic life are summarized in **Tables 7-11 and 7-12**, respectively. There were no important bioaccumulative COPECs or complex surface water to fish exposure pathways associated with Area O surface water or sediment; therefore, a food chain exposure assessment was not conducted.

The direct contact assessment results suggest that the following COPECs in surface water (1-methylnaphthalene and phenanthrene) and sediment (acetone) may adversely affect aquatic life associated with the ditch alongside the roadway. However, as viable populations of aquatic organisms are not expected in the drainage ditch, direct contact risks were over-estimated.

Based on the results of the SLERA conducted at Area O, no further action to address ecological concerns is recommended for surface water or sediment.

8.0 DEVELOPMENT OF CORRECTIVE MEASURES OBJECTIVES

This chapter identifies the corrective measures objectives (CMOs) for the contaminants of interest (COIs) identified by the risk assessments and provides remediation volume estimates based on the CMOs and analytical results. CMOs are cleanup objectives that are developed during the RFI/CMS to protect human health and the environment. They consist of medium-specific goals for protecting human health and the environment. CMOs provide the basis for the identification, detailed analysis, and selection of corrective measures alternatives.

8.1 Summary of Chemicals of Interest

The SLERA concluded that remedial measures to address ecological concerns are not warranted for surface water or sediment. However, the residual risk to ecological receptors was calculated to evaluate whether remediation for human health concerns would be protective of the environment or significantly reduce ecological risks.

The HHRA (*Section 6.0*) identified eight COIs [bis(2-ethylhexyl)phthalate, PCE, chloroform, 1-methylnaphthalene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene] under both an industrial and residential future-use scenario for groundwater at Area O.

However, the maximum detected chloroform concentration of 14.2 µg/L is below the MCL of 80 µg/L. Also, the chloroform results in four out of the five samples in which it was detected were "B-flagged," indicating blank contamination. It is assumed that the chloroform did not originate from site-related activities. As discussed in *Section 4.2.3,* its presence is likely due to leaks in on-site aging water pipelines; therefore, chloroform will not be considered a COI at this site. PCE is not a fuel-related constituent and was only detected in wells cross-gradient to Area O. In addition, the maximum detected PCE concentration (0.61 µg/L) is below the MCL of 5. Therefore, PCE also will not be considered a COI at this site. Finally, bis(2-ethylhexyl)phthalate was only detected in one out of ten Area O wells at a concentration exceeding its MCL. This detection is isolated and bis(2-ethylhexyl)phthalate is a constituent that is used in plastics and may be a contaminant resulting from the well construction, sampling, and/or the laboratory. Therefore, bis(2-ethylhexyl)phthalate is not considered a COI in groundwater at Area O. Based on these conclusions, the five COIs selected for Area O groundwater include: 1-methylnaphthalene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene.

The HHRA concluded that exposure to soil, surface water, and sediment does not represent an unacceptable human health risk or hazard to any potential human receptors. Therefore, no COIs were identified for either the soil, surface water, or sediment at Area O.

8.2 Remedial Goals

Preliminary remedial goals were obtained from the USEPA Region III RBC table dated October 2007 (USEPA, 2007a). The site-specific CMO for Area O is to eliminate the potential threats to human health and the environment that exist from the groundwater. There are no MCLs for the identified COIs; therefore, remedial goals were based on tw-RBCs. 2-methylnaphthalene was used as a surrogate compound for 1-methylnaphthalene and its tw-RBC is used as the remedial goal since there is no tw-RBC established for 1-methylnaphthalene. The results of the Area O groundwater investigation identified five groundwater constituents with maximum concentrations above their respective remedial goals. The five COIs identified at Area O and their respective remedial goals are shown below in **Table 8-1**.

Table 8-1
Remedial Goals of the COIs Identified for Area O

Analyte	MCL	tw-RBC	Selected Remedial Goal	Maximum Concentration	Location of Maximum
1-Methylnaphthalene	na	2.4*	2.4	414	AOGW02
2-Methylnaphthalene	na	2.4	2.4	180	AOGW02
Naphthalene	na	0.65	0.65	50.7	AOGW02
Phenanthrene	na	18	18	163	AOGW02
Pyrene	na	18	18	18.9	AOGW02

* tw-RBC for 2-methylnaphthalene used

8.3 Area and Volume of Contamination

Groundwater containing chemical concentrations exceeding remedial goals is present at Area O. Fuel-related constituents are present in the groundwater and have migrated northeast of the site, in a direction parallel to groundwater flow. The volume of impacted groundwater (exceeding remedial goals) is estimated to be approximately 337,068 gallons. This estimate is based on a 15-foot saturated thickness, 30 percent porosity, and an area of 74,990 square feet.

9.0 CORRECTIVE MEASURES DEVELOPMENT

Technologies were screened during the CMS development on the basis of three criteria: effectiveness, implementability, and cost. The following three corrective measure alternatives were developed for Area O that are capable of meeting the CMOs described in *Section 8.0* and are effective, implementable, and cost-effective:

- Alternative One: No Further Action.
- Alternative Two: Monitored Natural Attenuation (MNA) and Long-Term Monitoring (LTM).
- Alternative Three: In-Situ Enhanced Bioremediation (ISEB) and MNA.

A detailed description of these alternatives is presented in this section. Data used for the CMS are located in **Table 9-1**.

9.1 Alternative One: No Further Action

The no further action alternative will be used as a baseline against which to measure the performance of other alternatives. Under this alternative, no actions would be performed to reduce the toxicity, mobility, or volume of contaminants at Area O. There would be no physical changes to the site conditions, and any increase or decrease of COI concentrations would not be known due to a lack of monitoring.

9.2 Alternative Two: MNA and LTM

Effectiveness. The natural attenuation of COIs is well documented and can be an effective remedial solution for sites with impacted groundwater. MNA has been defined by the USEPA (1997c) as “the reliance on natural attenuation processes to achieve site-specific remedial objectives within a time frame that is reasonable compared to other methods. The “natural attenuation processes” that are at work in such a remediation approach include a variety of physical, chemical, and biological processes that under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, and concentration of contaminants in groundwater. These in-situ processes include biodegradation, dispersion, dilution, sorption, volatilization, and chemical or biological stabilization, transformation, or destruction of contaminants.” At Area O, this option will not change the physical site conditions; however, groundwater monitoring would be performed to track concentration trends, develop degradation rates to calculate estimated times to reach site goals.

At this time, the current groundwater data is insufficient to determine statistically valid degradation rates. However, an LTM plan will produce data to observe trends and calculate degradation rates and attenuation times within the first year of the LTM sampling plan.

PAHs were detected above tw-RBCs in only three sampling points, AOGW02, OMW1, and S4W-1. Phenanthrene and pyrene were only detected above tw-RBCs in direct push sampling point AOGW02. 2-Methylnaphthalene was observed above the tw-RBC of 2.4 µg/L in OMW1 and AOGW02 at concentrations of 16 and 180 µg/L, respectively. An increase from 1.7 to 16 µg/L was observed at OMW1, from 1992 to 2007. Due to a lack of current data, it is unknown if an elevated level was observed between these two sampling events and concentrations are currently being attenuated. However, current groundwater conditions are favorable for the biological degradation of PAHs at this time and are expected to reduce the concentration levels

Table 9-1
Area O COI Data
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Analyte		Sample ID	OMW1									OMW2					
		Sample Date	**2/24/92**			**7/28/93**			**8/24/07**			**7/29/93**			**8/24/07**		
	MCL	**tw-RBC**	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q
COI (ug/L)																	
1-Methylnaphthalene	na	2.4	NT			NT			32.4			NT			1	U	UL
2-Methylnaphthalene	na	2.4	1.7	U		4			16			1.7	U		1	U	UL
Naphthalene	na	0.65	NT			NT			27.5			NT			1	U	UL
Phenanthrene	na	18	0.5	U		3.1			1.7			0.5	U		1	U	UL
Pyrene	na	18	2.8	U		2.8	U		0.98	U		2.8	U		1	U	UL
Misc. (mg/L)																	
Dissolved Oxygen	na	na	NT			NT			1.6			NT			2.11		
Oxidation-Reduction Potential (mV)	na	na	NT			NT			-183			NT			83		
Ferrous Iron	na	na	NT			NT			0.13			NT			0.04		
Total Organic Carbon	na	na	7.11			1.76			1.7			1	U		0.5	U	
Total Organic Halides	na	na	0.036			0.176			NT			0.232			NT		
Methane (ug/L)	na	na	NT			NT			6900			NT			0.5	U	
Ethane (ug/L)	na	na	NT			NT			1.0	U		NT			1.0	U	
Ethene (ug/L)	na	na	NT			NT			1.0	U		NT			1.0	U	
Chloride	250	na	NT			46			33.3			53			30.7		
Nitrate (as N)	10	na	NT			30			0.1			1.2			4		
Sulfate	500	na	NT			16.4			12			14.6			50		
Sulfide	na	na	NT			NT			2.0			NT			1.0		
Alkalinity	na	na	NT			NT			200			NT			225		
Dehalococcoides sp. (cells/mL)	na	na	NT			NT			45000			10	U		10	U	
pH	na	na	7.13		J	NT			7.2			NT			7.1		

* Refer to legend immediately following this table for a list of dfinitions and table notes.

Table 9-1
Area O COI Data
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Analyte		Sample ID	P-1						P-2			P-3					
		Sample Date	**2/24/92**			**8/23/07**			**8/23/07**			**2/20/92**			**8/23/07**		
	MCL	**tw-RBC**	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q
COI (ug/L)																	
1-Methylnaphthalene	na	2.4	NT			0.98	U	UL	1	U	UL	NT			0.97	U	UL
2-Methylnaphthalene	na	2.4	1.7	U		0.98	U	UL	1	U	UL	1.7	U		0.97	U	UL
Naphthalene	na	0.65	NT			0.98	U		1	U		NT			0.97	U	UL
Phenanthrene	na	18	0.5	U		0.98	U		1	U		0.5	U		0.97	U	
Pyrene	na	18	2.8	U		0.98	U		1	U		2.8	U		0.97	U	UL
Misc. (mg/L)																	
Dissolved Oxygen	na	na	NT			3.78			1.19			NT			1.57		
Oxidation-Reduction Potential (mV)	na	na	NT			93			109			NT			121		
Ferrous Iron	na	na	NT			NT			NT			NT			NT		
Total Organic Carbon	na	na	6.34			0.7	J		0.61	J		2.06			0.5	U	
Total Organic Halides	na	na	0.0412			NT			NT			0.0607			NT		
Methane (ug/L)	na	na	NT			0.5	U		0.5	U		NT			0.18	J	
Ethane (ug/L)	na	na	NT			1	U		1	U		NT			1	U	
Ethene (ug/L)	na	na	NT			1	U		1	U		NT			1	U	
Chloride	250	na	NT			27.9			23.9			NT			21.9		
Nitrate (as N)	10	na	NT			3			3.2			NT			0.59		
Sulfate	500	na	NT			46.9			35.1			NT			22.6		
Sulfide	na	na	NT			1.0	U		2.7			NT			2.3		
Alkalinity	na	na	NT			205			203			NT			233		
Dehalococcoides sp. (cells/mL)	na	na	NT			5100			4900			NT			7000		
pH	na	na	6.96		J	7.1			7.1			7.02			7.1		

* Refer to legend immediately following this table for a list of dfinitions and table notes

Table 9-1
Area O COI Data
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Analyte		Sample ID	P-4						S4W-1									S4W-4 (RDWC*46)		
		Sample Date	2/20/92			8/27/07			2/24/92			7/28/93			8/27/07			2/28/92		
	MCL	tw-RBC	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q
COI (ug/L)																				
1-Methylnaphthalene	na	2.4	NT			0.98	U		NT			NT			7.6			NT		
2-Methylnaphthalene	na	2.4	1.7	U		0.98	U		53			1.7	U		2			1.7	U	
Naphthalene	na	0.65	NT			0.98	U		NT			NT			1			NT		
Phenanthrene	na	18	0.5	U		0.98	U		87			3.4			1.5			0.5	U	
Pyrene	na	18	2.8	U		0.98	U		5.5			2.8	U		0.99	U		2.8	U	
Misc. (mg/L)																				
Dissolved Oxygen	na	na	NT			9.61			NT			NT			0			NT		
Oxidation-Reduction Potental (mV)	na	na	NT			144			NT			NT			-187			NT		
Ferrous Iron	na	na	NT			0.04	U		NT			NT			2.2			NT		
Total Organic Carbon	na	na	1	U		38			9.93			2.5			1.6			14.9		
Total Organic Halides	na	na	0.134			NT			0.0461			0.15			NT			0.075		
Methane (ug/L)	na	na	NT			0.16	U		NT			NT			1020			NT		
Ethane (ug/L)	na	na	NT			1	U		NT			NT			1	U		NT		
Ethene (ug/L)	na	na	NT			1	U		NT			NT			1	U		NT		
Chloride	250	na	NT			7.9			NT			30.4			16.1			NT		
Nitrate (as N)	10	na	NT			1.4			NT			33			0.05	U		NT		
Sulfate	500	na	NT			10			NT			10	U		10.2			NT		
Sulfide	na	na	NT			1.0	U		NT			NT			1.0	U		NT		
Alkalinity	na	na	NT			285			NT			NT			168			NT		
Dehalococcoides sp. (cells/mL)	na	na	NT			10	U		NT			NT			1.4	U		NT		
pH	na	na	7.27			7.3			7.28		J	NT			7			7.49		J

* Refer to legend immediately following this table for a list of dfinitions and table notes

Table 9-1
Area O COI Data
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Analyte		Sample ID Sample Date	8B						WC1-2						AOGW02		
			2/25/92			8/27/07			2/28/92			8/28/07			8/23/07		
	MCL	**tw-RBC**	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q	Result	Lab Q	Val Q
COI (ug/L)																	
1-Methylnaphthalene	na	2.4	NT			1.1	U		NT			0.91	U		414		L
2-Methylnaphthalene	na	2.4	1.7	U		1.1	U		1.7	U		0.91	U		180		L
Naphthalene	na	0.65	NT			1.1	U		NT			0.91	U		50.7		
Phenanthrene	na	18	0.5	U		1.1	U		0.5	U		0.91	U		163		
Pyrene	na	18	2.8	U		1.1	U		2.8	U		0.91	U		18.9	J	J
Misc. (mg/L)																	
Dissolved Oxygen	na	na	NT			0			NT			NT			NT		
Oxidation-Reduction Potential (mV)	na	na	NT			-52			NT			NT			NT		
Ferrous Iron	na	na	NT			4.0			NT			NT			NT		
Total Organic Carbon	na	na	6.57			1.0			18.3			0.61	J		2.6		
Total Organic Halides	na	na	0.102			NT			0.0603			NT			NT		
Methane (ug/L)	na	na	NT			1.4			NT			NT			1380		
Ethane (ug/L)	na	na	NT			1.0	U		NT			NT			1.0	U	
Ethene (ug/L)	na	na	NT			1.0	U		NT			NT			1.0	U	
Chloride	250	na	NT			17.5			NT			13			18.2		
Nitrate (as N)	10	na	NT			0.16			NT			0.77			0.05	U	
Sulfate	500	na	NT			22.5			NT			18			9.1		
Sulfide	na	na	NT			1.0	U		NT			1.0	U		1.0	U	
Alkalinity	na	na	NT			335			NT			308			478		
Dehalococcoides sp. (cells/mL)	na	na	NT			130000			NT			10	U		43000		
pH	na	na	7.67		J	7.0			7.42		J	7.2			7.1		

* Refer to legend immediately following this table for a list of dfinitions and table notes

Table 9-1
Legend

12	J	Shading and black font indicate an MCL exceedance.
12	J	Bold outline indicates a tw-RBC exceedance.
12	*12*	Shading in the MDL/MRL columns indicates the MDL exceeds a criterion.

tw-RBCs for non-Carcinogenic compounds have been recalculated to an HI of 0.1.

The pyrene tw-RBCs were used for acenaphthylene, benzo(g,h,i)perylene and phenanthrene.

The 2-methylnaphthalene tw-RBC was used for 1-methylnaphthalene.

Secondary MCLs were used for aluminum, iron, manganese, silver, and zinc.

MCL Action Levels were used for copper and lead.

MCL = Maximum Contaminant Level (USEPA, 2006).

tw-RBC = Tap Water Risk-Based Concentration (USEPA, October 2007).

tw-RBC value in table is for the more conservative chromium VI.

tw-RBC value for chromium III is 5,500, which was not exceeded.

ng/L = nanograms per liter (parts per trillion).

µg/L = micrograms per liter (parts per billion).

NA = not applicable.

NT = analyte not tested.

Lab Q = Lab Data Qualifiers

B = (organics) Blank contamination. Value detected in sample and associated blank.

A (Dioxins) = B = (metals) Value <MRL and >MDL and is considered estimated.

E (metals) = Reported value is estimated because of the presence of interferences.

EMPC (Dioxins) = The ion-abundance ratio between the two characteristic PCDD/PCDF ions was outside accepted ranges. The detected PCDD/PCDF was reported as an estimated maximum possible concentration (EMPC).

J = (organics) Value <MRL and >MDL and is considered estimated.

U = Analyte not-detected at the method reporting limit.

X = (dioxins) Ion abundance ratio outside acceptable range. Value reported is EMPC.

Val Q = Validation Data Qualifiers

B = blank contamination. Value detected in sample and associated blank.

J = estimated concentration.

K = estimated concentration bias high.

L = estimated concentration bias low.

N = presumptive evidence for tentatively identified compounds using a library search.

U = analyte not detected.

UJ = estimated concentration non-detect.

UL = estimated concentration non-detect bias low.

in these two areas. Naphthalene was also detected in three wells (OMW1, S4W-1, and AOGW02) in August 2007. This was the first time naphthalene was detected in Area O wells; therefore, trends were not observed. An LTM plan will provide additional data to determine trends and attenuation estimates for PAH constituents.

At Area O, the COIs have been observed at levels that are conducive to MNA as an effective remedy. The groundwater geochemical conditions are also favorable for the reduction of COIs at Area O. Therefore, the use of MNA at Area O is an effective remedy to reduce COI levels below the CMO.

Implementation/Ramp-Down Strategy. To evaluate natural attenuation at Area O, LTM will be implemented to obtain data to produce concentration trends, calculate degradation rates, and attenuation estimates. To create a sufficient well network, a permanent monitoring well will be installed near direct push sample point (AOGW02) to monitor concentrations over time in this area. The LTM plan at Area O will include 7 years of groundwater sampling at ten monitoring wells. During the first 2 years (years 1-2), sampling will occur quarterly (4 times a year) until the concentrations decrease by 30 percent. Then, groundwater sampling will occur semi-annually (2 times a year) for the next 2 years (years 3-4), until the concentrations decrease by at least 50 percent. Annual sampling will then be conducted during the last 3 years (years 5-7), until the concentrations have reached and remained below the remedial goals for two consecutive sampling events. Sampling analysis will include: PAHs, gases (methane, ethane, and ethane), TOC, and anions.

Groundwater will be collected from nine existing monitoring wells and one proposed well, as displayed on **Figure 9-1**. The wells and the rationale as to their selection are as follows:

- 8B (downgradient to the east).
- OMW1 (downgradient to the southeast).
- OMW2 (upgradient).
- P-1 (upgradient).
- P-2 (downgradient to the west).
- P-3 (downgradient to the north).
- P-4 (downgradient to the east).
- S4W-1 (downgradient to the east).
- WCI-2 (downgradient to the east).
- Proposed well near AOGW02 (downgradient and the highest levels of PAHs).

Exit Strategy. The LTM plan at Area O is expected to include 7 years of groundwater sampling at ten monitoring wells. If the established remedial goals have been attained for 2 consecutive sampling events, then LTM activities will conclude.

Reporting/Design Work Plans. Shaw will prepare an LTM work plan prior to LTM activities that will include a QA planning component, health and safety component, and field procedures. The work plan will be reviewed and approved by the USEPA and VDEQ prior to sampling activities.

LEGEND

⊕ Proposed Monitoring Well Location

⊕ Monitoring Well Location

🟥 Area O Boundary

⬛ Other SWMU Boundary

Notes:

1) Aerial photo, dated 2005, was obtained from Montgomery County, VA GIS & Planning Services.

N

Scale:

0 75 150 300

Feet

U.S. Army Corps of Engineers

Shaw® Shaw Environmental, Inc.

FIGURE 9-1

Long-Term Monitoring Well Locations at Area O

Radford Army Ammunition Plant,
Radford, VA

RFAAP_Fig9-1_AREAO_MW_Locations.mxd (joy.pasquarelli) (5/22/2008 5:20:18 PM)

After the LTM have been completed and the final inspection approved by the USEPA and VDEQ, a Corrective Measures Summary Report will be completed. Writing and compilation of the information for the report will occur throughout the duration of the LTM. As part of the annual review process, available data will be analyzed as to assess whether the remedy is effective or if additional remedial actions may be required. The report will include site drawings, sample data, and a detailed narrative of the corrective measures.

Cost. The present worth over the remedial duration of 7 years is estimated at $478,515 (**Table 9-2**). Capital costs associated with the implementation of MNA include a work plan, groundwater monitoring, reporting, and project management. The groundwater monitoring would initially consist of sampling on a quarterly basis for the first 2 years (baseline is included). The groundwater sampling frequency would then occur semi-annually, until the concentrations decrease by at least 50 percent. Annual sampling would then be conducted during the last 3 years, until the concentrations have reached and remained below the remedial goals for two consecutive sampling events.

Table 9-2
Cost for Alternative Two: MNA and LTM

ITEM	UNITS	UNIT COST	NUMBER	TOTAL
CAPITAL COSTS				
Reporting/Work Plans				
Long-term Sampling Plan	Report	$21,520	1	$21,520
Reporting (Annual)	Report	$28,664	7	$200,648
Subtotal				**$222,168**
O&M COSTS				
Performance Monitoring				
Sampling (7 years)	Sampling Event	$16,264	7	$178,907
Analytical (7 Years)	Sampling Event	$7,040	11	$77,440
Subtotal				**$256,347**
	SUBTOTAL			**$478,515**
	SUPERVISION AND ADMIN @ 8%			$38,252
	CONTINGENCY @ 30%			$11,475
PRESENT WORTH (30 YEARS AT 5%)				**$478,515**

9.3 Alternative Three: ISEB and MNA

Effectiveness. ISEB is a technology that entails the addition of amendments to the subsurface for the purpose of creating groundwater conditions favorable to increase rates of biodegradation. For fuel-related compounds, enhanced bioremediation can be accomplished by supplying oxygen to the subsurface and microorganisms in the impacted area to increase metabolic rates. At Area O, the ISEB treatment would be focused in the area of direct push sampling point AGOW02 where elevated levels of COIs were observed in 2007. Injectable oxygen sources available include (but are not limited to) oxygen releasing compound (ORC), Regen-Ox, Perm-Ox, and peroxide. This option will enhance microbial populations to reduce concentrations in a shorter time within the treatment area.

In the remaining areas of the site where low levels of contamination exists, natural attenuation of COIs will be the selected technology. Natural attenuation relies on a variety of physical, chemical, and biological processes to reduce concentrations of contaminants in groundwater. This option will not change the physical site conditions; however, groundwater monitoring would be completed to monitor concentration trends, develop degradation rates, and calculate estimated times to reach site goals.

At Area O, as discussed in *Section 9.2*, MNA will be an effective remedy at Area O. However, the elevated concentrations of COIs observed during direct push groundwater sampling at AWOG02 may require a more aggressive approach to reduce levels in a timely manner. Due to limited data at this area (one sampling event), evidence to determine if MNA is occurring at this time is not evident. Therefore, ISEB along with MNA at Area O is an effective remedy and may reduce the time required to reach concentration levels below the CMO.

Implementation

ISEB. Alternative Three involves two technologies. The first technology is the enhancement of biodegradation around AOWG02 using an ORC. The second technology is MNA for the remainder of the impacted area. ISEB will include a groundwater injection of an ORC in a grid pattern using direct push. To accomplish this task, a slurry consisting of water and an ORC will be produced in a holding tank. Using an injection pump and a direct push rig, the slurry is injected into the groundwater target zone from 36 to 46 ft bgs. To treat the impacted groundwater, the oxygen releasing solution will be injected in a grid pattern with 25-foot spacing. To monitor the effectiveness of the ISEB treatment, a monitoring well will be installed within 5 ft of AOWG02 and added to the LTM plan along with MNA procedures at Area O.

MNA. An LTM plan will be designed to assess MNA and will consist of sampling monitoring wells to monitor concentration changes over time at Area O. As described in *Section 9.2*, the LTM plan will include 7 years of groundwater sampling at ten monitoring wells. During the first 2 years (years 1-2), sampling will occur quarterly (4 times a year) until the concentrations decrease by 30 percent. Then, groundwater sampling will occur semi-annually (2 times a year) for the next 2 years (years 3-4), until the concentrations decrease by at least 50 percent. Annual sampling will then be conducted during the last 3 years (years 5-7), until the concentrations have reached and remained below the remedial goals for two consecutive sampling events. Sampling analysis will include PAHs, gases (methane, ethane, and ethane), TOC, and anions.

Groundwater will be collected from nine existing monitoring wells and one proposed well, as shown on **Figure 9-1**. The wells and the rationale as to their selection follow:

- 8B (downgradient to the east).
- OMW1 (downgradient to the southeast).
- OMW2 (upgradient).
- P-1 (upgradient).
- P-2 (downgradient to the west).
- P-3 (downgradient to the north).
- P-4 (downgradient to the east).
- S4W-1 (downgradient to the east).
- WC1-2 (downgradient to the east).
- Proposed well near AOGW02 (to track the ISEB effectiveness).

Reporting/Design Work Plans. Shaw will prepare an LTM work plan prior to LTM activities that will include a QA planning component, health and safety component, and field procedures. The work plan will be reviewed and approved by the USEPA and VDEQ prior to sampling activities.

After the LTM have been completed and the final inspection approved by the USEPA and VDEQ, a Corrective Measures Summary Report will be completed. Writing and compilation of the information for the report will occur throughout the duration of the LTM. As part of the annual review process, available data will be analyzed as to assess whether the remedy is effective or if additional remedial actions may be required. The report will include site drawings, sample data, and a detailed narrative of the corrective measures.

Cost. The present worth over the remedial duration of 7 years is estimated at $536,290 (**Table 9-3**). Capital costs associated with the implementation of ISEB and LTM include a work plan, a groundwater injection of an ORC, groundwater monitoring, reporting, and project management. The ISEB injection would take place in the first year of implementation. During the first 2 years (years 1-2), sampling will occur quarterly (4 times a year) until the concentrations decrease by 30 percent. Then, groundwater sampling will occur semi-annually (2 times a year) for the next 2 years (years 3-4), until the concentrations decrease by at least 50 percent. Annual sampling will then be conducted during the last 3 years (years 5-7), until the concentrations have reached and remained below the remedial goals for two consecutive sampling events.

Table 9-3. Cost for Alternative Three: ISEB and MNA

ITEM	UNITS	UNIT COST	NUMBER	TOTAL
CAPITAL COSTS				
Reporting/Workplans				
Long-term Sampling Plan	Report	$21,520	1	$21,520
Reporting (Annual)	Report	$28,664	7	$200,648
Subtotal				**$222,168**
O&M COSTS				
Performance Monitoring				
ISEB Injection	Injection Event	$57,775	1	$57,775
Sampling (7 years)	Sampling Event	$16,264	7	$178,907
Analytical (7 Years)	Sampling Event	$7,040	11	$77,440
Subtotal				**$256,347**
	SUBTOTAL			**$536,290**
	SUPERVISION AND ADMIN @ 8%			$42,903
	CONTINGENCY @ 30%			$12,870
PRESENT WORTH (30 YEARS AT 5%)				**$536,290**

10.0 DETAILED ANALYSIS OF CORRECTIVE ACTION ALTERNATIVES

10.1 Evaluation Criteria

The criteria used to evaluate each corrective action alternative include effectiveness, implementability, and cost, as described below.

10.2 Effectiveness of the Alternative

The effectiveness of an alternative was based on the ability of the alternative to address technical, human health, and ecological concerns. The effectiveness of each alternative is evaluated in this section based on the ability to:

- Meet the corrective action objective for the study area.
- Achieve remedial action goals for groundwater in a timely manner.
- Provide proven and reliable technologies.
- Reduce impacts to human health and the environment during corrective action implementation.

10.3 Implementability of the Alternative

Identified alternatives need to be readily available, easily completed, and reliable. Evaluation is focused on:

- Ability to put the corrective action in place.
- Availability of equipment, materials, to complete the task.

10.4 Cost of the Alternative

Cost factors used to evaluate alternatives include costs associated with implementation of each corrective action alternative. Costs were included for project planning, project implementation reports, and project administration. The cost for each alternative was developed based on a conceptual design for each alternative. These costs are present worth/equivalent cost (plus 50 percent to minus 30 percent). Actual cost of each alternative is dependent on the final scope, schedule, market conditions, and other variables. Development of the cost for each alternative included:

- Engineering level design of final remedy.
- Capital cost.
- Implementation cost.

10.5 Effectiveness

10.5.1 Overall Protection of Human Health and the Environment

No risks to ecological receptors were determined for Area O; therefore, all alternatives provide protection to the environment. However, Alternative One does not meet this criterion as no measures are taken to determine the reduction of COIs and, therefore, the reduction in risk to human health and the environment would not be observed. Alternative Two provides protection of human health as COIs are monitored to measure the reduction in risk via MNA processes. For Alternative Three, protection of human health is achieved by a more rapid reduction in COI concentrations in one area using an ORC, and the remaining areas are monitored to measure the reduction in risk via MNA processes.

10.5.2 Compliance with Federal, State, and Local Regulations

Alternative One does not provide a method to measure a reduction in concentrations below tw-RBCs by MNA and therefore does not meet compliance requirements. Alternative Two relies on MNA and LTM, a viable technology as recommend by the federal, state, and local environmental divisions. The LTM plan will collect data to calculate concentration trends and attenuation estimates as recommended by the USEPA to assess MNA. Alternative Three also employs MNA along with ISEB and an LTM plan which are viable technologies as recommended by the federal, state, and local environmental divisions. Each alternative will be designed to comply with applicable or relevant and appropriate federal, state, and local regulations. Additional information regarding the alternatives' compliance with National Environmental Policy Act requirements is presented in **Appendix G**.

10.5.3 Long-Term Effectiveness and Permanence

Alternative One does not provide long-term effectiveness or permanence because concentrations are not monitored and effectiveness is unknown. Alternative Two provides a long-term effectiveness as MNA is able to reduce concentrations over time. LTM will observe the effectiveness at Area O. Alternative Three will also provide long-term effectiveness as an LTM plan will be used to monitor concentrations.

10.5.4 Reduction of Toxicity, Mobility, or Volume

Alternative One will be used as a baseline against which to measure the performance of other alternatives. Under this alternative, no actions would be performed to reduce the toxicity, mobility, or volume of contaminants at Area O. There would be no physical changes to the site conditions, and any increase or decrease of COI concentrations would not be known due to a lack of monitoring. Although Alternative Two will not change the physical site conditions, groundwater monitoring would be performed to monitor concentration trends and estimate degradation rates to calculate estimated times to reach site goals. Alternative Three, through the injection of an ORC, would reduce the toxicity and volume of concentrations more quickly in the ISEB treatment area.

10.5.5 Short-Term Effectiveness

Alternative Two is not expected to achieve short-term effectiveness in reducing COI concentrations, as natural processes prevail in this technology. However, Alternative Two will provide data in the short term to monitor the effectiveness of the MNA technology. Alternative Three will provide a short-term rapid reduction of COIs within the ISEB treatment area alone.

10.6 Implementability

10.6.1 Technical Feasibility

Alternative One is technically implementable, as no actions will be implemented under this alternative. Alternative Two involves proven technologies and the implementation requires sampling procedures performed on a regular basis. Alternative Three also involves proven ISEB technologies that are technically feasible. This alternative (Alternative Three) also requires sampling procedures that are implementable and technically feasible.

10.6.2 Administrative Feasibility

Alternative One is administratively feasible, as no actions are to be implemented under this alternative. Administrative activities for Alternatives Two and Three are expected to be routine.

10.6.3 Availability of Services and Materials

Alternative One does not require any services or materials as no actions will be performed. Alternatives Two involves the installation of one monitoring well and groundwater sampling to evaluate MNA processes. The services and materials required for these activities are readily available. Alternative Three employs pilot-scale technologies using both self-performed mixing and subcontracted direct push services that are readily available. This alternative also requires the installation of one monitoring well and groundwater sampling, which the services and materials are available.

10.7 Cost

Costing assumptions are in the description of the alternatives in *Section 9.0*. The detailed cost estimates for Alternatives Two and Three are presented in **Tables 9-2 and 9-3**, respectively. Costs for each of the alternatives are summarized in **Table 10-1**.

Table 10-1
Summary of Costs
Area O Corrective Measures Alternatives

Alternative Number	Capital Costs ($)	Annual Operation and Maintenance Total ($)	30-Year Operation and Maintenance Total ($)	Present Worth ($)
1 – No Further Action	$0	$0	$0	$0
2 – MNA + LTM	$22,080	$20,000		$478,515
4 – ISEB + MNA	$621,380	$0	$0	$536,290

11.0 RANKING OF CORRECTIVE MEASURES ALTERNATIVES

The three corrective measures alternatives presented in *Section8.0* and evaluated in *Section 10.0* are assessed in this section using a numerical ranking system. The alternatives are ranked according to the criteria discussed in *Section 10.0* that include effectiveness, implementability, and cost. Each selection criterion for each alternative was ranked 1 through 5. A score of 5 indicates the most favorable alternative. A score of 1 indicates the least favorable alternative.

In addition, the criteria were weighted based on importance. Effectiveness was given a weight factor of 3, because the primary purpose of the selected action is to be protective of human health and the environment. Implementability was given a weight factor of 2. Costs were given a weight factor of 1, because this criterion was considered the least important for selection of an alternative. The ranking for the four corrective action alternatives is provided in **Table 11-1**.

Based on the ranking, Alternative Two, MNA is the selected corrective alternative for Area O.

Table 11-1
Ranking Assessment of Corrective Measures Alternatives

Alternative	Effectiveness	Implementability	Cost	Total Score
Alternative 1 – No Further Action	COI concentration levels may be reduced by MNA processes; however, any concentration trends would not be known and attaining site goals could not be determined. 3 3X 1	This alternative does not entail activities to be implemented. Therefore, an assessment of implementability is not applicable. 10 2X 5	$0 5 1X 5	18
Alternative 2 – Monitored Natural Attenuation (MNA) and Long-Term Monitoring (LTM)	COI concentration levels will be reduced by MNA processes. LTM will include the collection of data over time to determine concentration trends, calculate degradation rates and cleanup times to reach site goals. 15 3X 5	LTM will consist of quarterly sampling during the first 2 years (years 1-2) until the concentrations decrease by 30 percent. Then, groundwater sampling will occur semi-annually for the next 2 years (years 3-4), until the concentrations decrease by at least 50 percent. Annual sampling will then be conducted during the last 3 years (years 5-7), until the concentrations have reached and remained below the remedial goals for two consecutive sampling events. Sampling will occur in a total of ten wells, including the proposed installation of a permanent monitoring well near AWOG02. After each sampling event, a report will be written to include groundwater data and interpretation of the remedial remedy. 10 2X 5	$478,515 3 1X 3	28
Alternative 3 – In-Situ Enhanced Bioremediation (ISEB) and MNA	Concentration levels will be reduced more rapidly by ISEB near AWOG02. The COI concentrations in the remainder of the site will be reduced via MNA processes. LTM will produce data to determine concentration trends and calculated cleanup times. This alternative may reduce concentrations in the same amount of time as Alternative Two as degradation rates are not known at this time. 9 3X 3	The ISEB treatment will consist of a subsurface groundwater injection of an ORC in a grid formation near the area of AWOG02. The treatment area will be included in an LTM plan that will consist of quarterly sampling during the first 2 years (years 1-2) until the concentrations decrease by 30 percent. Then, groundwater sampling will occur semi-annually for the next 2 years (years 3-4), until the concentrations decrease by at least 50 percent. Annual sampling will then be conducted during the last 3 years (years 5-7), until the concentrations have reached and remained below the remedial goals for two consecutive sampling events. Sampling will occur in a total of ten wells, including the proposed installation of a permanent monitoring well near AWOG02. After each sampling event, a report will be written to include groundwater data, and interpretation of the remedial remedy. 10 2X 5	$536,290 2 1X 2	21

Ranking Value

1 – Least Favorable → 5 – Most Favorable

Weight Factor

Effectiveness	3
Implementability	2
Cost	1

Note:

9 = Score

3 X 3 = weight factor X ranking value

12.0 SUBSTANTIATION/JUSTIFICATION OF FINAL REMEDY

The Area O RFI/CMS identified five COIs (1-methylnaphthalene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene) in groundwater as being a potential concern to human health (see *Section 8.0*). The CMO for the Area O study area is to reduce COI concentrations below tw-RBCs. Three alternatives were developed and evaluated to select the best remedy for the site. These alternatives include:

- Alternative One: No Further Action.
- Alternative Two: MNA.
- Alternative Three: ISEB and MNA.

Both Alternatives One and Two were found to reduce COI concentration levels by MNA processes; however, concentration trends would not be known and attaining site goals could not be determined by implementing Alternative One. Alternative Two entails an LTM plan to monitor the reduction of the COIs concentrations via natural attenuation process. The current data is not sufficient to determine if COI levels have increased or decreased in the past 16 years. Alternative Three provides a short-term rapid reduction of COIs within the ISEB treatment area, but requires MNA in areas outside the primarily impacted groundwater zone.

Alternative Two was selected as the final alternative for Area O because it can be readily implemented and provides a level of protection to human health and the environment not provided by Alternative One. In addition, Alternative Two has a lower cost than Alternative Three. LTM data from this alternative may conclude that no further action is required to attain CMOs.

This alternative includes the following:

- Installation of one monitoring well near AOGW02.
- LTM.
- Reporting.

This alternative can be implemented in approximately 1 year. This timeframe is considered an estimate, and the actual time to attain CMOs will be dependent on data obtained during LTM activities.

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The appendices for this report are included on a CD following this page.