U.S. Army
Environmental
Center

DRAFT

RCRA FACILITY INVESTIGATION FOR SOLID WASTE MANAGEMENT UNITS 17, 31, 48, AND 54 AT RADFORD ARMY AMMUNITION PLANT, VIRGINIA

PREPARED FOR:

U. S. ARMY ENVIRONMENTAL CENTER

Aberdeen Proving Ground, Maryland

PREPARED BY:

PARSONS ENGINEERING SCIENCE, INC.

**10521 Rosehaven Street
Fairfax, Virginia 22030**

JANUARY 1996

PARSONS ENGINEERING SCIENCE, INC.

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January 17, 1996

Mr. Robert Davie
Project Manager
U.S. Army Environmental Center
Building E-4480
Aberdeen P.G., Maryland 21010-5041

Re: Radford Army Ammunition Plant, Draft RCRA Facility Investigation Report

Dear Robert:

Parsons Engineering Science, Inc. (Parsons ES) is pleased to provide you with revised sections of the Draft RCRA Facility Investigation (RFI) Report for Solid Waste Management Units 17, 31, 48, and 54. We have also forwarded complete copies of the report to the addressees on the distribution list.

The revisions to the report are based on the review comments ~~received~~ from you on January 4, 1996. A formal response to the comments is also enclosed; all issues have been addressed. Additionally, in-house review discovered minor typographical errors; these have also been corrected.

To facilitate an easy update of the report, the following revised sections have been enclosed:

- The first clipped set of revisions includes new covers (for both volumes) and various up-front sections (Table of Contents, Executive Summary, distribution list, comment/response page). These pages can directly replace the old pages. The distribution list and comment/response page should go after the inside cover page.
- The next set includes various single page revisions through Section 5 of the report; please replace the old pages.
- An entire new section 6 has been enclosed; please replace the old one.
- For each site characterization section (7 through 12), all new pages, from the Nature and Extent sub-section through the summary sub-section, have been enclosed. Some individual revised pages have also been included for the up-front sub-sections (including some revised figures). All pages are numbered for easy substitution.
- An entire new Section 13 and Section 14 have been enclosed; please replace the old ones.

PARSONS

USAEC COMMENTS ON DRAFT RFI FOR SWMUs 17, 31, 48, AND 54
RADFORD ARMY AMMUNITION PLANT

1) USAEC Comment: The risk assessment assumes that a residential land use and exposures are probable for all the SWMUs. However, the most probable land use will be industrial resulting in a risk assessment which is too conservative. The risk assessments for all the SWMUs, excluding the New River and Stroubles Creek for reasons outlined in the report, should be modified to reflect industrial land use and criteria.

Parsons ES Response: Concur. The report has been revised as appropriate. Additionally, based on various discussions, more realistic exposure parameters reflecting decreased exposure time and quantity, have been evaluated for the New River and Stroubles Creek; these sections have also been revised.

2) USAEC Comment: The uncertainty sections of the risk assessment should discuss or acknowledge the repeated J4 and J6 flags on the analytical data. Section 5 explains that this data should be considered an estimate only therefore the uncertainty section of the risk assessment should repeat this conclusion.

Parsons ES Response: Concur. The uncertainty section of the risk assessment has been revised to include a more detailed explanation of the J flags.

3) USAEC Comment: In the figures showing the conceptual model for exposure pathways, the area residents column should be removed from the future receptor section in order to be consistent with comment number 1.

Parsons ES Response: Concur. All revisions caused by the change in exposure scenarios have been made where appropriate.

4) USAEC Comment: The recommendation section draws conclusions consistent with the findings of the RFI. It will only need modification if using industrial criteria and exposure scenarios changes the outcome of the risk assessment significantly.

Parsons ES Response: Concur. A reevaluation of exposure scenarios did not significantly change the recommendations. Although the groundwater pathway evaluation was significantly revised, where groundwater was shown to impact other areas, the recommendations based on the control or abatement of groundwater movement were not changed. The soil pathway risks for site workers did not significantly change (the quantification of risk and the specific contaminants of concern may have changed for the soil pathway, but the risk posed for these receptors remained to form the basis of the recommendations).

Concerning the following document:

The RCRA Facility Investigation Report for Solid Waste Management Units 17, 31, 48, and 54 at Radford Army Ammunition Plant, Virginia.

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: JOHN R. LOYD

TITLE: LTC, OD, Commanding
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SIGNATURE: James E Woolwine

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John Segna, Parsons Engineering Science, Inc.

RCRA FACILITY INVESTIGATION FOR SOLID WASTE MANAGEMENT UNITS 17, 31, 48, AND 54 AT RADFORD ARMY AMMUNITION PLANT, VIRGINIA

PREPARED FOR:

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Aberdeen Proving Ground, Maryland

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JANUARY 1996

RCRA FACILITY INVESTIGATION REPORT
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

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EXECUTIVE SUMMARY

This document is the draft report for the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) for the Radford Army Ammunition Plant (RAAP), Radford, Virginia. It has been prepared for the U.S. Army Environmental Center (USAEC) by Parsons Engineering Science, Inc. (Parsons ES) and is being submitted under the requirements of Contract No. DAAA15-90-D-0008, Task DA04. RAAP is a government-owned contractor-operated (GOCO) military installation supplying solvent and solventless propellant grains and TNT explosives. The present contractor-operator is Alliant Techsystems, Inc.

RAAP was issued a Permit for Corrective Action and Incinerator Operation (Permit) by the U.S. Environmental Protection Agency (USEPA), effective December 13, 1989. The Permit requires RAAP to conduct RFIs for suspected releases of contamination from Solid Waste Management Units (SWMUs). The objective of the RFI is to characterize the nature, extent, concentration, and rate of migration of releases of hazardous wastes or hazardous constituents; identify potential receptors; provide detailed geologic and hydrogeologic characterizations; determine the need for corrective measures, or provide recommendations for other appropriate actions, for each SWMU.

Dames & Moore completed RFIs or Verification Investigations (VI) for all of the identified SWMUs in 1991-1992. Further characterization of certain SWMUs was recommended. This report contains the results of RFI activities at four SWMUs; SWMU 17, SWMU 31, SWMU 48, and SWMU 54. SWMU 40 was grouped with SWMU 17 because of geographical proximity and similar subsurface features. Additionally, characterization of the New River and Stroubles Creek, two significant surface water bodies at RAAP, was included in the RFI. The work was completed in general accordance with USEPA review comments on the previous Dames & Moore investigations, and the applicable guidance documents, including the RCRA Corrective Action Program Guide and the RCRA Corrective Action Manual.

RAAP is located in the mountains of southwestern Virginia, in Pulaski and Montgomery Counties. The facility consists of two noncontiguous areas; The Radford Unit (or Main Section) and the New River Storage Area Unit located about 6 miles west of the Main Section. The Main Section is the focus of this report. The New River divides the Main Section into two areas. Within the meander loop of the New River is the "Horseshoe Area" and south of the New River is the "Main Manufacturing Area."

The SWMUs discussed in this report were characterized by drilling exploratory soil borings, installing groundwater monitoring wells, performing a structural geology study, a dye tracing study, and aquifer testing to investigate facility-wide and site-specific geology and hydrogeology, collecting groundwater, surface water, sediment, soil, waste ash, and associated QA/QC samples for chemical analysis, collecting soil samples for geotechnical testing, collecting composite soil or waste samples for disposal characterization, completing a study to establish background concentrations of metals occurring in the soils as the basis of statistical comparisons to metals levels found in the SWMU samples, and using the data to complete a quantitative human health risk assessment.

A summary of the RFI field activities implemented at each SWMU is presented below.

SWMU 17/SWMU 40 (CONTAMINATED WASTE BURNING AREAS AND SANITARY LANDFILL) The RFI investigation at SWMU 17/SWMU 40 consisted of performing a dye tracing study, drilling seven soil borings, collecting 42 soil samples, collecting one sediment sample, collecting one surface water sample, collecting four groundwater samples, and collecting appropriate QA/QC samples to ensure data usability.

SWMU 31 (COAL ASH SETTLING LAGOONS) The RFI investigation at SWMU 31 consisted of installing four wells, performing aquifer testing of the wells, placing staff gauges in the lagoons, collecting eight soil samples and six lagoon sediment samples, collecting four groundwater samples, and collecting appropriate QA/QC samples.

SWMU 48 (OILY WASTEWATER DISPOSAL AREA) The RFI investigation at SWMU 48 consisted of drilling two soil borings, installing four wells, performing aquifer testing of the wells, collecting 18 soil samples, collecting four groundwater samples, and collecting appropriate QA/QC samples.

SWMU 54 (PROPELLANT ASH DISPOSAL AREA) The RFI investigation at SWMU 54 consisted of drilling 16 soil borings, collecting 33 soil samples, collecting three groundwater samples, collecting two waste ash samples, and collecting appropriate QA/QC samples.

Additional field sampling activities were conducted in support of the RFI activities.

STROUBLES CREEK Two surface water samples and two sediment samples were collected from Stroubles Creek. Appropriate QA/QC samples were collected.

NEW RIVER Six surface water samples and six sediment samples were collected from the New River. Appropriate QA/QC samples were collected.

Finally, a study to determine background concentrations of metals in the soil was completed by drilling 16 soil borings and collecting 36 soil samples. QA/QC sampling was also performed for these investigations. Data from these areas were used to support the characterizations of the SWMUs presented in the RFI report.

The following recommendations for further action have been developed based on the success of the RFI program in evaluating the risks associated with each SWMU. Table ES-1, which is located at the end of this section, summarizes the risks associated with each SWMU and the recommendations presented.

- **SWMU 17/40**

  1) Recommendation: Interim Measures

  The human health risk assessment indicates a potential for noncarcinogenic and carcinogenic adverse human health effects for ingestion and dermal contact of surface and subsurface soils and groundwater. The dye tracing study demonstrated a subsurface connection between SWMU 17 and the New River; chemicals of concern found at SWMU 17 were also detected at the discharge point, indicating a release of contaminants. Surface and near surface contamination of soils in areas of active operations indicates the need for interim measures to control potential threats to the health of site workers.

Interim measures would consist of the implementation of relatively simple engineering controls to prevent or minimize dermal contact with surface soils, including: protective clothing (appropriate gloves and coveralls) and wash stations at easily accessible locations.

2) Recommendation: Conduct Corrective Measures Study (CMS)

A CMS is recommended to address long term solutions to contaminant migration from SWMU 17. Since the active operations represent a continuing source of contamination to the soils and groundwater, corrective measures should be developed which can mitigate contaminant releases while minimizing the impact to the active operations. Such corrective measures might include:

- Construction of a concrete pad with appropriate drainage controls for all burning operations;
- Construction of an impermeable cap to prevent infiltration of precipitation and reduce contaminant flushing; and
- Excavation of the shallow fill materials and installation of an impermeable liner to abate future contaminant migration.

The objective of the CMS is to identify and develop proposed corrective measures and alternatives by screening available technologies, assessing site conditions, and examining financial, institutional, and health impacts. A CMS would justify the recommended corrective actions on a technical, environmental and human health basis, including applicable cleanup levels. The CMS would provide complete information on the status of remediation activities and establish a system for regular reporting, record keeping, and compliance requirements. Finally, the CMS would provide sufficient information so that remedial design and implementation could proceed.

- **SWMU 31**

1) Recommendation: Collect Additional RFI Data

The human health risk assessment indicates a risk based on the hypothetical future site worker groundwater usage scenario. However, migration of metals from the coal ash lagoon sediments to the groundwater and eventually to the New River appears to be occurring. Since the lagoon sediments were only sampled for TCLP waste disposal characterization during the RFI, they could not be considered in the human health risk assessment. Although the previous investigation included sediment sampling data, this information could not be fully assessed for human health risks. Additionally, the compositing procedure used in the previous investigation to collect the samples may not have been appropriate to characterize the sediments. Therefore, additional sampling is recommended to define the nature and extent of contamination at SWMU 31.

Based on the available sampling data, a "No Further Action" recommendation would be inappropriate. However, sampling of the sediments, coupled with the additional sampling of the New River, would allow for risk assessment of the sediment pathway and may provide sufficient information to support a "No Further Action" recommendation. Should the supplemental data demonstrate a significant release of contaminants to the groundwater and the New River, the following action alternatives should be considered:

- Eliminate the discharge of filter backwash and drinking water overflow to the lagoons. The discharge to the lagoons is a flushing mechanism which facilitates the migration of metals from the sediments to the groundwater; and

- Closure of SWMU 31 through excavation of sediments and backfilling of the lagoons.

- **SWMU 48**

1) Recommendation: Perform Dye Tracing Study

Better definition of the groundwater flow at the SWMU 48 area and identification of specific discharge points are necessary to fully evaluate site conditions in this vicinity. Therefore, a dye tracing study is recommended for the SWMU 48 area. The study would help to define groundwater movement throughout this vicinity, providing useful information for SWMUs 13, 16, 27, 28, 29, 30, 50, 51, 52, 53, and 59.

2) Recommendation: Access Restriction/Surface Water Runoff Drainage Control

Human health risk analysis suggests the potential for carcinogenic adverse human health effects for ingestion and dermal contact with surface soils (the most significant surface soil contamination appears to be from the upper disposal mound). However, the risk analysis determined that the inhalation of particulates pathway is not a concern. Therefore, restriction of access by installing a fence around the upper oily waste disposal mound at this SWMU is recommended to minimize contact with surface soils. Construction of surface water drainage controls will minimize the potential for contaminant migration through runoff.

- SWMU 54

1) Recommendation: Conduct Corrective Measures Study (CMS)

Risk analysis indicates the potential for noncarcinogenic and carcinogenic adverse human health effects for dermal and ingestion exposure scenarios for subsurface soils and groundwater. Chemicals of concern identified for SWMU 54 were also found in New River sediments indicating contaminant migration. Additionally, this area is not within the facility security fence and is accessible from the New River. SWMU 54 is also prone to flooding which may transport contaminants to downstream receptors. Therefore, a CMS is recommended to define methods of source remediation.

- STROUBLES CREEK

1) Recommendation: Additional Sampling

Risk analysis suggests a low potential for carcinogenic adverse human health effects for dermal and ingestion exposure scenarios for sediments and for dermal exposure scenarios for surface water. However, since contaminants were found in the sample taken upstream of RAAP, and since only two samples were collected, additional work is required to fully characterize the creek. Additional sampling may indicate contaminant sources unrelated to activities at RAAP. Complete characterization of the creek should include a detailed analysis of the effects of dilution on the contaminants.

- **NEW RIVER**

1) Recommendation: Additional Sampling

Risk analysis suggests the potential for carcinogenic adverse human health effects for dermal and ingestion exposure scenarios for sediments and for dermal exposure scenarios for surface water. However, since sample locations were chosen to correspond to the likely discharge point of the four SWMUs investigated for this report, the possible impacts of other SWMUs or permitted outfall discharges to the river have not been fully explored. Therefore, additional work is necessary to completely characterize the river. Additional sampling may indicate contaminant sources unrelated to activities at RAAP. Complete characterization of the river should include a detailed analysis of the effects of dilution on the contaminants.

TABLE ES-1

SUMMARY OF RFI RECOMMENDATIONS
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

SWMU or Area of Concern	Human Health Risk Concern[1]	Media	Receptor[2]	Exposure Route	Recommendation
SWMU 17/40: Contaminated Waste Burning Areas and Sanitary Landfill	Yes	Groundwater Soil	Site Workers Construction Workers Recreational Users	Dermal Ingestion	Conduct Corrective Measures Study Interim Measures
SWMU 31: Coal Ash Settling Lagoons	Yes	Groundwater	Site Workers	Dermal Ingestion	Collect Additional RFI Data
SWMU 48: Oily Wastewater Disposal Area	Yes	Groundwater Soil	Site Workers Construction Workers Recreational Users	Dermal Ingestion Inhalation	Perform Dye Tracing Study Access Restriction/Surface Water Runoff Drainage Control
SWMU 54: Propellant Ash Disposal Area	Yes	Groundwater Soil	Site Workers Construction Workers	Dermal Ingestion	Conduct Corrective Measures Study
Stroubles Creek	Yes	Surface Water Sediment	Site Workers Recreational Users	Dermal Ingestion	Additional Sampling
New River	Yes	Surface Water Sediment	Site Workers Recreational Users	Dermal Ingestion	Additional Sampling

[1] Risk Criteria Defined in the Baseline Risk Assessment (Section 6)

[2] The potential receptors listed may be affected by one or more of the media identified.

LIST OF ACRONYMS AND ABBREVIATIONS

ACD	Air Curtain Destructor
ACL	Alternate Concentration Limit
ACO	Administrative Contracting Officer
ARARs	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
atm-m^3/mole	Atmosphere - cubic meter per mole
BCF	Bioconcentration Factor
BCM	Betz-Converse-Murdock, Inc.
bgs	Below Ground Surface
BTU	British Thermal Unit
CAA	Clean Air Act
CBC	Complete Blood Count
CL	Silty Clay
CIH	Certified Industrial Hygienist
CMS	Corrective Measures Study
COC	Chain of Custody
COD	Chemical Oxygen Demand
CRAVE	Carcinogenic Risk Assessment Verification Endeavor
CTM	Charles T. Main of Virginia, Inc.
CWA	Clean Water Act
dBA	Decibel
DCL	Data Chem Laboratories
DNT	Dinitrotoluene
E	Exposure Level
EM	Electromagnetic
EP	Extract Procedure
FAL	Fly Ash Landfill
FLFA	Former Lead Furnace Area
Fm.	Formation
FVC	Forced Vial Capacity
FWQC	Federal Water Quality Criteria
GCMS	Gas Chromatograph Mass Spectrometer
GM	Silty Gravel
GOCO	Government-owned, Contractor-operated
GW	Groundwater
HBN	Health-based Number
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HMX	High melting point explosive
HSP	Health and Safety Plan
HSWA	Hazardous and Solid Waste Amendments
ID	Identification Number
IR	Installation Restoration
IRDMIS	Installation Restoration Data Management Information System
IRFDS	Inhalation Reference Doses
ISF	Inhalation Slope Factor
IVR	Inhalation Unit Risks
KCl	Potassium Chloride
KoC	Organic Carbon (soils) Partition Coefficient
KoW	Octanol/water Partition Coefficient
LQAC	Laboratory QA Coordinator
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goals
MDL	Method Detection Limits
mg/kg	Milligrams Per Kilogram
mg/L	Milligrams Per Liter

LIST OF ACRONYMS AND ABBREVIATIONS

mgd	Million Gallons Per Day
ML	Sandy Silt
mm-Hg	Millimeters of Mercury
mph	Miles Per Hour
MSDS	Material Safety Data Sheet
msl	Mean Sea Level
MTBE	Methyl Tertiary Butyl Ether
MW	Monitoring Well
NBS	National Bureau of Standards
NC	Nitrocellulose
ND	Nondetect
NEIC	National Enforcement Investigation Center
NG	Nitroglycerin
NIST	National Institute of Standards and Technology
NROW	New River Ordnance Works
NRVPDC	New River Valley Planning District Commission
Parsons ES	Parsons Engineering Science, Inc.
PAHs	Polynuclear Aromatic Hydrocarbons
PC	Personal Computer
PEF	Particulate Emission Factor
PID	Photoionization Detector
PNA	Polynuclear Aromatic Hydrocarbons
PPE	Personal Protective Equipment
PQL	Practical Quantification Limit
psi	Pounds per Square Inch
PVC	Polyvinyl Chloride
QA	Quality Assurance
QAP	Quality Assurance Plan
QAPP	Quality Assurance Project Plan
QC	Quality Control
RAAP	Radford Army Ammunition Plant
RAGS	Risk Assessment Guidance for Superfund
RBC	Risk Based Concentration
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose
RFI	RCRA Facility Investigation
RL	Reporting Limit
RME	Reasonable Maximum Exposure
ROW	Radford Ordnance Works
RPD	Relative Percent Difference
RW	Drilling/Rinse Water
SB	Soil Boring
SCS	Soil Conservation Service
SE	Sediment
SES	Safety and Environmental Service
SF	Slope Factor
SM	Silty Sand
SO	Soil
SOP	Standard Operating Procedure
SS	Surface Soil
SVOC	Semivolatile Organic Compound
SW	Surface Water
SWMU	Solid Waste Management Unit
TAL	Target Analyte List

LIST OF ACRONYMS AND ABBREVIATIONS

TBC	To Be Considered
TBD	To Be Determined
TCE	Trichloroethene
TCLP	Toxic Characteristic Leaching Procedure
TEFs	Toxicity Equivalency Factors
TIC	Tentatively Identified Compound
TNT	Trinitrotoluene
TOC	Top of Well Casing or Total Organic Carbon
TOX	Total Organic Halogens
TPH	Total Petroleum Hydrocarbon
µgg	Micrograms Per Gram
µg/L	Micrograms Per Liter
USAEC	U.S. Army Environmental Center
USAEHA	U.S. Army Environmental Hygiene Agency
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USCS	Unified Soil Classification System
USDOT	U.S. Department of Transportation
USEPA	U.S. Environmental Protection Agency
UST	Underground Storage Tank
VDMR	Virginia Division of Mineral Resources
VI	Verification Investigation
VOC	Volatile Organic Compound
VPI&SU	Virginia Polytechnic Institute and State University
WQC	Walter Quality Criteria

SECTION 1

INTRODUCTION

1.1 INTRODUCTION

1.1.0.1. This document is the draft report for the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) in support of the Permit for Corrective Action and Incinerator Operation at Radford Army Ammunition Plant (RAAP) located in Radford, Virginia. This report has been prepared for the U.S. Army Environmental Center (USAEC), formerly the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), and is being submitted under the requirements of Contract No. DAAA15-90-D-0008, Task DA04. The report was prepared by Parsons Engineering Science (Parsons ES), formerly Engineering-Science, Inc.

1.1.0.2. A Permit for Corrective Action and Incinerator Operation (No. VA1-21-002-0730) was issued to Hercules Incorporated by the U.S. Environmental Protection Agency (USEPA), under the authority of the Solid Waste Disposal Act, as amended by RCRA (1976), and the Hazardous and Solid Waste Amendments (HSWA) of 1984. RAAP, which is currently operated by Alliant Techsystems, Inc., is owned by the U.S. Army. The RCRA permit allows Alliant Techsystems to operate a hazardous waste treatment, storage, and disposal facility in Radford, Virginia. The full RCRA permit comprises USEPA's portion, which addresses provisions of HSWA, and the Virginia Department of Environmental Quality portion, which addresses the provisions of RCRA for which the Commonwealth of Virginia is authorized. Corrective action is addressed by HSWA and enforced by USEPA. Section 3004(u) of RCRA (Section 206 of HSWA requires corrective action as necessary to protect human health and the environment from releases of hazardous waste constituents from any solid waste management unit (SWMU). The corrective action permit includes requirements for RAAP to conduct verification investigations (VIs) at sites of suspected contamination, RFIs at sites of known contamination, and Corrective Measures Studies (CMSs) at sites requiring remediation.

1.1.0.3. In 1992, RAAP completed several VIs and RFIs at selected SWMUs throughout the installation. Results of those studies were presented in the Draft RFI Report

(Dames & Moore, 1992a) and the Draft VI Report (Dames & Moore, 1992b). Parsons ES was tasked to conduct further investigations at SWMUs 17, 40, 31, 48, and 54, based upon recommendations made in those reports. The recommendations included:

- SWMU 17-Contaminated Waste Burning Areas: Based on the RFI, additional characterization of hydrogeologic conditions, utilizing a dye-tracer study, was required as well as a sampling program for groundwater discharge points.
- SWMU 40-Sanitary Landfill (Nitroglycerin Area): The VI conducted in this area concluded that groundwater sampling should be performed and that the dye tracer study for SWMU 17 include this adjacent area.
- SWMU 31-Coal Ash Settling Lagoons: The Waste Characterization Study conducted at this site concluded that a groundwater investigation was needed.
- SWMU 48-Oily Wastewater Disposal Area: The VI report recommended that future activities include groundwater and soils investigations to determine the source and extent of fuel contamination.
- SWMU 54-Propellant Ash Disposal Area: An RFI/CMS was recommended in the VI report.

This report presents the results of these investigations.

1.2 PROJECT OBJECTIVES

1.2.0.1. The objectives of the RFI, as specified in the permit, are to: characterize the nature, extent, concentration and rate of migration of releases of hazardous waste or hazardous constituents from the SWMUs into groundwater, surface water, soil, or any other identified media; identify and evaluate potential impacts to human and environmental receptors; provide a detailed geologic and hydrogeologic characterization of the area surrounding and underlying the SWMUs; and determine the need for and scope of corrective measures.

1.2.0.2. The objectives were accomplished by performing the investigation field tasks and data analysis in accordance with the RFI Work Plan (Engineering-Science, Inc., 1994a) and the RCRA Corrective Action Program Guide-Interim (U.S. Department of Energy, May 1993).

1.3 SCOPE OF WORK

1.3.0.1. The RFI scope of work included the following field tasks.

SWMU 17/40-Contaminated Waste Burning Areas and Sanitary Landfill (SWMUs were combined because of proximity and similar subsurface conditions):

- A dye trace study test was performed preliminary to the other characterization activities to provide an understanding of groundwater movement in karstic environments. The final report was submitted by Parsons ES to the USEPA in March 1994 (amended in September 1994);
- Seven soil borings were installed;
- Three surface soil samples were collected;
- Four groundwater samples were collected - two monitoring wells were dry; and
- The discharge point at the New River was sampled.

SWMU 31-Coal Ash Settling Lagoons:

- Four groundwater monitoring wells were installed;
- Four groundwater samples were collected;
- Aquifer testing (slug tests) was conducted on each new well;
- Six lagoon sediment samples were collected; and
- Staff gauges (water elevations) were installed in the lagoons and river.

SWMU 48-Oily Wastewater Disposal Area:

- Four groundwater monitoring wells were installed;
- Four groundwater samples were collected;
- Three aquifer slug tests were conducted;
- Two soil borings were installed; and

- Six surface soil samples were collected.

SWMU 54-Propellant Ash Disposal Area:

- Two waste composite samples were collected;
- 16 soil borings were installed; and
- Three groundwater samples were collected.

Other non SWMU-specific field activities were completed based on identified deficiencies in the existing characterization information. These activities included:

- Two sediment and surface water samples were collected from Stroubles Creek;
- Six sediment and surface water samples were collected from the New River; and
- 18 soil borings (36 soil samples) were installed in background areas to establish background metals concentrations.

These field tasks were conducted during December 1994/January 1995, and July 1995.

1.4 REPORT ORGANIZATION

1.4.0.1. This report consists of fourteen sections and nine supporting appendices. The report is Volume I. The Appendices are contained in Volume II. Section 1 provides an introduction and statement of the project objectives. A detailed description of the current conditions at RAAP, including facility background and summary of previous investigations is presented in Section 2. Section 3 describes the environmental setting including the results of a geological structural study performed by Parsons ES. Section 4 outlines the procedural aspects of the field investigation program.

1.4.0.2. Section 5 discusses data management and data quality issues, including entry of all data into the USAEC's Installation Restoration Data Management Information System (IRDMIS) database, while Section 6 presents a baseline risk assessment. Sections 7 through 12 present the site characterization of the four SWMUs, Stroubles Creek and the New River. Section 13 presents conclusions and recommendations. References can be found in Section 14.

1.4.0.3. A listing of acronyms and abbreviations used throughout the report is included as Appendix A and is also presented after the Table of Contents. Other appendices contain the detailed information from the field tasks (drilling logs, aquifer testing, etc.) and analytical data (data summary tables, risk tables, etc.). Oversized maps are presented as Plates 1, 2, and 3.

SECTION 2

FACILITY DESCRIPTION

The background information in this section has been adapted from previous RFI and VI reports prepared for the USAEC (Dames & Moore, 1992a and 1992b).

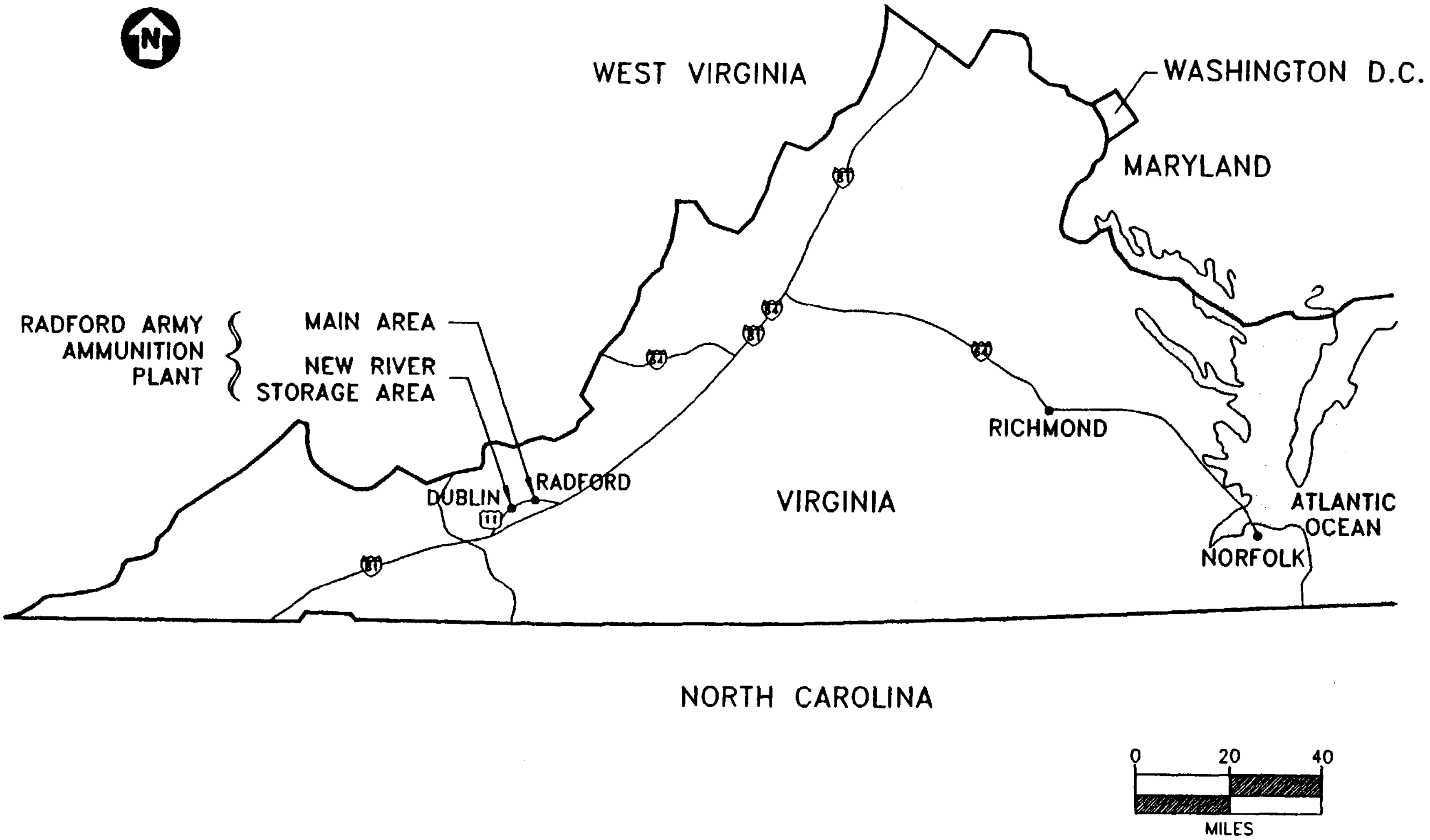
2.1 FACILITY LOCATION

2.1.0.1. RAAP is located in the mountainous region of southwestern Virginia (Figure 2.1) in Pulaski and Montgomery Counties. These two counties along with Floyd and Giles Counties make up the New River Valley Planning District Commission. The installation consists of two noncontiguous areas - the Radford Unit (or Main Section) and the New River Ammunition Storage Area Unit. The Main Section is located approximately 4 miles northeast of the city of Radford, Virginia, approximately 10 miles west of Blacksburg, Virginia, and 47 miles southwest of Roanoke, Virginia. The New River Unit is located about 6 miles west of the Main Section, near the town of Dublin, Virginia, (Figure 2.2). The Main Section of RAAP (Figure 2.3) is the focus of this report; all uses of the terms "RAAP," "the facility," or "the installation" in this report refer to the Main Section only.

2.1.0.2. RAAP lies in one of a series of narrow valleys typical of the Appalachian Mountain region. This valley is oriented in a northeast-southwest direction, and is approximately 25 miles long, 8 miles wide at the southwest end, narrowing to 2 miles at its northeast end. The facility is situated along the New River in the relatively narrow northeast region of the valley.

2.1.0.3. RAAP is divided into two areas (northern and southern) by the New River. The northern half or "Horseshoe Area" is located within the New River meander. Located in the Horseshoe Area are the Nitroglycerin (NG) No. 2 Area, the Cast Propellant Area, and the Continuous Solvent Propellant Area. Many landfills at RAAP are located in this area, including the Hazardous Waste Landfill, the currently active Sanitary Landfill, and the Waste Propellant Burning Ground. Three of the SWMUs discussed in this report are located in this

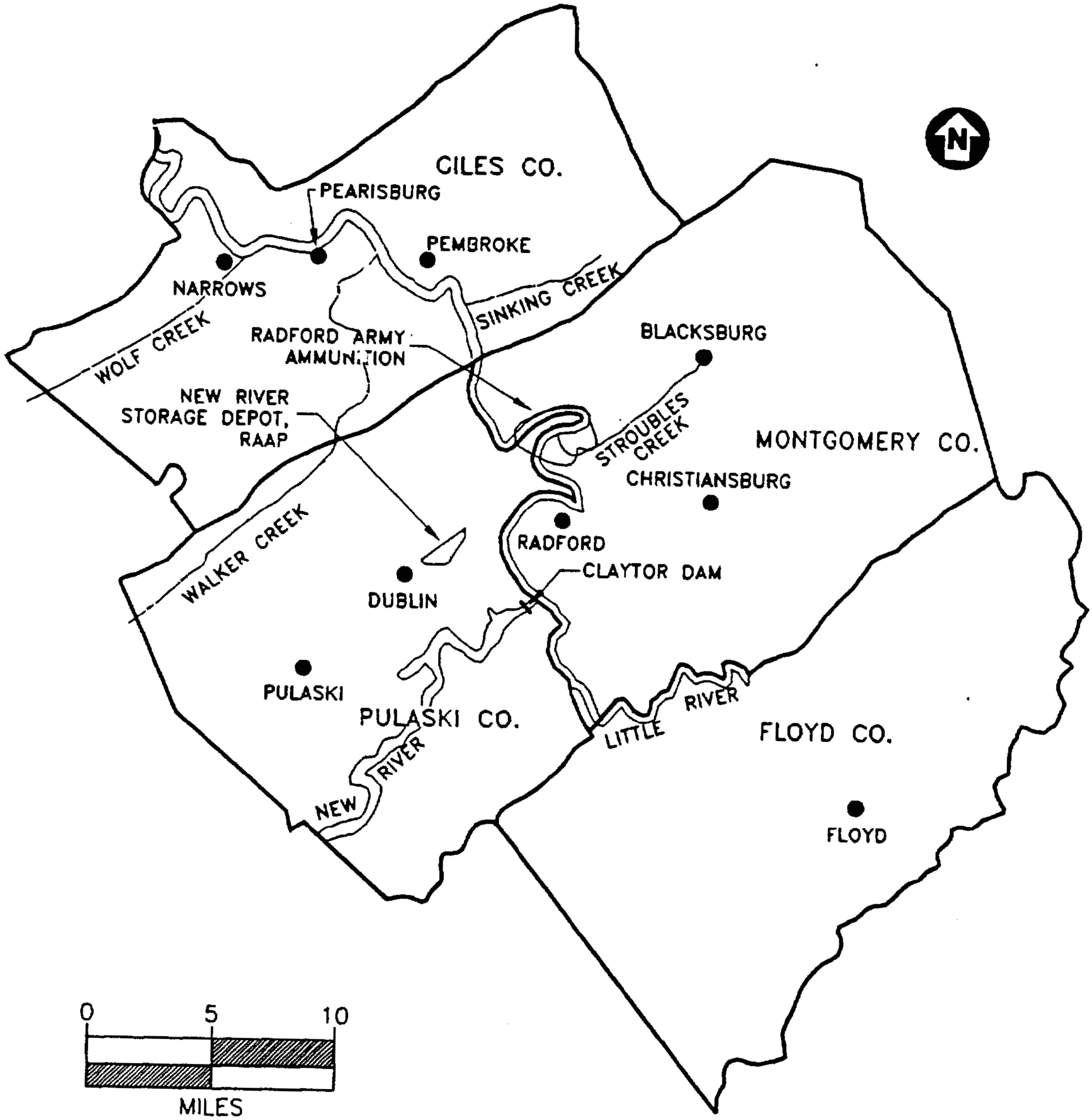
FIGURE 2.1
LOCATION MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



SOURCE: USAEHA, 1980, AS CITED IN DAMES & MOORE, 1992

FB517001

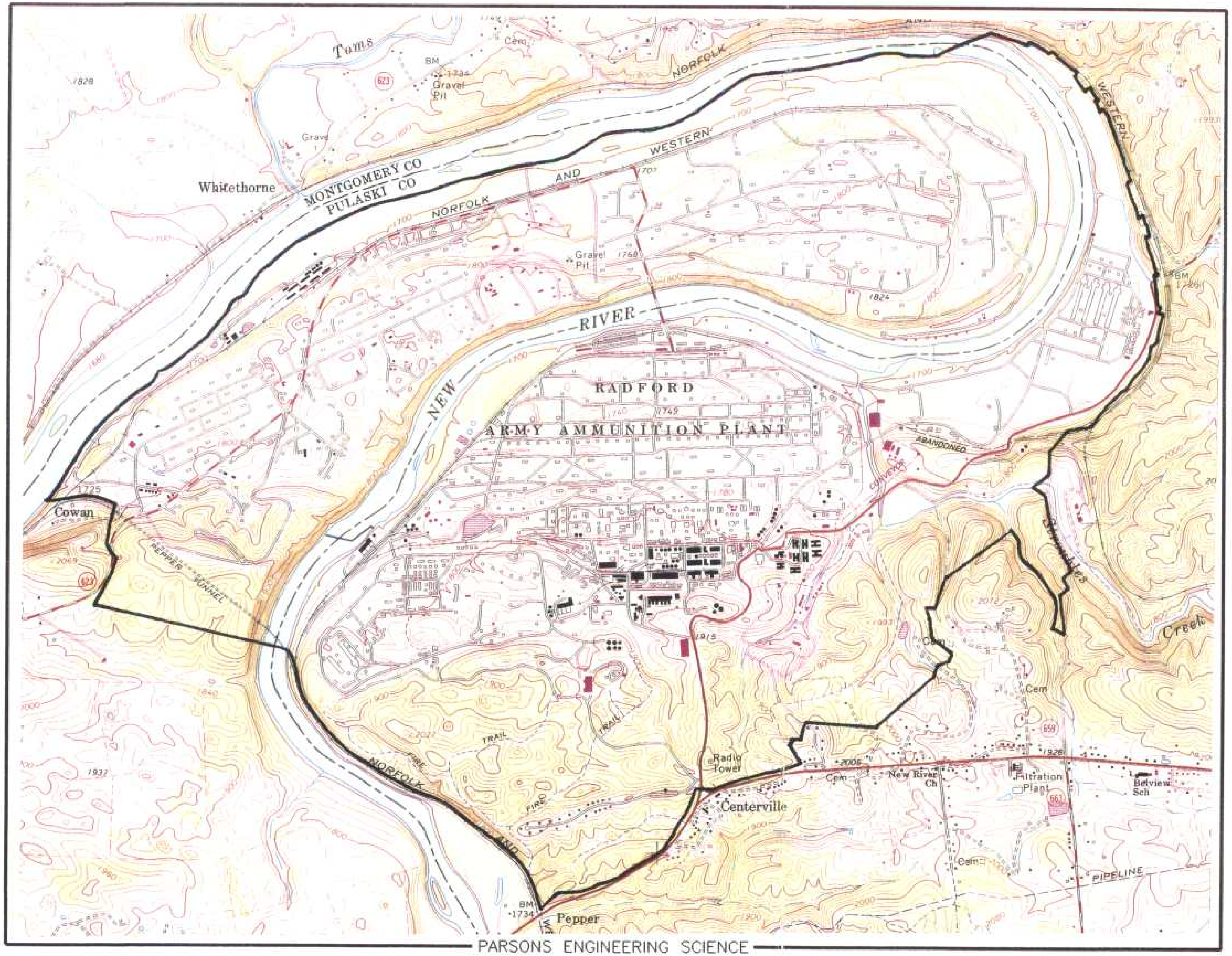
FIGURE 2.2
RAAP AND VICINITY MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



SOURCE: USAEHA, 1980, AS CITED IN DAMES & MOORE, 1992

FB517002

FIGURE 2.3
MAIN SECTION OF RAAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



PARSONS ENGINEERING SCIENCE

0 2,000 4,000
FEET

SCALE = 1:24,000

LEGEND

— PROPERTY LINE

SOURCE: U.S. GEOLOGICAL SURVEY, RADFORD NORTH QUADRANGLE area, including SWMU 31 (Coal Ash Settling Lagoons), SWMU 48 (Oily Wastewater Disposal Area), and SWMU 54 (Propellant Ash Disposal Area). South of the New River is the "Main Manufacturing Area," which includes the Finishing Area; the TNT Area; the NG area; Nitrocellulose (NC) and Acid Areas; the Automated Propellant Area; and the Administration Area. Two SWMUs discussed in the report, SWMU 17 (Contaminated Waste Burning Areas) and SWMU 40 (Sanitary Landfill), as well as Stroubles Creek, are located in this area. Plate 1 presents a topographic and SWMU location map for the entire facility; the map includes all SWMUs including those which were not the subject of this investigation.

2.2 FACILITY HISTORY

2.2.0.1. RAAP is a government-owned, contractor-operated (GOCO) military industrial installation supplying solvent and solventless propellant grains and trinitrotoluene (TNT) explosives. From its inception as a GOCO facility in 1940 until 1995, RAAP had been operated by Hercules Incorporated. On March 16, 1995, Alliant Techsystems, Inc. bought out Hercules, Inc. and took over the operation of RAAP.

2.2.0.2. Construction of the RAAP production facility began in 1940 with the impending participation of the United States in World War II, and the determination by Congress of a need for increased ammunition production facilities. Initially, RAAP consisted of two distinct areas - a smokeless-powder plant (Radford Ordnance Works [ROW]) and a bag-manufacturing and loading plant for artillery, cannon, and mortar projectiles (New River Ordnance Works [NROW]). These two production facilities were operated separately from 1940 to 1945. Late in 1945, ROW was designated as the Radford Arsenal, and NROW was designated as a subpost. By January 1950, NROW was made an integral part of the Radford Arsenal and no longer considered a subpost. The arsenal was renamed Radford Ordnance Plant in 1961 and was finally redesignated as the RAAP in August 1963 (USATHAMA, 1984).

2.2.0.3. Expansion of both ROW and NROW continued throughout World War II. Late in 1945, the Radford Unit was placed on standby status. The following year, the nitric acid area of the plant was reactivated to produce ammonium nitrate fertilizer, an activity that continued until 1949 under contract with Hercules Powder Company (later Hercules

Incorporated). In September 1945, the NROW was declared surplus; but in April 1946, the magazine areas were changed from surplus to standby status. Between December 1946 and January 1948, large parcels of the NROW plant manufacturing area were sold (USATHAMA, 1984). These parcels were excess land holdings that had never been used for production purposes.

2.2.0.4. Between 1952 and 1958, Goodyear Aircraft Corporation, of Akron, Ohio, was contracted to manufacture component parts used in missile production at RAAP. The close coordination required between Goodyear and Hercules resulted in Goodyear moving its assembly and coating operations to RAAP. In 1958, Hercules took over the Goodyear operations at this plant (USATHAMA, 1984).

2.2.0.5. In mid-1968, the continuous TNT plant was put into production and remained in operation until destroyed by an explosion in May 1974. This plant had five main operational areas: the nitration lines, the finishing buildings, the red water concentration facility, the acid neutralization facility, and the spent acid recovery plant. The C-line in the TNT area ran from 1983 to 1986, when the TNT plant was placed on standby. Later, in December 1988, a facility cleanup was conducted and the plant was prepared for long-term standby status. Between 1990 and 1992 two nitroglycerin facilities went on line at RAAP. Although there was an explosion at one of these in 1993, they both remain active. A chronological listing of major RAAP activities is presented in Table 2.1.

2.3 FACILITY RESPONSIBILITY

2.3.0.1. Based on discussions with plant personnel (1995), the general responsibilities assigned to RAAP have not changed from those outlined by USATHAMA (1976), these include:

- Manufacture of explosives and propellants;
- Handling and storage of strategic and critical materials as directed for other government agencies;

TABLE 2.1

CHRONOLOGICAL LIST OF MAJOR ACTIVITIES AT RAAP

DATE	ACTIVITY
August 1940	Contract signed with Hercules Powder Company for Construction and Operation of smokeless powder plant
September 1940	Construction of Radford Plant
April 1941	Production started at Radford Plant
1941	Separate New River bag loading plant constructed
1941/45	Construction of various facilities continued
1945	Consolidation of Radford and New River plants
1945	Production stopped-plant in standby
1946-49	Ammonium nitrate produced in Acid Area
1949	Limited resumption of powder production
1950	Plant reactivated for Korean Conflict
1950/51	Large areas of plant rehabilitated
1951	Multibase propellant and cast rocket grain facilities constructed
1967/68	Continuous TNT lines constructed
1970/72	New acid plants constructed
1971	Preproduction project work on Continuous Automated Multibase Line (CAMBL) started
1972	Continuous Automated Single-Base Line (CASBL) construction started
1972	Continuous nitrocellulose nitration construction started
1973	Military Construction, Army (MCA) pollution abatement facilities construction started
May 1974	TNT plant explosion
1976	Continuous Automated Single-Base Line M6/M1 conversion started
1978	Construction started on biological wastewater treatment plant
1980	C-line Nitrocellulose Manufacturing Area closed
1983	TNT plant reopened
1986	TNT plant placed on standby
1987	C-line Nitrocellulose Manufacturing Area reopened
December 1988	TNT plant cleanup, preparation for long-term standby
1990	Nitroglycerin facility went on line
November 1992	Pollution control system upgrade completed for explosive waste incinerators
1992	Second nitroglycerin facility went on line
January 1993	Upgrade to biological wastewater treatment plant began
1993	Explosion at nitroglycerin facility
October 1994	Operating permit approved for explosive waste incinerators
March 1995	Alliant Techsystems, Inc. buyout of Hercules complete

Source: Modified from USATHAMA, 1976

- Operation and maintenance, as directed, of active facilities in support of current operations. Maintenance and/or lay-away, in accordance with Ammunition Procurement and Supply Agency instructions, of standby facilities, including any machinery and packaged lines received from industry,in such conditions as will permit rehabilitation and resumption of production within the time limitations prescribed;
- Receipt, surveillance, maintenance, renovation, demilitarization, salvage, storage, and issue of assigned Field Service Stock and industrial stock as required or directed;
- Procurement, receipt, storage, and issue of necessary supplies, equipment, components, and essential materials;
- Mobilization planning, including review and revision of plant as required;
- Custodial maintenance and administrative functions of subinstallations; and
- Support services for tenants.

2.3.0.2. These responsibilities are met through the efforts of the operating contractor, Alliant Techsystems, Inc. The Administrative Contracting Officer (ACO) and his staff provide technical assistance and administer the contracts with the civilian operating contractors. RAAP provides logistics support for tenant activities such as the U.S. Army Research, Development and Acquisition Information Systems Agency, which is charged with performing data processing activities during peacetime.

2.4 INDUSTRIAL OPERATIONS

2.4.0.1. From 1941 to the present the principal end products produced at RAAP have been TNT, single-base and multi-base propellants, and cast and solventless propellants. Intermediate products produced are oleum (concentrated sulfuric acid), nitric acid, NG, and NC.

2.4.0.2. Production at RAAP is accomplished at the primary and secondary manufacturing areas. The primary manufacturing processes are the production of single-base and multi-base solvent propellants, cast and solventless propellants, and TNT. Separate process areas are provided for the production of solventless propellant, referred to as rolled powder. The process steps are essentially the same for the production of solvent-type single-, double-, and triple-base propellants; the major differences are in the specific chemical and explosive ingredients added. Single-base and double-base propellants may include one or more of the following chemicals: barium nitrate, potassium nitrate, ethyl centralite, graphite, carbon black, potassium sulfate, lead carbonate, dibutylphthalate, and diphenylamine. Triple-base propellants consist of ethyl centralite and potassium sulfate cryolite, while special high-energy propellants contain high melting point explosives (HMXs). The secondary manufacturing processes include the production of oleum, nitric acid, NG, and NC.

2.4.1 Propellant Production

2.4.1.1. The separate processes used in the production of the various propellants are discussed below.

- Single-base solvent propellant - In this batch process, nitrocellulose is dehydrated and mixed with appropriate chemicals and solvents for the desired blend. The mixture then undergoes a series of operations where it is shaped into a cylindrical block, extruded into strands, and cut to desired size. The solvents ethyl alcohol and ethyl ether are recovered, and the grains are water and air dried. The last major operation includes glazing, blending, and packaging.
- Multibase solvent propellant - The manufacture of the multibase solvent propellant is similar to the single base except for the addition of nitroglycerin, nitroguanidine, and other chemicals for the formulation desired. The ethyl alcohol and acetone solvents are recovered, and the mix is forced-air dried.
- Cast propellant - The manufacturing of cast propellants for rocket grains requires the mixing of nitroglycerin with triacetin, diethyl phthalate, ethyl centralite and 2-nitrodiphenylamine (2-NDPA) (depending on formulation), and a casting solvent, followed by the addition of the base grain. The rocket grain is then cast, cured, machined, assembled, and packaged.
- Solventless propellant (rolled powder) - The solventless propellant is prepared by a batch process in which nitrocellulose, nitroglycerin, and other chemicals are slurried in water, wrung to a wet cake, and dried to a paste. After the paste is blended, the mixture is rolled into sheets. The propellant is then

wound into a carpet roll for extrusion into small rocket grains. The propellant is also rolled and finished for mortar increments.

2.4.2 TNT Production

2.4.2.1. Before its destruction in May 1974, the TNT plant consisted of three manufacturing lines (A, B, and C), each with a rated capacity of 50 tons/day using the modern Canadian Industries, Limited (CIL), continuous nitration and purification process and an advanced drying, solidifying, and packaging operation. When the TNT plant reopened in 1983, the B and C lines were restored, and improved safety equipment, process equipment, and a TNT wastewater treatment facility were added. The overall volume of TNT production was reduced. Operations for fume recovery, red water concentration and destruction, waste neutralization, and spent acid recovery were located in the TNT plant area. These operations directly support the manufacture of TNT.

2.4.2.2. In the nitration process, a toluene feed stock was reacted with a mixture of nitric acid and oleum to yield a crude trinitrotoluene by using eight nitrators and eight separators connected in series for the three nitrating steps (mono, di, and tri). The crude TNT then flowed to adjacent, series-connected tanks located in the same building. The steps in the purification process involved an acid wash and two sellite (sodium sulfite) wash operations. A yellow water produced in the acid wash step was normally fed back into the No. 2 (di-) nitrator in the nitration process. The unwanted isomers removed in sellite washing produced a red water waste.

2.4.2.3. After purification, the molten TNT was mixed with water and the slurry was pumped to the finishing building. The water was then separated from the TNT and recycled to the purification process. The TNT was passed through a holding tank, then dried and flaked for packaging into cardboard cartons to a net weight of 50 pounds.

2.4.2.4. Nitrogen oxide fumes generated during nitration were exhausted and scrubbed in the fume recovery towers for recovery of the oxides as nitric acid for reuse in the process. The red water generated in the sellite TNT purification process has been disposed of by various means, including incineration in rotary kilns or sale to the paper industry. Incineration ash has been landfilled in various RAAP locations. Acid waste was processed through three tanks wherein the pH level was adjusted by the addition of soda ash (sodium carbonate). The treated effluent was then diluted with TNT Area cooling water and released to Stroubles Creek. The spent acid from the nitration process was separated by distillation into nitric acid, which was reused, and into sulfuric acid, which was concentrated at another part of the plant and sold.

2.4.3 Secondary Manufacturing Operations

2.4.3.1. The secondary manufacturing operations at RAAP are the production of oleum, sulfuric and nitric acids, nitroglycerin, and nitrocellulose, as described below:

- Oleum 40 percent is manufactured by absorbing sulfur trioxide (SO_3) in 100 percent sulfuric acid. A new plant, constructed in 1970, uses a sulfur acid regeneration (SAR) process.
- The ammonia oxidation process (AOP) is used to make weak, 60 percent nitric acid. A new plant was constructed in 1970.
- The sulfuric acid concentration (SAC) process produces 93 percent sulfuric acid, and concentrates the sulfuric acid residue from the nitric acid concentration (NAC) and TNT processes. This process was replaced by the SAR process in 1970.
- The NAC process is used to concentrate the weak nitric acid produced in the AOP plant and to recover the spent acids from the manufacture of NC and NG. This was replaced by a new facility constructed in 1970.

2.4.3.2. NG was manufactured at RAAP by both the batch and continuous (Biazzi) processes. The batch process employed three steps: nitration of glycerin to produce NG, separation, and neutralization of the NG charge. The continuous process is a fully automated controlled method in which the NG is produced by reactions similar to the batch process. In 1984, the batch process became inoperative and was replaced by a continuous process. Since 1984, only the continuous process has been operating.

2.4.3.3. The manufacture of NC starts with the preparation and air drying of cotton linters and wood pulp fibers and the preparation of mixed acid (nitric/sulfuric acid). The remaining major steps consist of nitration and purification. A dry charge of cotton linters or wood pulp fibers, depending on the type and grade of NC desired, is agitated with the mixed acid in a dipping pot. After nitration, the spent acid is separated from the NC. The raw NC from the nitration operation is stabilized by a stabilization acid boil and two neutral boils in the boiling tub house. It is then transferred to the beater house, where it is cut to suitable size and partially neutralized. Next, in the poacher house, a series of NC boils are performed; first, a soda boil neutralizes any remaining acid, then neutral boils and washes are performed to remove the soda. The NC is then screened, filtered, and washed. In the blender house, NC of various classes is mixed to produce the mixture or blend desired. The mixture is then wrung through centrifugal wringers in the final wringer house to obtain a product containing a small and uniform amount of moisture. The NC is then shipped to the green powder lines for processing into single-base solvent propellant and to the NG premix area for processing into multibase solvent and solventless propellant.

2.5 SUMMARY OF PREVIOUS INVESTIGATIONS

2.5.0.1. Various areas of RAAP have been the subject of numerous environmental investigations by government organizations and private contractors. The earliest extensive environmental studies were conducted in the early- to mid-1980's by the U.S. Army Environmental Hygiene Agency (USAEHA) and the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). USATHAMA is now known as the U.S. Army Environmental Center (USAEC). These investigations ranged in scope from site specific soil sampling studies (USAEHA, 1987), to large scale pollution abatement studies involving the installation and sampling of numerous groundwater monitoring wells (USAEHA, 1981).

2.5.0.2. As a result of a RCRA Facility Assessment conducted at RAAP (USEPA, 1987), several SWMUs were identified as having the potential for releasing contaminants into the environment. RAAP was issued a RCRA Permit for Corrective Action and Incinerator Operation by the USEPA effective December 13, 1989. As a requirement of this permit, RAAP was tasked to conduct Verification Investigations (VIs) at sites of suspected contamination, RCRA Facility Investigations (RFIs) at sites of known contamination, and Corrective Measures Studies (CMSs) at sites requiring remediation. In 1992, RAAP completed VIs for 36 solid waste management units (SWMUs) (Dames and Moore, Inc. 1992a) and RFIs for 6 SWMUs (Dames and Moore, Inc. 1992b).

2.5.0.3. A dye-trace study was conducted (spring 1994) to better identify groundwater flow paths through the karst limestone in the south-central section of the main manufacturing area (Engineering-Science, 1994b). The results of this study were used to develop the Work Plan for the RFI of SWMUs 17 and 40 (Engineering-Science, 1994a).

2.5.0.4. As a result of the findings of VIs conducted at SWMUs 17/40, 31, 48, and 54, which identified releases of contamination, Parsons ES performed RFIs on these SWMUs in December 1994 through July 1995. Those findings are presented in this report.

SECTION 3

ENVIRONMENTAL SETTING

3.1 CLIMATE

3.1.0.1. The climate of the area encompassing RAAP is classified as "moderate continental." This climate is characterized by moderately mild winters and warm summers. The prevailing winds are from the southwest, with a northerly component during the cold season. The average yearly windspeed is 8 miles per hour [NRVPDC, 1994; Dames & Moore, Inc., 1992(a)].

3.1.0.2. Tables 3.1 and 3.2 list the average monthly precipitation and temperature from four weather stations in the vicinity of RAAP. The average monthly temperature ranges from 29.6°F in January to 72°F in July, with an annual average temperature of about 52°F. Average monthly precipitation ranges from about 2.5" to 4.0" with an annual total precipitation between 36.9" and 41.5" (Virginia State Climatological Office, 1995). Class A pan evaporation was measured in the Roanoke, Virginia, area at 43" per year. Lake evaporation was measured at 32" per year in the same area. Potential evapotranspiration has been calculated at 30" per year using the Thornthwaite method (Virginia State Climatological Office, 1995). Based on these data, the net precipitation in the vicinity of RAAP ranges between 6.9" and 11.5" annually. Snowfall in the vicinity of RAAP averages 17" annually. Montgomery and Pulaski Counties lie in one of the areas of highest occurrence of dense fog in the United States. Dense fog can be expected to occur between 20 and 45 days per year.

3.2 PHYSIOGRAPHY

3.2.0.1. RAAP lies within the Valley and Ridge province of the Appalachian physiographic division. The Valley and Ridge province is characterized by a series of long, narrow, flat-topped mountain ridges separated by valleys of varying widths. Either of these landforms may predominate; the mountains may be widely spaced and isolated or so closely spaced that the lowlands are disconnected or absent. A distinctive feature of the installation area is the absence of mountain ridges.

TABLE 3.1

AVERAGE MONTHLY PRECIPITATION (1961-1990) FOR LOCATIONS NEAR RAAP

Station	Location Latitude	 Longitude	Annual Precipitation (Inches)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blacksburg	37°11'N	80°25'W	40.91	2.76	2.89	3.56	3.62	4.04	3.41	4.01	3.77	3.51	3.63	2.89	2.82
Pulaski	37°03'N	80°45'W	36.93	2.28	2.66	3.05	2.84	3.81	3.45	3.92	3.29	2.99	3.34	2.57	2.73
Staffordsville	37°16'N	80°43'W	37.54	2.53	2.73	3.12	3.31	3.66	3.21	3.95	3.50	3.17	3.12	2.67	2.57
Floyd	37°56'N	77°27'W	41.45	2.67	2.97	3.68	3.58	3.94	3.34	3,85	3.40	3.83	4.01	3.48	2.70

Source: Virginia State Climatological Office, 1995

TABLE 3.2

AVERAGE MONTHLY TEMPERATURES (1961-1990) FOR LOCATIONS NEAR RAAP

Station	Location		Average Annual Temp (°F)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
	Latitude	Longitude													
Blacksburg	37°11'N	80°25'W	51.0	29.6	32.4	41.8	50.5	59.2	66.8	70.6	69.6	63.1	51.9	43.2	33.8
Pulaski	37°03'N	80°45'W	51.9	31.0	33.4	42.4	50.9	60.3	67.7	71.3	70.2	63.7	53.0	43.7	35.3
Staffordsville	37°16'N	80°43'W	53.1	32.1	35.3	45.1	53.3	61.1	68.0	72.0	70.8	64.6	53.7	44.9	36.4
Floyd	37°56'N	77°27'W	51.3	31.3	34.2	42.8	50.9	59.1	66.0	69.6	68.6	62.5	52.0	43.2	34.8

Source: Virginia State Climatological Office, 1995

3.2.0.2. The topography within the installation varies from a relatively flat floodplain to elevated uplands in the extreme southeast section (Figure 2.3). The New River forms the RAAP boundary on the north, with the elevation approximately 1,675 feet above mean seal level (msl). The eastern boundary represents a transition from floodplain elevation (1,680 feet msl) to an elevation of 1,900 feet msl in the upland. The southern boundary traverses terrain consisting of creek bottoms and sharply rising summits. The western boundary follows the bluff line overlooking the New River to a point where the Norfolk and Southern Railroad crosses the lower arm of the Horseshoe Area. This facility displays an overall relief of 342 feet. In the Horseshoe Area to the north and east, the New River has a narrow floodplain. Just west of the Waste Propellant Burning Ground, the floodplain is terminated by steep bluffs that extend westward to the plant boundary. The Horseshoe Area exhibits rolling karst terrain, with three prominent terraces and escarpments that are remnants of ancient New River floodplains.

3.2.0.3. RAAP contains prominent karstic features including sinkholes, caves and caverns. Karst landforms occur in carbonate rock formations as the result of the dissolution of rock by naturally occurring carbonic acid in rainwater. As the rock is dissolved, cavities or caverns are formed beneath the earth's surface. Occasionally, large caverns collapse producing a depression or sinkhole on the surface. Numerous sinkholes are apparent along the western and southern boundaries of the facility.

3.3 LAND USE/DEMOGRAPHICS

3.3.0.1. Because of the steep terrain, the area surrounding RAAP has not been highly developed. Land use in the vicinity of RAAP has been mostly rural; the less rugged areas are primarily used for agriculture. The Jefferson National Forest is located approximately two miles north of the facility. The majority of land in the New River Valley, which includes Montgomery, Pulaski, Giles, and Floyd Counties as well as the city of Radford, is forested. Only 38 percent of the area of the New River Valley is classified as nonforest land, including agricultural land, developed land, and water acreage (NRVPDC, 1994). The Blacksburg, Christiansburg VPI Water Authority owns four parcels of land adjacent to RAAP. There are approximately 200 private residences located adjacent to RAAP (Dames & Moore, 1992b). The largest substantial development, Fairlawn, is located about two miles southwest of the facility boundary. The city of Radford, with a population of 15,940 in 1990, is located about four miles southwest of the facility. Urbanization greatly

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influences the population density in the vicinity of RAAP. The city of Radford has 1,626 persons per square mile, while Montgomery and Pulaski Counties have population densities of 190 and 108 persons per square mile, respectively (NRVPDC, 1994).

3.3.0.2. Between 1960 and 1980, Montgomery and Pulaski Counties experienced strong population growth. Montgomery County continues to show the strongest population growth in the New River Valley. Population projections indicate a general decrease in population growth rate for the New River Valley through 2010 (Table 3.3). The median age within individual jurisdictions in the New River Valley varies between 22 years old for the city of Radford, to 38.1 years old for Giles County. The median age for Montgomery County (25.6 years old) and the city of Radford is lowered by the concentration of college students in these jurisdictions.

3.4 REGIONAL SOILS

3.4.0.1. RAAP is underlain by 10 predominant soil types as mapped by the Soil Conservation Service (SCS, 1985a; 1985b). The identified SCS soil types are discussed in detail in the following subsections. Site specific information concerning soil types was obtained from a soil background metals study completed for the RFI. The study, which is described in Subsection 4.4, was undertaken to derive background concentrations of metals in unimpacted site soils. Background soils were collected to reproduce the soil types and depths sampled during previous investigations to allow valid comparisons between naturally occurring background metals and concentrations in soils from any SWMU. A review of previous sampling investigations revealed that only three soil types covered all the areas of concern across the site. Therefore, only the Wheeling Sandy Loam, the Braddock Loam, and the Unison-Urban Land Complex soils were sampled for the background study. Figure 3.1 presents the SCS soil types covering the facility, the relative SWMU locations, and the background sampling locations.

3.4.1 Soil Type 1: Fluvaquents

3.4.1.1. Fluvaquents consist of soils on long-narrow floodplains. The soils are more than 60 inches deep to bedrock and have a seasonal high water table at or near the surface. Slopes range from 0 to 2 percent. The soil is unconsolidated, stratified alluvium with varied

ff

TABLE 3.3

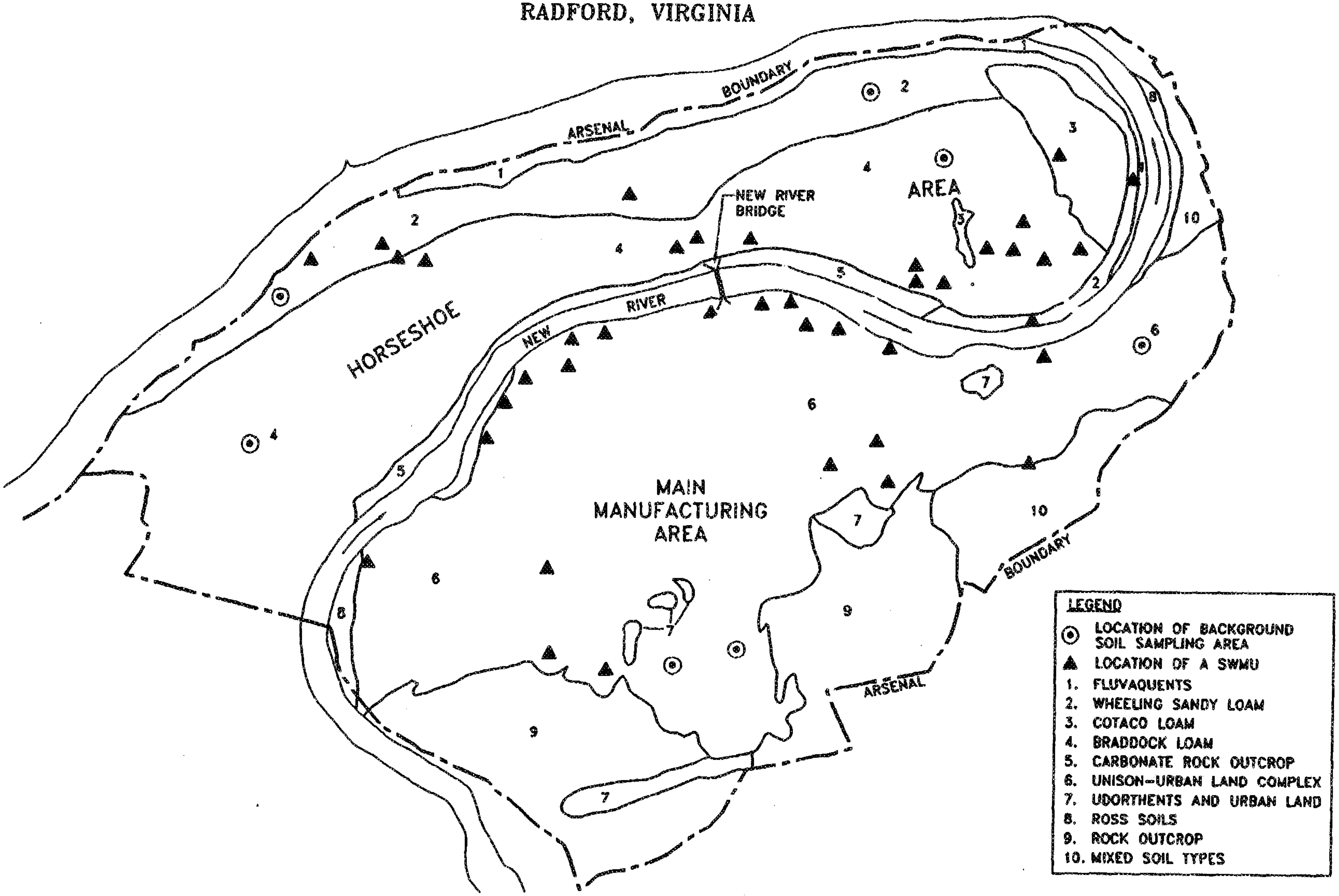
POPULATION IN VICINITY OF RAAP

Jurisdiction	1980	Percent Change (1970-1980)	1990	Percent Change (1980-1990)	2000[a]	Percent Change[a] (1990-2000)	2010[a]	Percent Change[a] (2000-2010)
Montgomery Co	63,516	34.7	73,913	16.4	79,604	7.7	83,915	5.4
Pulaski Co	35,229	19.2	34,496	-2.1	34,206	-0.8	34,198	0.0
City of Radford	13,225	14.0	15,940	20.5	17,203	7.9	17,999	4.6
Floyd Co	11,563	18.3	12,005	1.0	12,459	3.8	12,898	3.5
Giles Co	16,741	6.4	16,366	-1.0	16,121	-1.5	16,042	-0.5

(a) Projected

Source: Virginia Population Projections, 1993

FIGURE 3.1
SOIL TYPES AND SWMU LOCATION MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



BASE MAP SOURCE: USATHAMA 1976, AS CITED IN DAMES & MOORE, 1992

SOIL DATA SOURCE: SOIL CONSERVATION SERVICE, SOIL SURVEY OF MONTGOMERY CO., VA (1985) AND PULASKI CO., VA (1985).

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texture typically including layers of gravel. At RAAP, this soil type is found in a narrow strip along the floodplain at the northern boundary of the Horseshoe Area.

3.4.1.2. The surface of this soil type is often strewn with debris deposited during flooding. Reaction, permeability, available water capacity, natural fertility, organic matter content, and other chemical and physical properties are variable in this soil type.

3.4.2 Soil Type 2: Wheeling Sandy Loam

3.4.2.1. The Wheeling Sandy Loam soil is level to nearly level (slopes ranging from 0 to 2 percent) and is at least 60 inches deep to bedrock. The seasonal high water table is not within six feet of the surface. Typically, the surface layer is a 10-inch-thick, dark-brown-sandy loam underlain by a 42-inch-thick subsoil. The upper 23 inches of the subsoil is dark brown sandy clay loam, and the lower 19 inches is dark brown sandy loam. The substratum is dark brown gravely sandy loam to a depth of 60 inches or more. This soil type comprises about 25 percent of the upland regions of the Horseshoe Area at RAAP.

3.4.2.2. The permeability and available water capacity of the Wheeling soil is moderate; surface runoff is slow. The soil is medium in natural fertilizer, moderately low in organic matter content, and moderately to strongly acidic. The hazard of erosion is slight. The Wheeling soil is prime farmland and is very well suited to cultivating crops.

3.4.2.3. During the soil background metals study, these soils were sampled throughout the Horseshoe Area. The lithology of the upper 60 inches of the background soil samples generally corresponded with the description of the Wheeling Sandy Loam as given above. At greater than 60 inches in depth, the soils are predominantly a mixture of silt and sand, with minor amounts of clay. SWMU 31 and SWMU 54 are underlain by the Wheeling Sandy Loam. The soils sampled at SWMU 54 contained a relatively high percentage of sand, and are generally characterized as silty sand. The background samples from the Wheeling Sandy Loam appeared to correlate well with the soils from SWMU 54 and SWMU 31. Some SWMU 31 samples contained relatively more silt and clay in the upper 15 feet, and displayed a sand and gravel layer at about 15 feet below ground surface (bgs).

3.4.3 Soil Type 3: Cotaco Loam

3.4.3.1. The Cotaco Loam soil has a variable slope between 0 and 15 percent. The seasonal high water table is at a depth of about 2.5 feet; it is more than 60 inches deep to bedrock. The surface layer is typically a 9-inch-thick layer of brown loam. The subsoil, which extends to a depth of 60 inches or more, is yellowish-brown loam and clay loam and is mottled. This soil type is found in a small area near the eastern end of the Horseshoe Area at RAAP.

3.4.3.2. The permeability of the Cotaco soil is moderate, natural fertility is low, and organic matter content is moderately low, available water capacity is moderate. The less steeply sloped areas of this soil are prime farmland and are well suited to cultivate crops grown in the area. The permeability of this soil causes a hazard of seepage in landfills.

3.4.4 Soil Type 4: Braddock Loam

3.4.4.1. The Braddock Loam soil has a variable slope between 2 and 30 percent. This soil is more than 60 inches deep to bedrock and does not have a seasonal high water table within six feet of the surface. At RAAP, the Braddock Loam comprises about 70 percent of the up-land regions of the Horseshoe Area. Typically, the surface layer is a dark yellowish-brown loam, seven inches thick. The subsoil, which is a yellowish-red and red clay, extends to a depth of 60 inches or more.

3.4.4.2. The permeability of the Braddock Loam soil is moderate, natural fertility is low, and organic matter content is moderately low. The soil is acidic or very strongly acidic. The less steeply sloped areas of this soil are prime farmland and well suited to all locally grown cultivated crops.

3.4.4.3. During the soil background metals study, these soils were sampled throughout the Horseshoe Area. Although the lithology of the upper 60 inches of the background soil samples collected did not corresponded well with the description of the Braddock Loam as given above, the background samples collected did correlate well with the soils observed at SWMU 48. SWMU 48 is underlain by the Braddock Loam. Specifically, both areas are predominantly underlain by red-brown to orange-brown silt with some sand and clay. At depth, variable amounts of a red-brown to orange-brown clay-rich layer was observed.

3.4.5 Soil Type 5: Carbonate Rock Outcrop

3.4.5.1. This unit consists of steep and very steep soils and rock outcrop. The depth of bedrock is between 10 and 40 inches. At RAAP, this unit forms a narrow strip along the slopes of the southern boundary of the Horseshoe Area. The area of this unit is made up of about 50 percent rock outcrop and 50 percent soils. Typically the soils are a yellowish-brown silty clay loam about seven inches thick. The subsoil is strong brown clay, 26 inches thick. Limestone or dolomite bedrock is typically at a depth of 31 inches.

3.4.6 Soil Type 6: Unison-Urban Land Complex

3.4.6.1. This complex of soils varies in slope from 2 to 25 percent. The Unison-Urban Land Complex consists of about 50 percent deep and well drained Unison soils, 30 percent Urban land, and 20 percent other soils. This complex makes up about 70 percent of the surface area in the Main Manufacturing Area of RAAP. In an undisturbed area, the Unison soils have a surface layer of dark brown loam about 15 inches thick. The subsoil is a yellowish-red, sticky plastic clay about 43 inches thick, this layer is underlain by a red sandy clay loam to a depth of 58 inches. Urban land is land covered by pavement or structures; the original soil has been so altered or obscured that classification is not practical.

3.4.6.2. Permeability is moderate in Unison soils, natural fertility is low, and organic matter content is low to moderate. The soil is medium to strongly acidic. Cultivation of various vegetables is good in this soil; crop production is limited in disturbed areas.

3.4.6.3. During the soil background metals study, these soils were sampled throughout the Main Manufacturing Area. The lithology of the upper seven feet of the background soil samples collected consisted primarily of brown to red-brown clay with some silt and sand. This composition corresponds well with the above description of the Unison Soils. This clay-rich layer is typically underlain by a brown sand to about 10 feet bgs, which then grades into a brown clay. The Unison-Urban Land Complex soils observed at SWMU 17 consisted of a brown to yellow-brown clay-silt mixture which was often directly over the weathered bedrock. The SWMU 17 soils sampled generally correlated with the background soil samples collected from this soil type.

3.4.7 Soil Type 7: Udorthents and Urban Land

3.4.7.1. This soil class is about 45 percent Udorthents, 30 percent Urban Land, and 25 percent other soils. Udorthents are soils with variable characteristics. The surface layer is 5-15 inches thick and variable in color and texture. This soil type comprises less than 10 percent of the surface area in the Main Manufacturing Area of RAAP.

3.4.7.2. Permeability of Udorthents ranges from slow to moderately rapid. Other physical and chemical characteristics are also variable.

3.4.8 Soil Type 8: Ross Soils

3.4.8.1. Ross Soils are deep, nearly level and well drained. These soils are on levees and floodplains adjacent to streams and are commonly flooded for very brief periods. This soil makes up less than 5 percent of the area of the Main Manufacturing Area of RAAP, along the New River. Typically, the surface layer is a dark brown loam about 10 inches thick. This layer is underlain by brown loam to a depth of 35 inches.

3.4.8.2. Permeability is moderate in Ross Soils, natural fertility, and organic matter content is high. Depth to bedrock is more than 60 inches. The soil is slightly acidic to moderately alkaline. Cultivated crops are well suited to these soils.

3.4.9 Soil Type 9: Caneyville-Opequon-Rock Outcrop Complex

3.4.9.1. This complex consists of about 30 percent Caneyville soils, 25 percent Opequon soils, 20 percent rock outcrop, and 25 percent other soils. This complex comprises about 15 percent of the main manufacturing area at RAAP and is found in the undeveloped areas at the southern portion of this facility. The Caneyville soils have a brown silt loam surface layer about eight inches thick. The subsoil is a yellowish-red plastic clay about 24 inches thick. This is underlain by a limestone bedrock at a depth of about 32 inches. The surface layer of the Opequon soil is a brown plastic silty clay loam about 4 inches thick. The subsoil is a yellowish-red very plastic clay about 11 inches thick. Limestone bedrock is at a depth of about 15 inches. Rock outcrop consists of limestone and dolomite.

3.4.9.2. Permeability is moderately slow in both the Caneyville and Opequon soils. Natural fertility and organic matter content is moderate for both soils. Cultivated crops are poorly suited for these soils; they are used mainly for woodland.

3.4.10 Soil Type 10: Mixed Soil Types

3.4.10.1. This undeveloped region consists of a variety of soil types comprising about five percent of the Main Manufacturing Area at RAAP. These soils have variable profiles and variable physical and chemical characteristics.

3.5. REGIONAL GEOLOGY

3.5.0.1. In June 1995, Parsons ES performed a mapping project of the complex geological structural features at RAAP. This effort was done to supplement the existing geologic data for the area and to address site specific deficiencies in the geologic database. Although the area surrounding RAAP has been mapped geologically in detail (Schultz, VDMR open file in preparation), the facility itself had not previously undergone rigorous geologic mapping due to the inaccessibility associated with high security restrictions. The results of the research and mapping associated with this project are included in this section.

3.5.1 Regional Geology of the Southern Appalachian Valley and Ridge Province

3.5.1.1. RAAP is located in the Valley and Ridge Physiographic Province of southwestern Virginia. This province consists of closely spaced valleys and ridges that are directly related to folds in the underlying Paleozoic sequence of rocks. A nearly complete 4000 meter thick section of Cambrian through Pennsylvanian age sedimentary rocks is present in the Valley and Ridge province. Therefore, this area displays a reasonably complete history of the Paleozoic Era, from 550 to 300 million years ago. This history includes a series of sea level transgressions and regressions, as well as at least two major orogenic (mountain building) events. The transgressions are recorded by the deposition of marine sediments (carbonates/dolomite) and the regressions are evidenced by clastic deposition. The orogenic events are recorded by deformation (faulting, folding and cleavage) in the rocks.

3.5.1.2. From the Cambrian through Ordovician periods, primarily carbonates were deposited in the area that became the Valley and Ridge province. These rocks record the presence of a shallow warm sea, much like the present day Caribbean, extending from eastern Canada through Alabama. During this time, the east coast of North America was rotated parallel to, and within 15 degrees of the equator. A series of clastic (terrestrial) sedimentary rocks with minor amounts of carbonate were deposited from the Late Ordovician through Pennsylvanian periods. Most of RAAP is underlain by Cambrian-aged carbonates and clastic rocks of the Elbrook Formation and similar rocks of Ordovician age. Much younger Mississippian-aged shales and mudstones of the Mccrady/Price Formations are also present at RAAP.

3.5.1.3. All of the rocks of the Valley and Ridge display evidence of Paleozoic deformation. The first deformational episode began in the Mid-Cambrian and lasted through the Devonian period. This compressional event was responsible for the formation of the Blue Ridge Mountains, located immediately east of the Valley and Ridge province. However, little evidence of this Early Paleozoic deformational event is preserved in the rocks of the southern Valley and Ridge province. Therefore, the rocks at RAAP display little evidence of this deformational episode. Most of the extensive folding and faulting observed in the southern Valley and Ridge province is attributed to the Late Paleozoic Alleghanian orogenic event. This event was caused by the collision of North America with a another major land mass to the east in the Mid-Pennsylvanian period. The folds and faults in the southern Valley and Ridge were caused by an extended period of compression resulting in a series of deformational events.

3.5.1.4. During the Mesozoic Era, eastern North America experienced extension related to the opening of the proto-Atlantic Ocean. This extensional event produced the Mesozoic rift valleys to the east, such as the Culpeper Basin in Fairfax County. These basins filled with lacustrine and terrestrial sediments, leading to deposition of the characteristic red beds and black shale layers. Occasionally these beds contain abundant dinosaur footprints. From the Mesozoic Era to the present, the Valley and Ridge province has experienced gentle uplift and constant erosion.

3.5.2 Structural History of the Southern Appalachian Valley and Ridge Province

3.5.2.1. The structure of the Valley and Ridge province from southern Virginia to Tennessee is extremely complex due to the presence of extensive thrust faulting. The Valley and Ridge province north of this area is relatively unfaulted and consists of a series of northeast trending folds. Commonly these folds have overturned northwest limbs. In the south, faulting and folding occurred simultaneously, producing a series of northwest directed thrust faults. These thrust faults are often folded, and cut through preexisting folds. The large scale faults and folds in the study area were produced throughout the Late Paleozoic orogenic event.

3.5.2.2. In the Blacksburg area, east of RAAP, Early Paleozoic folds (categorized as F1 folds) have been described (Bartholomew and Lowry, 1979). These F1 structures include isoclinal folds with axial planar foliation apparent in the Rome Formation. These folds are typically stretched out and sheared so that the axial-plane foliation approximately parallels bedding in most exposures.

3.5.2.3. Middle- to Late Paleozoic deformation is apparent in the rocks exposed at RAAP. At the outcrop scale, this deformation takes the form of tight folds (F2) which have refolded the F1 folds. F2 folds are commonly associated with well developed slip cleavage in the Rome Formation (Bartholomew and Lowry, 1979). The F2 structures include several generations of isoclinal, asymmetric, sometimes overturned folds (Bartholomew and Lowry, 1979).

3.5.2.4. The Late Paleozoic deformational event produced the Pulaski thrust fault in post-Early Mississippian time as a result of northwest-directed shortening. The Pulaski thrust is the largest of several major southeast-dipping Alleghanian thrusts of the southern and central Appalachians (Schultz, 1988). It has been traced along strike approximately 310 miles (500 km) from near Staunton, Virginia, southward into Tennessee where it is overridden by rocks of the Blue Ridge thrust sheet. Based on seismic data, the Pulaski thrust originated well below the Blue Ridge thrust and extends into the Precambrian basement. Estimated displacement of the thrust near Radford ranges from 15 km to 50 km (Bartholomew and Lowry, 1979). At RAAP, Cambrian rocks are thrust over rocks of Mississippian age. Thus, the maximum age of thrust emplacement is Mississippian. The maximum thickness of the Pulaski thrust sheet ranges from 1500 m to 4000 m. The decollement (detachment) of this thrust sheet is within shales and dolomites of the Lower Cambrian Rome formation. The Pulaski thrust sheet includes a series of imbricated (shingle-like) thrusts that record several periods of movement during the Late Paleozoic. Rocks of the Pulaski thrust sheet have typically undergone two-stages of Alleghanian deformation. The first stage involved decollement and ramp thrusting on Mississippian strata. The second stage involved folding and faulting of the thrust sheet. The second stage of deformation involved large-scale (several mile-long) folding resulting in broad east-west trending antiforms and synforms that warped the Pulaski thrust sheet. Most of RAAP lies above the Pulaski thrust fault. At several locations, including at RAAP, the Cambrian rocks in the Pulaski thrust sheet have been eroded away to display the younger Mississippian aged rocks below (windows). The older deformed rocks represent rootless tectonic slices of basement material (horses) that lie above relatively less deformed younger rocks.

3.5.2.5. Rocks of the Pulaski thrust sheet display low grade (lower greenschist facies) regional metamorphism as evidenced by conodont color alteration indicating a maximum temperature range of 300-400° C. Chlorite and muscovite occur in carbonates near the base of the Pulaski thrust sheet and were probably derived from clay minerals during regional metamorphism. The fault surface is rarely exposed. In the vicinity of RAAP, evidence of the close proximity to the thrust fault takes the form of tectonic breccia.

3.5.3 Geology of RAAP

3.5.3.1. RAAP is located in the New River Valley, at the northwest terminus of the southern Valley and Ridge province. The New River crosses the Valley and Ridge province approximately perpendicular to the regional strike of bedrock and it chiefly cuts Cambrian and Ordovician limestone and dolomite. The valley is covered by river flood plain and terrace deposits; karst topography is dominant. Deep clay-rich residuum is prevalent in areas underlain by carbonate rocks. Karst features include sinkholes, caverns and springs caused by the dissolution of calcium carbonate by naturally occurring carbonic acid in rainwater. The greatest areas of karst features are controlled by bedrock stratigraphy and structure, and by the presence of major drainages. Late Cambrian and Mid-Ordovician limestones are more soluble than Cambrian and Lower Ordovician dolomite and shaley dolomite; therefore, they have the greatest number of sinkholes and caverns. However, both rock types show increased karst development in areas of; low bedrock dip, where bedding is intensely folded, cleaved or jointed, and near major drainages.

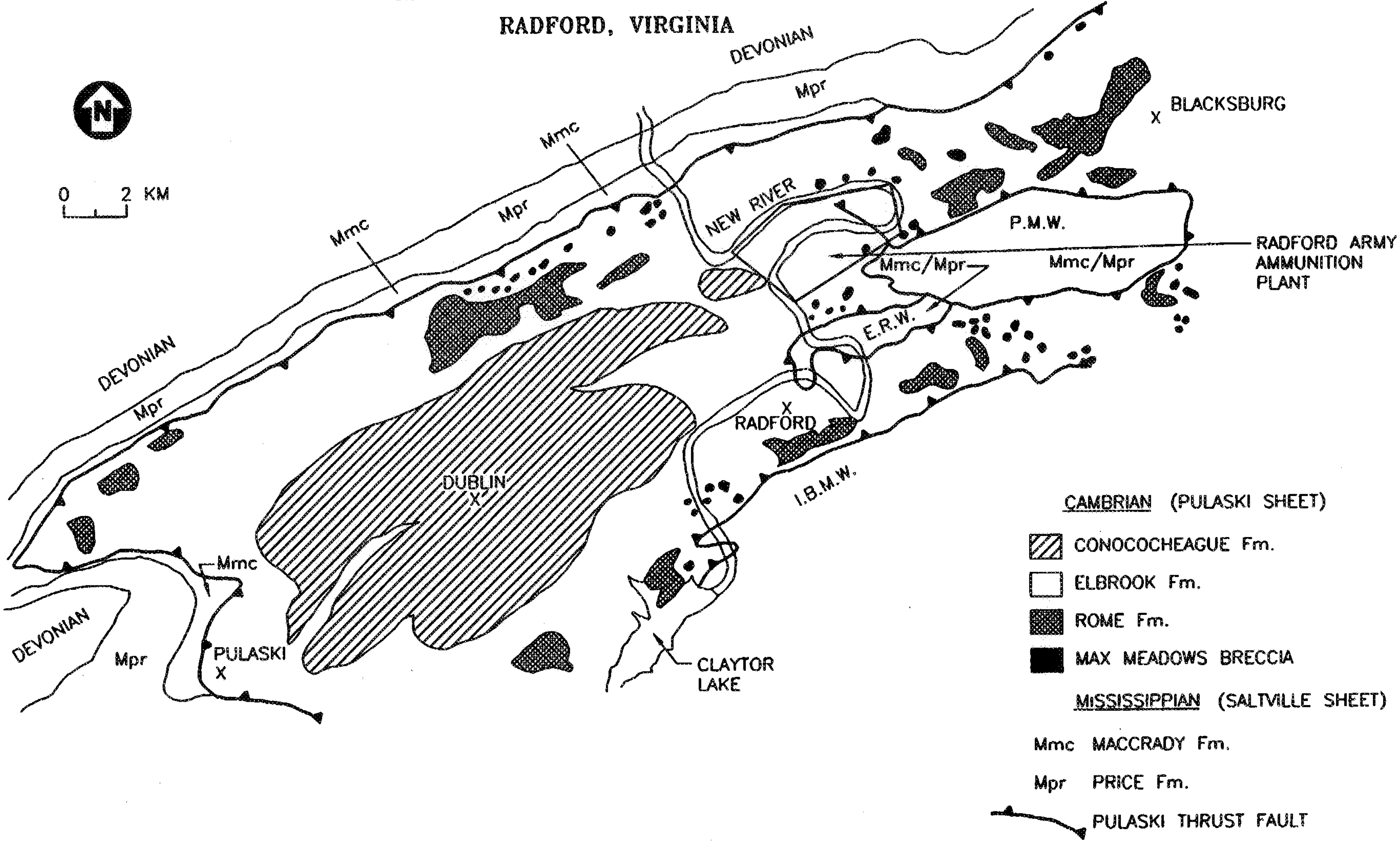
3.5.3.2. As shown in Figure 3.2, RAAP occupies the central portion of the Pulaski fault thrust sheet (Schultz, 1988). RAAP is underlain by four major rock units and one unconsolidated sedimentary unit that range in age from Cambrian to Quaternary. The rock units are: Cambrian Formations (Elbrook, Rome, and Conococheague) and Mississippi Formations (Mccrady/Price). Only the Elbrook and Mccrady/Price Formations outcrop at RAAP. Dip of the rock units varies over RAAP from nearly horizontal to nearly vertical. However, typical dips are in the range of 20 to 30 degrees. The unconsolidated sediments are of Quaternary age and include alluvial, residual, and colluvial deposits. Table 3.4 is the legend to Figure 3.3, a geologic map of the major consolidated rock formations at RAAP. The consolidated and unconsolidated formations at RAAP are described below (USAEHA, 1980).

3.5.3.3. The *Elbrook Formation* is a major rock unit cropping out at RAAP. This Formation is composed of thickly bedded, blue-gray dolomite interspersed with blue-gray to white limestone; brown, green, and red shale; argillaceous limestone; and brecciated limestone (colors range from mottled light- to dark-gray and yellow-brown). Sinkholes, solution channels, pinnacled surfaces, and springs are common to the Elbrook. This Formation ranges from 1,400 to 2,000 feet thick. The strike of bedding in the Elbrook Formation is variable throughout the region. The general orientation of bedding is seen in the nearly east-west alignment of sinkholes at RAAP and the surrounding area. Most sinkholes in the area are oval shaped and elongated with respect to the strike of the bedding; they most likely represent fractured or faulted zones within the underlying Elbrook Formation.

3.5.3.4. The *Rome Formation* underlies the Elbrook Formation; however, the Rome does not crop out at RAAP. This Formation is composed of red and green shales, sandstone, dolomite, and limestone. The red shales commonly mark the basal unit. Thickness ranges from 1,000 to 2,000 feet.

3.5.3.5. The *Conococheague Formation* overlies the Elbrook Formation and is composed of limestone, dolomite, and sandstone. It ranges in thickness from about 2,200 feet to 1,700 feet. This unit does not crop out within RAAP.

FIGURE 3.2
GEOLOGIC MAP OF THE PULASKI THRUST SHEET IN THE VICINITY OF RAAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



NOTE:
P.M.W., PRICE MOUNTAIN WINDOW; E.R.W., EAST RADFORD WINDOW, I.B.M.W., INGLES-BARRINGER MOUNTIAN WINDOW. FIGURE MODIFIED AFTER A. SCHULTZ (1983).

TABLE 3.4

LEGEND TO THE BEDROCK GEOLOGIC MAP of the RADFORD ARMY AMMUNITION PLANT

Rock Characteristics[1]

Paleozoic	Mississippian	Mmc/ Mpr	Lower Mccrady Fm., sandstones overlain by mottled maroon and green mudstones. Upper Price Fm., mottled maroon and green mudstones underlain by dark gray to black mudstone and coal.
	Devonian	Db	Brailler Fm., interbedded sequence of dark-gray to black mudstone, medium-gray siltstone and fine-grained commonly crossbedded sandstone.
	Ordovician	Oku	Undivided Knox Group, light- to medium-gray, massive, thick-bedded, fine- to medium-grained dolomite interbedded with massive to layered gray chert.
	Cambrian	[illegible]	Max Meadows tectonic breccia, poorly sorted angular to subrounded clasts of dolomite and calcareous mudstones in a fine- to very fine-grained matrix of crushed dolomite.
		[illegible]	Conococheague Fm., limestones, dolomite, and sandstone. The Formation is approximately 2000 feet thick.
		Ce	Elbrook Fm., cyclic sequences of medium-gray, finely laminated, fine-grained dolomite. Limestone units range up to 50 feet in thickness. The percentage of limestone diminishes downward.
		Cr	Rome Fm., interbedded mottled maroon and green phyllitic mudstone, fine-grained sandstone and siltstone, and dark-gray, fine-grained dolomite.

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[1] Lithologic contacts for areas outside of RAAP modified after A. Schultz (VDMR open file in preparation). Lithologic descriptions modified after Bartholomew and Lowry (1979).

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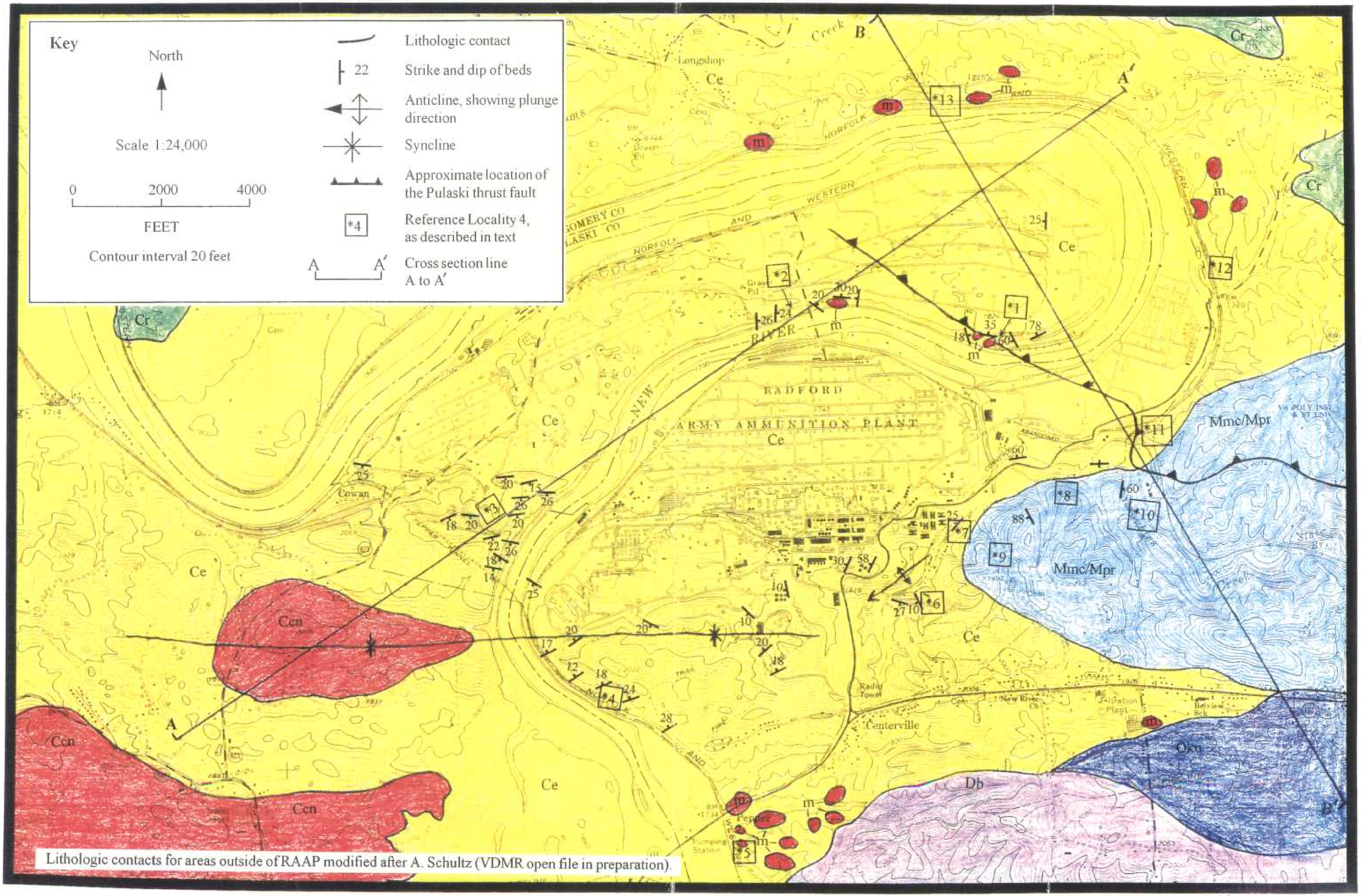
FIGURE 3.3 BEDROCK GEOLOGIC MAP OF THE RADFORD ARMY AMMUNITION PLANT



Lithologic contacts for areas outside of RAAP modified after A. Schultz (VDMR open file in preparation).

3.5.3.6. Mississippian rocks of the *Mccrady/Price Formations* outcrop in a fenster (window) east of the main plant area along Stroubles Creek. This Formation consists of mottled red and green shale and mudstone interspersed with brownish-green siltstone and sandstone. The Formation may be up to 1,500 feet thick.

3.5.3.7. The *Max Meadows tectonic breccia*, which is evidence of the close proximity of the Pulaski fault surface, was observed within and in the vicinity of RAAP. This tectonic breccia consists of poorly sorted, angular to subrounded clasts of massive dolomite, laminated dolomites, and finely-laminated greenish gray calcareous mudstones in a fine- to very fine-grained matrix of crushed dolomite. Clasts range from less than 1 inch to more than 3 feet in length. The breccias are massive to crudely layered and are well to poorly indurated. The breccia, which is most fine-grained along the fault contact (Schultz, 1986a), is an integral part of the highly deformed rocks along the base of the Pulaski thrust sheet. Tectonic breccia has been described along the entire strike (310 miles) of the Pulaski thrust sheet. The tectonic breccia which occurs well above the basal Pulaski fault surface (up to 900 feet above), decreases in abundance away from this contact. The breccia probably formed by cataclastic (brittle) deformation associated with the emplacement of the Pulaski Fault. The clasts have undergone rigid-body rotation and size reduction within a fine-grained deformed dolomite matrix. The breccia typically exists as either sill-like bodies parallel to bedding that may be folded, or as dike-like bodies that truncate bedding. These bodies display irregular map patterns and may range in scale from less than 1 inch to several hundred feet in width. Schultz (1986a) describes specific outcrops of the Max Meadows tectonic breccia in the vicinity of RAAP.

3.5.3.8. Figure 3.3 summarizes the geologic mapping conducted at RAAP by Parsons ES. The majority of this facility is underlain by the Elbrook Formation. Small-scale folds and faults are apparent on virtually all rock exposures within the facility. Bedding strike and dip measurements are displayed on Figure 3.3. A large-scale syncline is present trending east-west in the western region of RAAP. A large-scale anticline is apparent plunging to the southwest in the southeastern region of the plant. The Max Meadows breccia, which was observed in abundance in the southeastern region of the horseshoe area, is interpreted as evidence of the close proximity of the Pulaski thrust fault surface. Therefore, this significant subsurface feature controlling structural and hydrogeological activity, is present on site. Previous work did not extend the fault through the site (Schultz, VDMR open file in preparation). Thirteen Reference Localities are identified on Figure 3.3. Table 3.5 summarizes field data and observations for each of these Reference Localities. Geologic cross-sections A-A' and B-B' are presented in Figures 3.4 and 3.5, respectively. These cross-sections demonstrate the structural complexity of this region. Note in these figures that the Elbrook Formation within RAAP has been thrust upon younger Mississippian-aged rocks. All of these rocks were then folded into broad anticlines and synclines, which have wavelengths on the order of 10,000 to 12,000 feet. The folds were then eroded. The thrust sheet has been breached by erosion, exposing Mississippian sandstones and shales of the McCrady/Price Formation in a fenster east of the main plant area, along Stroubles Creek (Figures 3.3 and 3.5). Figures 3.6 and 3.7 are photographs that correspond with Reference Localities described in Table 3.5. The outcrop cross-sections in Figure 3.8 also correspond with Reference Localities described in Table 3.5.

3.5.3.9. Unconsolidated sediments (overburden) mantle the major portion of RAAP. These include alluvial plain sediments deposited by the New River prior to entrenchment, residual deposits from in-place weathering of parent bedrock, and colluvial deposits developed by residual slope wash. Alluvial plain deposits commonly line the New River and Stroubles Creek; some as recent floodplain material and some as geologically older terraces. Table 3.6 is the legend to Figure 3.9 which displays the location of river terrace deposits in the vicinity of RAAP. This figure also summarizes structural data outside of RAAP as presented by Schultz (VDMR open file in preparation). On the horseshoe loop, three terraces are evident. In general, there is a textural fining upwards in these terrace deposits. Gravels and silty, clayey sands form the basal unit. These are overlain by finer micaceous silts and clays. Sporadic cobbles and boulders (known as river jack) occur as lenses throughout the alluvial strata. Thickness of the alluvial deposits varies from a few feet to 50 feet, with an average of 20 feet. Residual deposits (clays and silts) are a result of chemical and physical weathering of the parent bedrock (primarily Elbrook dolomite at RAAP). Most of RAAP is covered by residual deposits. In most cases along the New River and in the Horseshoe Area, these residual deposits underlie the alluvium, except where the residuum has been eroded to bedrock and replaced by alluvium. The depth of the overburden varies from a few feet to 70 feet.

3.5.3.10. Colluvial deposits are generally formed from mass-wasting of slopes and escarpments. In general, these deposits are a heterogeneous mixture of alluvium, residuum, and rock debris that has moved from its original position. These deposits are generally interbedded between the strata of alluvium and residuum; thickness is variable.

TABLE 3.5

REFERENCE LOCALITY DESCRIPTION

Reference Locality 1	Several isolated outcrops of the Elbrook Formation and Max Meadows Breccia along hillside between SWMU 48 and SWMU 13. Orientation of bedding in the Elbrook varies due to small scale folding; however, bedding is generally oriented N40°W, 30 NE. Joints are apparent in some outcrops. The Max Meadows Breccia displays a distinctive brown-red weathering pattern with many voids (solution channels). This unit consists of angular and subrounded dolomite clasts in a well indurated fine-grained dolomite matrix. 8 to 12 foot tall pinnacles of the breccia with extensive solution channels are present approximately 400 feet west of Reference Locality 1. The breccia in this region was not observed in direct contact with the Elbrook.
Reference Locality 2	Series of hillside outcrops of the Elbrook Fm. west of the New River bridge in the horseshoe area. Thick to thinly bedded, gray to brown limestone with bedding generally oriented N10°E, 24SE. Deformation in the limestone is less intense than in the vicinity of Reference Locality 1. Localized areas of breccia are present which grade to relatively undeformed limestone. East of Reference Locality 2, about 800 feet east of the New River bridge, an antiform trending N10°E is apparent. Relatively undeformed dolomite is present in the upper beds near the crest off the antiform, while breccia is observed in the underlying beds near the core of the antiform.
Reference Locality 3	Numerous exposures of the Elbrook are displayed in the vicinity of Reference Locality 3, within the ballistics test area. These exposures are found along the roadsides and at the tops of the limestone cliffs overlooking the New River in this region. Thinly bedded to laminated fissile, tan to light-gray, limestone with bedding generally oriented N80°W, 26SW is present along the roadsides in the ballistics test area, east of Reference Locality 3. Outcrops at the cliff tops south of Reference Locality 3 consist primarily of gray thin to medium bedded micritic limestone, with bedding generally oriented N60°W, 30SW. Minor amounts of deformation is apparent in the Elbrook in this vicinity. Rocks in this area represent the northern limb of a large scale syncline that bisects the western region of RAAP.

TABLE 3.5

REFERENCE LOCALITY DESCRIPTION (CONTINUED)

Reference Locality 4	Numerous cliff side outcrops of the Elbrook in the southern limb of the syncline referred to in Reference Locality 3. The beds are typically oriented N70°E, 15NW. The Elbrook in this region is generally dark-gray, fine-grained limestone with minor deformation. Some laminated to thinly bedded light-gray, fine-grained dolomite is interbedded with the more abundant limestone.
Reference Locality 5	Outcrops of the Max Meadows breccia and Elbrook Fm as described by Schultz (1986a). The Pulaski thrust fault is exposed at this locality. The breccia consists of poorly sorted, angular to subrounded clasts of massive dolomites, laminated dolomites, and finely laminated greenish-gray calcareous mudstones in a fine- to very fine-grained matrix of crushed dolomite (Figure 3.6). Clasts range from less than 1 inch to more than 3 feet long. The breccias are massive to crudely layered and are well to poorly indurated. Breccia is finest grained along the fault contact. Dolomite is present between the tectonic breccias of the hanging wall of the Pulaski thrust and the Devonian Millboro Shale in the footwall (Schultz, 1986a).
Reference Locality 6	A large roadcut in the TNT area exposing approximately a 150 foot section of the Elbrook Fm. Distinct units are apparent within the outcrop including; a medium-to thickly-bedded, tan and gray limestone; a thickly bedded, light-gray limestone that weathers dark-gray; a thinly bedded, to shaley, light-tan dolomite; and a dark-gray thin to medium bedded limestone (Figure 3.7). The orientation of bedding varies somewhat throughout the roadcut, but is generally N60°W, 20SW. Three distinct sets of joints are apparent. These joint sets are oriented; N30°W, 70NE; N50°W, vertical; and N70°E, 88NW. Vertical faults (tensional?) with minor offsets are apparent, the fault surfaces are oriented N60°E. Calcite filled fractures are locally abundant in the thickly bedded units, many of which are oriented N70°W, 25SW.

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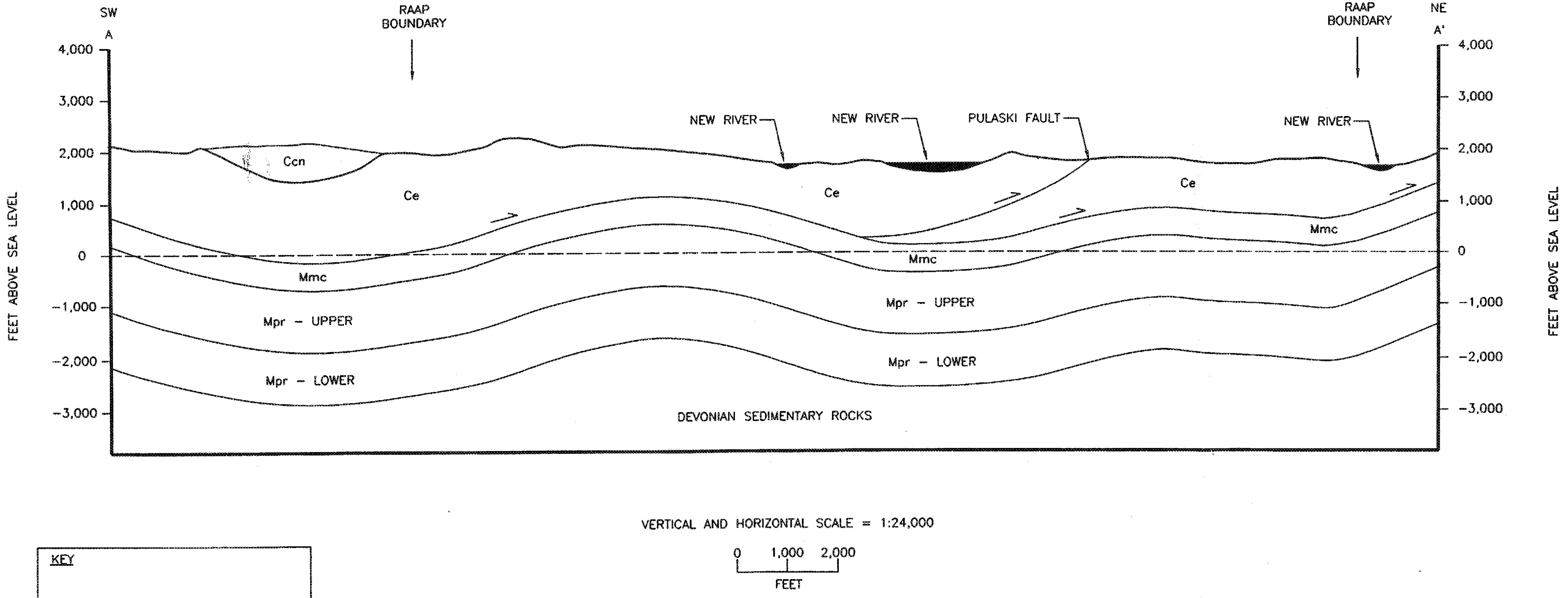
TABLE 3.5

REFERENCE LOCALITY DESCRIPTION (CONTINUED)

Reference Locality 7	A 12 foot high by 60 foot long roadside outcrop in the vicinity of the TNT area of thinly bedded light-gray to shaley dolomite unit of the Elbrook Fm. This unit weathers tan. Numerous small scale folds are apparent in this outcrop, bedding is generally oriented N47°E, 25NW. Localized areas of the Max Meadows breccia are present.
Reference Locality 8 and Reference Locality 9	Isolated outcrops of fine- to medium-grained red brown sandstone. These rocks are interpreted as being part of the undifferentiated Mccrady and Price Formations.
Reference Locality 10	Large roadcut along Virginia State Road 659 outside and adjacent to RAAP property. Interbedded fissile shales and siltstones of the undifferentiated Mccrady and Price Formations. Bedding is generally oriented N5°W, 50NE. The rocks weather red-brown, but are greenish gray on fresh surfaces.
Reference Locality 11, Reference Locality 12 and Reference Locality 13	Approximate locations of cross-sections described by Schultz (1986b) and presented in Figure 3.8. Note in Figure 3.8 that the breccia occurs as both sill-like bodies (bedding-parallel) or as dike-like bodies which truncate bedding.

FIGURE 3.4
GEOLOGIC CROSS SECTION A–A' OF RAAP AND ADJACENT AREAS

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



VERTICAL AND HORIZONTAL SCALE = 1:24,000

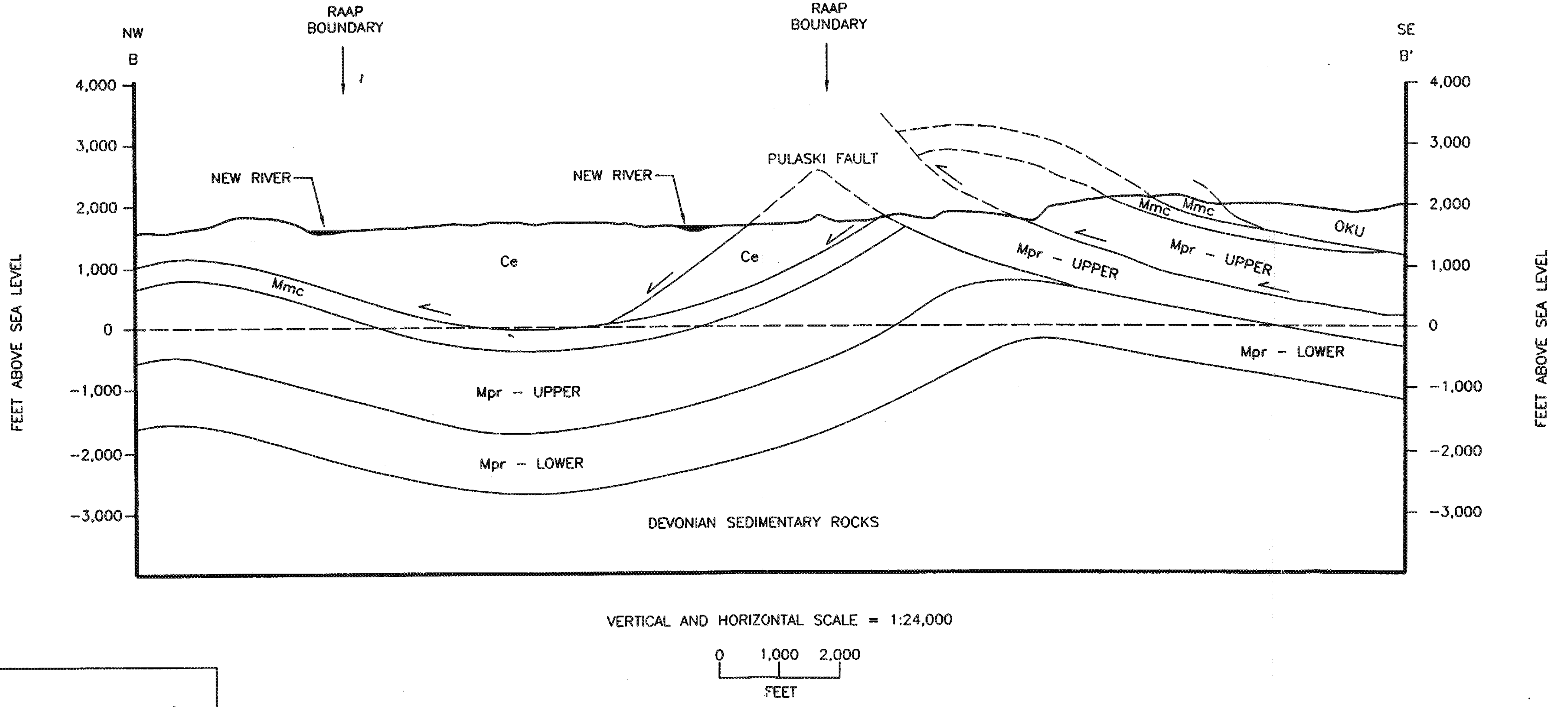
KEY

→ DIRECTION OF MOVEMENT ALONG THE PULASKI THRUST FAULT

NOTE: Ccn CONOCOCHEAGUE Fm.; Ce, ELBROOK Fm.; Mmc, MCCRADY Fm.; Mpr, PRICE Fm.

FIGURE 3.5
GEOLOGIC CROSS SECTION B–B' OF RAAP AND ADJACENT AREAS

RADFORD ARMY AMMUNITION PLANT
RADFORD VIRGINIA



VERTICAL AND HORIZONTAL SCALE = 1:24,000

KEY

← DIRECTION OF MOVEMENT ALONG THE PULASKI THRUST FAULT

– – – POSITION OF GEOLOGIC FEATURES PRIOR TO EROSION.

NOTE: Mmc, MACCRADY Fm; Mpr, PRICE Fm; OKU, UNDIVIDED KNOX GROUP; Ce, ELBROOK Fm. FIGURE MODIFIED AFTER A. SCHULTZ (VDMR OPEN FILE IN PREPARATION.)

FIGURE 3.6
PHOTOGRAPH OF AN OUTCROP OF THE MAX MEADOWS BRECCIA

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

Note: Photograph of a railroad cut exposing a weathered surface of the Max Meadows tectonic breccia in the vicinity of Reference Locality 5. See Table 3.5 for description.

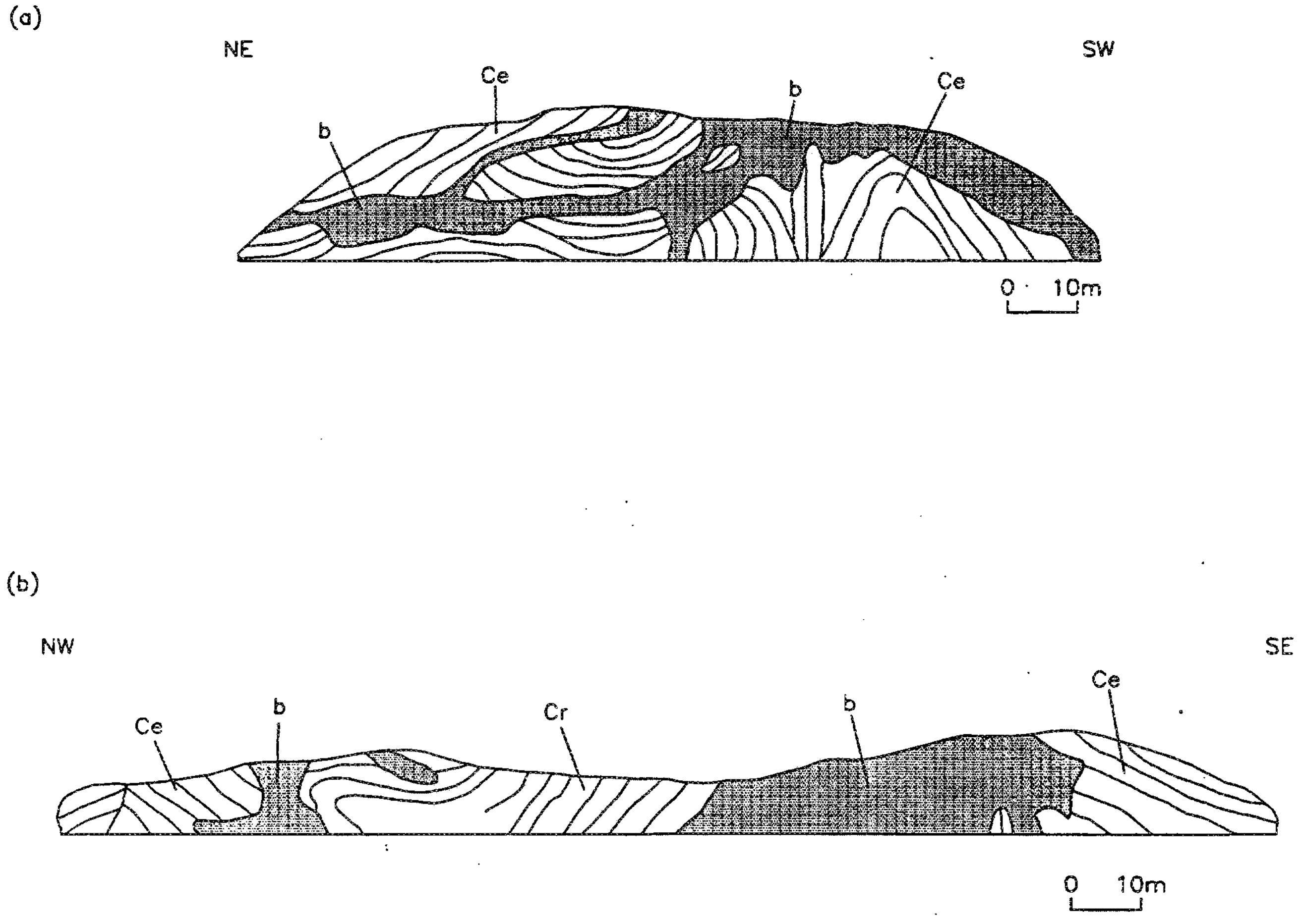
FIGURE 3.7
PHOTOGRAPH OF AN OUTCROP OF THE ELBROOK FORMATION

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

Note: Photograph of a road cut exposing a large section of the Elbrook Formation at Reference Locality 6. See Table 3.5 for description.

FIGURE 3.8
OUTCROP SECTIONS IN THE VICINITY OF RAAP

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



(a) SKETCH OF OUTCROP EXPOSURE AT REFERENCE LOCALITY 11. FOLDED, FAULTED AND BRECCIATED ELBROOK DOLOMITE.

(b) SKETCH OF OUTCROP EXPOSURE AT REFERENCE LOCALITY 12. FOLDED AND FAULTED ROCKS OF THE ROME AND ELBROOK FORMATIONS AND MAX MEADOWS.

Ce: ELBROOK Fm. Cr: ROME Fm. b: MAX MEADOWS BRECCIA

FIGURE MODIFIED AFTER A. SCHULTZ (1983).

TABLE 3.6

LEGEND TO THE GEOLOGIC MAP of RAAP SHOWING RIVER TERRACE DEPOSITS

Rock Characteristics[1]

	Quaternary	td	Terrace deposits, unconsolidated, poorly stratified deposits of dark-brown to dark-reddish-brown, 2-8 inch thick well rounded cobbles in an extensively weathered soil matrix.
Paleozoic	Mississippian	Mmc/ Mpr	Lower Mccrady Fm., sandstones overlain by mottled maroon and green mudstones. Upper Price Fm., mottled maroon and green mudstones underlain by dark gray to black mudstone and coal.
	Devonian	Db	Brailler Fm., interbedded sequence of dark-gray to black mudstone, medium-gray siltstone and fine-grained commonly crossbedded sandstone.
	Ordovician	Oku	Undivided Knox Group, light- to medium-gray, massive, thick-bedded, fine- to medium-grained dolomite interbedded with massive to layered gray chert.
	Cambrian	m	Max Meadows tectonic breccia, poorly sorted angular to subrounded clasts of dolomite and calcareous mudstones in a fine- to very fine-grained matrix of crushed dolomite.
		Ccn	Conococheague Fm., limestones, dolomite, and sandstone. The Formation is approximately 2000 feet thick.
		Ce	Elbrook Fm., cyclic sequences of medium-gray, finely laminated, fine-grained dolomite. Limestone units range up to 50 feet in thickness. The percentage of limestone diminishes downward.
		Cr	Rome Fm., interbedded mottled maroon and green phyllitic mudstone, fine-grained sandstone and siltstone, and dark-gray, fine-grained dolomite.

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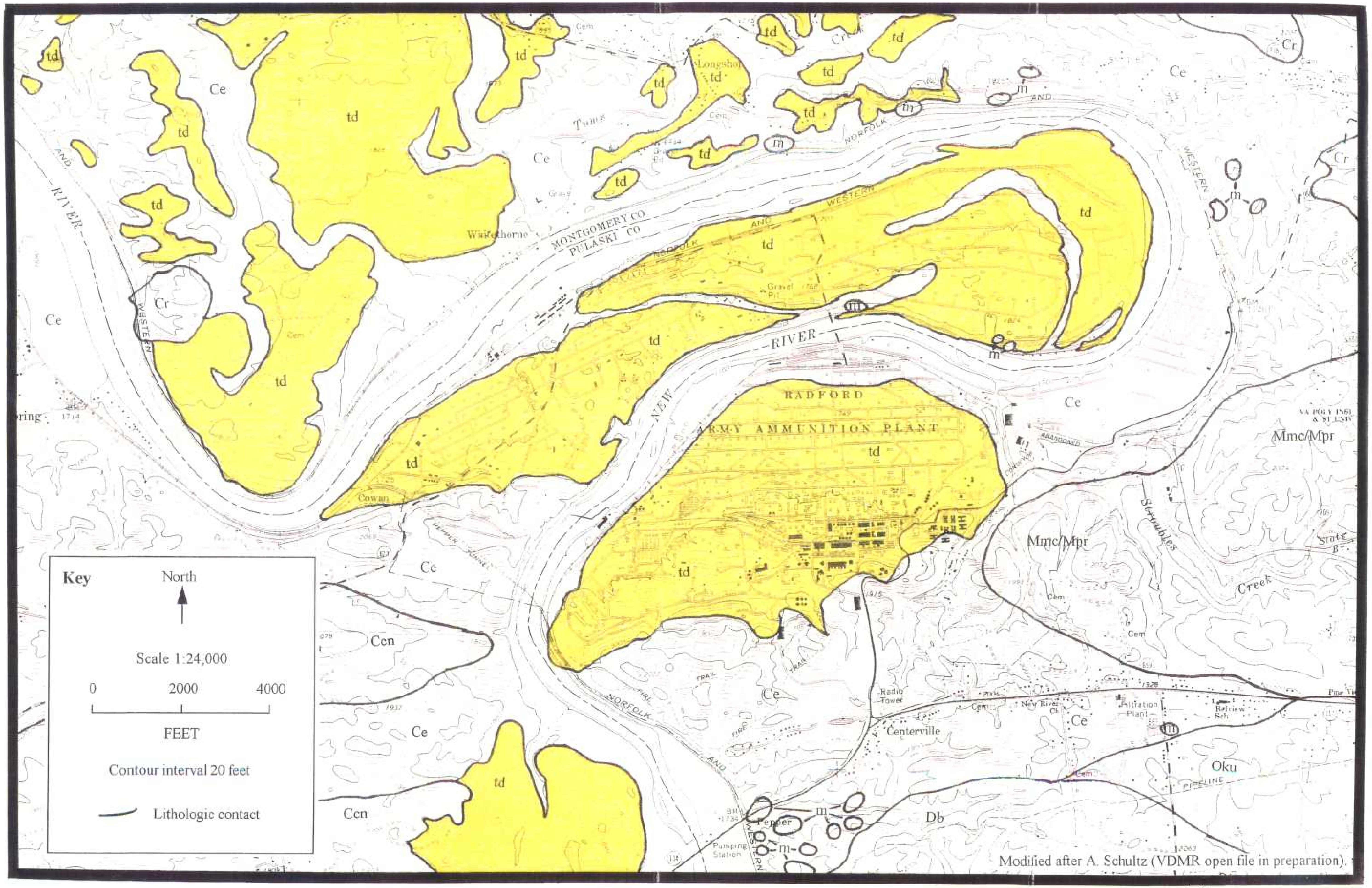
[1] Geologic map modified after A. Schultz (VDMR open file in preparation). Lithologic descriptions modified after Bartholomew and Lowry (1979).

P1

FIGURE 3.9 GEOLOGIC MAP OF RAAP SHOWING RIVER TERRACE DEPOSITS



Modified after A. Schultz (VDMR open file in preparation).

3.5.3.11. No evidence of recent faulting exists in the vicinity of RAAP. However, the Radford area has experienced seven earth tremors in the last 200 years with a recorded intensity of VI or higher on the Modified Mercalli Scale (USAEHA, 1980a). Several recent studies (Bollinger and Wheeler, 1983, 1988) have delineated a low level seismic zone in the central and northwestern part of the Valley and Ridge province in Giles County, VA. The largest recorded quake occurred in 1897, had a modified Mercalli Intensity of VIII, and was centered in Pearsburg, VA. Schultz and Southworth (1989) have shown that the largest slope failures in the folded Appalachians occur in the Giles County Seismic Zone, immediately northwest of RAAP.

3.5.3.12. A total of 66 fracture traces were identified within and around RAAP in a photo geologic study conducted by the USEPA's Environmental Photographic Interpretation Center (EPIC) in 1992 (Figure 3.10). Fracture traces are linear features identified in aerial photographs that represent the surface expression of major fractures and/or zones of fracturing. These features may be expressed as soil-tonal variations and vegetational and topographic alignments and are significant factors controlling groundwater flow at RAAP. The fractures or fracture zones can act as conduits for groundwater, thereby increasing flow rates and, in some cases, redirecting flow away from the "expected" flow direction. In karst terrain, such features are environmentally significant because carbonate dissolution and resulting conduits develop along bedding planes as well as fractures (USEPA, 1992a).

3.6 REGIONAL HYDROGEOLOGY

3.6.0.1. The hydrogeologic conditions at RAAP are complex due to the karstic nature of the aquifer underlying this facility. The karst aquifier at RAAP is contained within limestone and dolomite. The most characteristic feature of a karst aquifier is the flow of groundwater through conduits (caves/caverns) and along bedding planes and fractures enlarged by solution. Commonly, karst aquifiers discharge to springs. Dissolution of carbonates only occurs in acidic waters. The most common cause of groundwater acidity is by the formation of carbonic acid from reaction of water with carbon dioxide in the atmosphere and soils. Several other sources of acidity that can be locally significant, such as aqueous hydrogen sulfide in reducing environments, have not been a factor at RAAP. Solution rates of limestone by waters undersaturated with respect to calcium carbonate have been shown to be rapid. Direct measurements of limestone dissolution have shown rates as high as 0.4 to 0.8 mm/year in perennially active passages. Compatible rates have been

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produced by laboratory experiments (Howard and Howard, 1967). However, the rapid solution rate can hinder the formation of solution conduits. Measured rates are so high that water approaches saturation after only a short distance of travel. However, more recent work has shown that solution rates drop sharply as the water approaches chemical equilibrium with the rock. As a result, this water can penetrate a large distance into limestone while retaining its ability to dissolve the rock (Palmer, 1990). In most karst aquifers, dissolution by groundwater is highly selective. Although there may exist an abundance of presolution openings, very few are enlarged significantly during solutionization. The result is a sharp discontinuity in the scale of underground voids, with large caves surrounded by a network of tiny openings that have been enlarged very little, if at all. The larger conduits will develop along bedding plane partings or fractures that are most open initially or are favorably oriented along the prevailing hydraulic gradient. Sinkholes and conduits evolve interdependently. Sinkholes develop in the land surface at the groundwater input locations to the larger conduits as a result of concentrated dissolution, collapse and transport of overburden through the conduit by groundwater.

3.6.0.2. The initial development of solution conduits requires the through flow of water to carry away the dissolved material. Therefore, to develop a karst aquifer, a preexisting interconnected network of openings must be present between the recharge and discharge points. These openings include intergranular pores, fractures and bedding-plane partings. Fractures and bedding-plane partings are of nearly equal importance. Most karst aquifers show a combination of fracture and bedding plane control. Fault surfaces tend to have less of an affect on solutionization. Solutionization in intergranular pores is typically significant only in young poorly-indurated carbonates, where this process forms irregular voids like the pores in a sponge. Specific groundwater flow paths within a karst aquifer rarely follow the steepest component of the hydraulic gradient. Stratigraphic and structural data are necessary to explain local patterns of subsurface flow (Palmer, 1990). In massive rock with fractures, groundwater flow is typically discordant with bedding. In rocks with prominent bedding planes, such as at RAAP, the groundwater flow patterns are responsive to the strike and dip of the rocks. In these situations, perching of groundwater in the unsaturated zone is more common, and is typically associated with shaley beds. Fractures typically do not penetrate through an entire sequence of beds within the unsaturated zone. Therefore, the downward movement of groundwater will typically take on a stair-step pattern; moving down the length of a fracture, then moving down the dip of a bedding plane until another fracture is encountered.

3.6.0.3. The rate of infiltration of water through limestone in the unsaturated zone in karst environments varies greatly. In areas where the limestone contains insoluble clastic material, there may be a well defined C-horizon of rubbly material. In areas of more pure limestone and dolomite, such as at RAAP, the soil bedrock contact is typically very sharp. This is because the limestone and dolomite rubble is rapidly leached from the soil (White, 1990). The bedrock surface is typically sculptured into an elaborate network of joints widened by solution and small channels along bedding planes. The top few meters of these solution openings are usually filled with soil and provide a permeable zone for temporary storage of perched groundwater. After a rain event, groundwater may be held up in this region of the unsaturated zone for a period of days or weeks. If the soil becomes saturated with respect to calcite in the reaction zone at the base of the soil, it will move into the subsurface through fractures and joints with little additional reaction with the wall rocks. Joints and fractures carrying calcite saturated waters will only be slightly enlarged (White, 1990). Waters undersaturated with respect to calcite will enlarge the pathways while maintaining the overall geometry of the original joints and bedding plane sets. The width of the openings varies from less than a centimeter to greater than 2 meters.

3.6.0.4. The groundwater flow rate in karst aquifiers is generally much faster than in other types of aquifiers. Two types of flow can occur within karst aquifiers; conduit flow and diffuse flow. These two flow types are end members of a continuum; flow within most portions of a karst aquifier include some combination of each. Conduit flow is turbulent and includes groundwater flow through open cavities. Because this type of flow responds rapidly to rainfall and has a high ratio between the maximum discharge and the base- flow discharge (typically 10:1 to 1000:1), it is termed "flashy." Waters within conduit flow have low, but highly variable hardness. The turbidity, discharge and temperature of these waters also is highly variable. In less developed karst aquifiers, diffuse flow is more common. Diffuse flow involves groundwater flow through poorly integrated pores, joints and tubes within the rock. The discharge from karst aquifiers that have a substantial amount of diffuse flow responds slowly to rainfall. These aquifiers have a low ratio between maximum and baseflow discharge, typically 4:1 or less. Diffuse flow is generally laminar. The hardness of waters from diffuse flow is higher than for conduit flow. Also, the hardness, turbidity, discharge and temperature are less variable in diffuse flow (Quinlan, 1990).

3.6.0.5. The water table level in karst aquifers is strongly controlled by the elevation of the springs to which the aquifer is discharging. The spring elevation is typically controlled by an entrenched river, as the New River does at RAAP. The solution conduits which feed the spring are typically so efficient in transmitting water, that they possess a low hydraulic gradient. Often, the potentiometric surface within or above the conduits lies only slightly higher than the spring elevation. During low flow, hydraulic heads in the large conduits are typically lower than the heads in the surrounding smaller and less efficient fractures. Therefore, water flows towards the conduit from the surrounding narrow fissures and pores. This trend is often reversed during flood conditions, when large openings are subjected to sudden surges of water from the surface (Palmer, 1984). The groundwater table in most karst regions is highly irregular and discontinuous, due to the great variation in the characteristics of the underground openings. Within most karst aquifers, conduits tend to form a branching system in which tributaries join to form larger passages with larger discharge. A karst aquifer can be viewed as an elaborate underground plumbing system through which water flows in discrete conduits. Water may stand at different elevations in nearby wells, and dry or poorly productive wells may occur in the same area as successful wells (Palmer, 1990). Because of these and other complexities apparent in karst aquifers, some researchers deny the existence of a karst water table. However, perched zones and water table irregularities apparent in karst aquifers are also observed in other aquifer types. These irregularities are more pronounced and on a larger scale in soluble rock than in other materials. Therefore, the water table concept can be valid for karst regions, but only if applied regionally rather than on the scale of individual solution conduits or wells (Palmer, 1990).

3.6.0.6. It is difficult to define the water table and the available supply of groundwater at RAAP. Several borings and groundwater monitoring locations within the Horseshoe Area indicate that the water table within the floodplain is approximately the same elevation as the surface water of the New River. These conditions also exist in the floodplain across the river in the Main Manufacturing Area of RAAP. In areas of high elevation within the Horseshoe and Main Manufacturing Areas, the water table is extremely variable. Because of impervious layers, solution cavities, and the thickness of overburden, extreme caution must be exercised in projecting water table data from existing groundwater monitoring locations into areas for which no groundwater data exist. The limestone and dolomite underlying RAAP is fractured, foliated, and faulted as a result of Paleozoic deformation. Topographic maps of RAAP show evidence of solution cavities and collapse structures (sinkholes) oriented along bedding planes within the less competent limestone units (Figure 3.10). There is a significant potential for movement of water through these features;

generally in an east-west direction. However, the groundwater flow direction is dependent on groundwater gradient which is generally directed toward the New River.

3.6.0.7. Groundwater levels in the bedrock aquifer generally respond to heavy precipitation within approximately 14 hours and may rise several feet in a short time (Engineering-Science, 1994b). This situation demonstrates that the karst aquifer underlying RAAP is characterized primarily by conduit flow and illustrates the direct connection between the groundwater and surface water that could impact the quality of groundwater for domestic use. The condition exists throughout RAAP, especially in areas where surface water infiltrates through sinkholes. Stormwater typically flows to the bottom of the sinkholes and rapidly travels downward through conduits into the unconfined aquifer. The New River appears to be the discharge area for groundwater at RAAP as well as for the regional groundwater. Open fractures and karst structures beneath the soil mantle coupled with the relatively low elevation of the New River (1,680 feet msl), provide accessible conduits for groundwater flow, thereby rapidly draining the overlying, less permeable soils (Charles T. Main of Virginia, 1988).

3.6.0.8. It is not completely understood how the Pulaski Fault, present at the facility, affects groundwater movement. The fault is not a simple planar feature, but rather a zone of regional deformation. At some areas, the location of the fault surface can be identified by the presence of lithologic unconformities. However, at RAAP and most other localities, the proximity of the fault surface is generally indicated by the abundance of the Max Meadows tectonic breccia. This breccia displays distinct weathering characteristics that appear to be the result of intergranular dissolution. As shown in Figure 3.6, the breccia develops extensive solution cavities which can allow for rapid conduit flow of the groundwater.

3.6.0.9. A dye-trace study conducted by Parsons ES (May 1994) identified a specific flow path connecting injection point 1 in SWMU 17 to a spring (sample SPG 3) discharging to the New River (Figure 3.10). This flow path closely parallels a series of west-northwest to east-southeast trending fracture traces and acts as a direct conduit for groundwater migration. This conduit was most likely created by solution openings along subsurface fractures. A more detailed discussion of groundwater conditions is included within each specific SWMU section of the report.

3.6.0.10. Water levels from 80 monitoring wells throughout RAAP are measured during quarterly sampling events at this facility. Table 3.7 summarizes groundwater elevation data collected during the 1995 first quarter sampling event. These data were used to develop a facility-wide groundwater gradient map (Plate 2). Some wells at this facility display unusually shallow or deep water levels compared with other nearby wells. These wells possibly intercepted perched groundwater zones or are influenced by karst features, such as sinkholes or conduits, which exert a strong local influence and are not reflective of the overall unconfined water table. Groundwater flow is generally towards the New River and away from areas of higher elevation.

3.6.0.11. Groundwater supplies in the Valley and Ridge province are presently of good or superior quality compared to surface water supplies. However, due to extended contact with minerals, many groundwater supplies contain higher levels of dissolved solids than the streams into which they discharge. Because of the sinkholes and underground caverns in karst aquifers, there is a potential for groundwater to be impacted by direct infiltration of contaminated surface water.

3.7 SURFACE WATER HYDROLOGY

3.7.0.1. The New River is the most significant surface water feature within RAAP. The facility is built within and adjacent to a prominent meander loop of this river. Within RAAP, the river width varies from 200 to 1,000 feet, but averages approximately 400 feet. The river flow varies due to water management at Claytor Dam, approximately 9 miles upgradient (south) from RAAP. Downstream from the Claytor Dam, typical flows of the New River range between 3,200 and 8,000 million gallons per day (mgd). During typical flow conditions, the depth is approximately 4 to 6 feet; however, pools may be 10 feet deep. There are 13 miles of river shoreline within the RAAP boundaries.

3.7.0.2. The headwaters of the New River are in northwestern North Carolina, near the Tennessee state line. In the vicinity of RAAP, the New River flows northwesterly cutting cliffs through the bedrock. The path of the New River, which is generally perpendicular to the ridge lines of the Valley and Ridge province, indicates that the river existed prior to the Paleozoic folding of these rocks. In some areas, this river has eroded 4000 feet of rock. During the Paleozoic, the erosion rate of the river was higher than the

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TABLE 3.7
GROUNDWATER ELEVATION SUMMARY
RADFORD ARMY AMMUNITION PLANT

SWMU	WELL ID	Ground Elevation*	Groundwater Elevation*	Date
4	P-3	1752.56	1747.54	1/4/95
4	WC9B	1726.50	1711.22	1/4/95
4	WC8B	1740.14	1730.03	1/4/95
4	W4B	1727.50	1707.55	1/4/95
4	MW7	1722.50	1711.52	1/4/95
4	W2B	1733.50	1714.57	1/4/95
4	WC2-1	1735.40	1714.41	1/4/95
4	WC2-2	1735.40	1717.32	1/4/95
4	WC2-3	1735.40	1718.15	1/4/95
4	WC3-2	1726.50	1707.12	1/4/95
4	WC4-1	1713.50	1705.22	1/4/95
4	WC4-2	1713.50	1701.05	1/4/95
4	WC4-3	1713.50	1705.26	1/4/95
4	W5A	1715.40	1700.43	1/4/95
4	W6A	1714.20	1699.82	1/4/95
4	W7A	1705.00	1695.50	1/4/95
5	W8B	1787.58	1769.46	1/12/95
5	W5B	1773.13	1759.07	1/12/95
5	W7B	1772.78	1762.24	1/12/95
5	5WC2-1	1768.80	1759.01	1/12/95
5	5WC2-2	1768.80	1758.97	1/12/95
5	5WC2-3	1768.80	1759.37	1/12/95
5	S5W5	1769.81	1760.40	1/12/95
5	S5W6	1769.42	1760.44	1/12/95
5	S5W7	1773.08	1761.92	1/12/95
5	W9A	1761.10	1755.97	1/12/95
5	W10A	1768.40	1753.72	1/12/95
5	W11A	1764.70	1750.46	1/12/95
7	W12B	1714.81	1691.61	1/20/95
7	7WCA	1712.40	1690.13	1/20/95
7	W11B	1712.90	1690.47	1/20/95
7	MW5	1713.20	1690.26	1/20/95
7	MW6	1712.80	1688.34	1/20/95
7	S7W9	1710.48	1686.86	1/20/95
7	W9C	1703.70	1689.44	1/20/95
7	W11	1712.82	DRY	1/20/95
7	W10B	1704.65	1690.93	1/20/95
7	W10C	1707.50	1687.90	1/20/95
10	DG-1	1709.96	1689.95	3/1/95
10	DDH4	1713.16	1690.30	3/1/95
10	D4	1713.42	1692.65	3/1/95
10	DDH2	1700.78	1686.66	3/1/95
10	D3	1700.51	1685.25	3/1/95
10	D3D	1700.70	1685.77	3/1/95
10	10MW1	1701.28	1685.96	3/1/95

* FEET ABOVE MEAN SEA LEVEL

TABLE 3.7
GROUNDWATER ELEVATION SUMMARY (CONTINUED)
RADFORD ARMY AMMUNITION PLANT

SWMU	WELL ID	Ground Elevation*	Groundwater Elevation*	Date
13	13MW1	1698.66	1680.71	2/14/95
13	13MW2	1701.21	1681.87	2/14/95
13	13MW3	1693.41	1681.38	2/14/95
13	13MW4	1695.18	1679.52	2/14/95
13	13MW5	1695.26	1679.73	2/14/95
13	13MW6	1693.81	1679.44	2/14/95
13	13MW7	1693.81	1679.78	2/14/95
16	C1	1836.78	1788.83	1/26/95
16	MW8	1815.82	1744.77	1/26/95
16	MW9	1808.88	1745.83	1/26/95
16	WC1B	1812.95	1745.33	1/26/95
16	WC1A	1812.61	1745.26	1/26/95
16	16-1	1813.88	1764.97	1/26/95
16	16-2	1808.78	1754.53	1/26/95
16	16-3	1823.83	1767.71	1/26/95
16	16-5	1739.50	1737.75	1/26/95
16	WC2A	1818.05	1755.83	1/26/95
16	WC2B	1818.71	1765.61	1/26/95
16	C3	1819.22	DRY	1/26/95
17	17PZ1	1904.70	1800.14	1/17/95
17	17MW2	1903.99	1799.35	1/17/95
17	17MW3	1904.27	1760.59	1/17/95
17	40MW2	1881.10	DRY	1/17/95
17	40MW3	1856.02	1763.83	1/17/95
17	40MW4	1906.10	DRY	1/17/95
26B	B2	1759.47	1682.42	2/24/95
26B	B3	1765.09	1692.72	2/24/95
26B	B4	1764.64	1695.88	2/24/95
26B	BDH3	1822.55	1741.34	2/24/95
31	31MW1	1713.45	1682.68	1/17/95
31	31MW2	1697.49	1679.43	1/17/95
31	31MW3	1697.20	1680.82	1/17/95
31	31MW4	1697.14	1678.40	1/17/95
48	48MW1	1817.79	1713.25	1/18/95
48	48MW2	1817.62	1701.39	1/18/95
48	48MW3	1809.96	1719.46	1/18/95
74	74MW1	1732.60	1710.41	2/3/95
74	74MW2	1803.10	1747.89	2/3/95
74	74MW3	1729.60	1710.38	2/3/95
74	74MW4	1728.80	1706.47	2/3/95
74	74MW5	1736.50	1712.02	2/3/95
74	74MW6	1731.40	1708.56	2/3/95
74	74MW7	1730.90	1707.81	2/3/95
FAL2	FAL2	1756.13	1723.54	2/23/95
FAL2	FAL3	1757.43	1691.35	2/23/95
FAL2	WELL7	1823.03	1798.66	2/23/95

* FEET ABOVE MEAN SEA LEVEL

uplift rate of the rocks. This produced the entrenched river channel present today. The New River is perhaps the oldest river in North America, estimated to be 350 million years old

3.7.0.3. Stroubles Creek is the largest local tributary of the New River and flows through the southeast sector of RAAP. This creek is fed by several branches that originate on and off the facility. The larger surface drainage ways within the installation and their direction of flow are shown in Figure 3.11. Manmade surface drainage ways at RAAP also influence local drainage. The direction of all surface drainage flow within RAAP is ultimately toward the New River.

3.7.0.4. Stroubles Creek consists primarily of stormwater runoff. Groundwater discharging from the karst bedrock may also supply significant stream flow. Prior to entering the facility, branches of Stroubles Creek flow through rural areas and through the City of Blacksburg. The creek empties into the New River within RAAP and contributes significant loading of domestic and industrial wastewater (USATHAMA, 1976). The Blacksburg Municipal Wastewater Treatment Plant discharges approximately 5.7 mgd of water into the New River just upstream of where Stroubles Creek empties into the river (Personal Communication with R. Graham at Peppers Ferry Wastewater Treatment Plant, 1995). The Commonwealth of Virginia has classified Stroubles Creek and the portion of the New River passing through the confines of RAAP as water generally satisfactory for beneficial uses; these include, public or municipal water supply, secondary contact recreation, and propagation of fish and aquatic life (USATHAMA, 1976).

3.7.0.5. All water used at RAAP is taken from the New River. Separate water systems are provided for the Main Manufacturing Area and the Horseshoe Area. Intake No. 1 is located approximately 2 miles upstream of the mouth of Stroubles Creek. Intake No. 2 is located approximately 6 miles downstream of the mouth of Stroubles Creek (Figure 3.11). Upstream of RAAP, the New River serves as a source of drinking water for the towns of Blacksburg and Christiansburg.

3.7.0.6. Both industrial and domestic wastewaters are discharged into the New River from the Peppers Ferry Regional Wastewater Treatment Plant (PFWWTP). This discharge is located within RAAP, just downstream from intake No. 1. Until 1987, the city of Radford provided only primary sewage treatment before discharging 2.5 mgd into the New River (USATHAMA, 1976). Secondary treatment is now provided at the PFWWTP. Currently this plant discharges approximately 4.5 mgd of water into the New River (Personal Communication with R. Graham at PFWWTP, 1995).

3.7.0.7. RAAP discharges approximately 25 mgd at fifteen industrial wastewater outfalls along the New River and Stroubles Creek under VPDES permit number VA0000248. The effluent consists of various treated process water, wash water, cooling water, run off, sanitary wastewater, and stormwater. The approximate locations of the discharge outfalls are shown in Figure 3.11. For internal use and reference, RAAP has identified a total of 135 outfalls to either the New River or Stroubles Creek from the Main Manufacturing and Horseshoe Areas. These outfalls discharge stormwater, spring-fed groundwater, and minor amounts of steam condensate.

3.7.0.8. The New River itself has experienced few major problems from the discharge of either treated or untreated effluent. The ability of the New River to recover from organic loading is generally high because of the river's natural reaeration characteristics, high base flow, and the present quality and quantity of waste discharge.

3.7.0.9. The upper reaches of the New River and its tributaries have water of excellent quality. These streams have less than 50 parts per million (ppm) of dissolved solids due to the underlying metamorphic rocks, which contribute very little to natural pollution. In the balance of the region, dissolved solids increase to the 50 - 199 ppm range as water drains from areas underlain by shale, sandstone, and limestone formations. Where carbonate rocks occur, the bicarbonate content of the water is particularly high, resulting in 100 - 199 ppm of calcium carbonate ($CaCO_3$) found in the waters of Walker Creek, Sinking Creek, Wolf Creek, and the New River downgradient of RAAP (Figure 2.2).

3.8 GROUNDWATER USAGE

3.8.0.1. Private and public groundwater wells are used in the vicinity of RAAP for drinking water and other domestic and agricultural purposes. A document search to identify private water well use within one mile of the RAAP property line was conducted as part of the current investigation to determine the extent of private water well use in this area (New River Health District, 1995). Since September 1, 1990, a total of 36 property owners living within 1 mile of RAAP applied for a permit through the appropriate County Health Department to construct individual water supply wells. These property owners primarily reside in the following developments; the River Bluffs subdivision and along gate ten road in Pulaski County and in the regions of Prices Fork, Longshop and McCoy in Montgomery County. The names and addresses of these property owners is given in Appendix B. Prior to September 1, 1990, property owners were not required to obtain Health Department approval prior to well installation. Therefore, it is estimated that 50 percent or more of the existing residents within one mile of RAAP have private water supplies (i.e. cisterns, springs, wells, etc.) for which the Health Department has no record (New River Health District, 1995).

3.8.0.2. In addition to the private water supply wells in the vicinity of RAAP, 14 public water supply wells have been identified within three miles of the RAAP boundary. Public water supply wells service more than 15 people and are regulated through the Virginia State Department of Health. The location of these supply wells is given in Appendix B. Plates 3A and 3B display the locations of the public water supply wells and the area utilizing private wells in the vicinity of RAAP.

3.8.0.3. For domestic purposes, most residents in the vicinity of RAAP utilize surface water supplied primarily by the water treatment plant at Claytor Dam. Areas on public water include the City of Radford, Fairlawn, and properties along Route 114 in Montgomery County.

3.8.0.4. Two groundwater supply wells are present on the RAAP facility. However, neither of these wells is currently being used for any purpose. Those well locations are shown on Plate 1.

3.9 ECOLOGY

3.9.0.1. The last comprehensive inventory of the mammals, birds, reptiles, aquatic invertebrates, trees, and plants found on the installation, and of the fish inhabiting the New River where it flows through the installation was conducted in 1976 during an installation assessment of RAAP (USATHAMA, 1976). Information from that assessment was summarized in previous documents (Dames & Moore, 1992a and 1992b). The summarized information was updated through personal communication with RAAP biologists and is presented in the following paragraphs.

3.9.0.2. Many of the reptiles, mammals, and birds listed in the 1976 Installation Assessment (USATHAMA, 1976) are believed to breed on the installation (Personal Communication, 1995). However, indications are that some species, including ruffed grouse and upland plovers, have decreased in number or have disappeared from RAAP (USATHAMA, 1976). Foxes which were once trapped to prevent rabies outbreaks have recently been reintroduced to RAAP as a control for groundhogs. Deer are common at RAAP and bow hunting has been allowed at the facility since 1991. Migratory waterfowl are found throughout the spring and winter near the New River because the installation is on the Atlantic Flyway. Federally protected black vultures are present at RAAP during certain times of the year. Between 1,500 and 3,000 of the migratory birds nest in thickets on the facility (Washington Post, 1995). Fishing occurs in the New River which flows through RAAP.

3.9.0.3. No threatened or endangered species have been found at RAAP. However, six endangered plant species, three threatened plant species, one endangered mollusk species, one threatened mollusk species, one endangered insect species, four threatened insect species, three endangered bird species, and the locally endangered mountain lion have been identified for Pulaski and Montgomery Counties by the Virginia Department of Game and Inland Fisheries. In addition, a fish, salamander, four bird species, and the river otter are identified as species of special concern in the two counties in which RAAP is located.

3.9.0.4. According to the RAAP Installation Assessment (USATHAMA, 1976), timber harvesting occurred on RAAP in the past. The most recent harvest was conducted in 1987. Tree species at RAAP 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 RAAP Conservation Specialist, 1995). No reforestation has occurred in the Main Manufacturing Area. In 1964, 922 acres of the Horseshoe Area were reforested.

SECTION 4

FIELD INVESTIGATION PROGRAM

4.1 OVERVIEW

4.1.0.1. The RCRA Facility Investigation field program was conducted during December 1994 and January 1995. USEPA comments suggested the need for additional investigative tasks which were not proposed in the RFI Work Plan (Engineering-Science, Inc., 1994a), including more sampling of existing wells, a soil background metals study, further characterization of the New River, and installation of an additional monitoring well at SWMU 48. These tasks were completed in July 1995. The field work included: monitoring well installation and development; soil boring completion; staff gauge installation; sampling of surface soils, sediments, surface water, groundwater, and waste piles; completion of a soil background metals study; and the performance of aquifer testing. The dye-tracing study for SWMU 17/40, which was conducted during the fall of 1993 and the spring of 1994, and ~~which~~ was submitted as a separate report, has been summarized in this document.

4.1.0.2. The field investigation program provided data to supplement existing information necessary to fully characterize SWMUs 17/40, 31, 48, and 54. Additionally, information was obtained which applies to the site-wide characterization of the facility. In particular, the New River sampling and the soil background metals investigation, provided data which can be used to address information gaps and identified deficiencies in the prior assessments of many of the SWMUs at RAAP. The work activities were completed in accordance with the RFI Work Plan and Quality Assurance Project Plan (Engineering-Science, Inc., 1994c), the Dye-Tracing Study Work Plan (Engineering-Science, Inc.,May 1993), and the Revised Addendum to the RFI Work Plan (Parsons ES, June 1995) to ensure that usable data of known and acceptable quality were generated. This section presents a general description of the field investigation program activities. More detailed information, such as sample locations and SWMU site plans, is included in each SWMU-specific section. The results of the field investigations decribed here are presented in subsequent sections of the report.

4.2 DRILLING PROCEDURES

4.2.0.1. A total of 43 soil borings and eight monitoring wells were completed during the investigation. Eighteen of the 43 soil borings were installed for the soil background metals study. All drilling was directed by an experienced geologist who prepared a detailed lithologic log using the Unified Soil Classification System (USCS). The lithologic logs and well construction diagrams are presented in Appendix C.

4.2.1 Soil Borings

4.2.1.1. Seven soil borings were advanced to the overburden-bedrock interface at various areas of SWMU 17 to characterize the vertical extent of contamination present. The borings were installed by hollow stem auger drilling methods. A truck mounted drilling rig (B80/92) used 4.25 inch (inside diameter) hollow stem augers to penetrate the unconsolidated material to depths of approximately 28 feet below ground surface in two filled-in sinkholes at SWMU 17. Soil samples were collected with split spoon devices at 5 foot intervals using the Standard Penetration Test (ASTM D-1586). Unless subsurface conditions (cobbles or gravel) caused minor deviations from the Work Plan, the samples were collected in 2 foot long spoons with the bottom depths in multiples of 5 feet (e.g., 3-5 feet, 8-10 feet).

4.2.1.2. All downhole equipment (augers, spoons, rods, and bits) was decontaminated by steam cleaning prior to starting a new drilling location. The spoons were decontaminated by washing with an Alconox solution followed by a methanol rinse and then a final deionized water rinse. All soil borings were backfilled by tremie pipe with a grout consisting of cement, bentonite powder, and USAEC approved water.

4.2.1.3. Two soil borings were advanced in the SWMU 48 disposal areas. At these locations, a continuous sampling spoon (Moss Sampler) was used at shallow depths to allow a more detailed examination of the soils for visual signs of hydrocarbon contamination. The Moss Sampler took continuous soil samples in 5 foot intervals (0-5 feet, 5-10 feet) for the top 15 feet of the upper disposal area (48SB4) and the top 10 feet of the lower disposal area (48SB5). The remainder of the holes, 21 feet and 37 feet total depths for 48SB4 and 48SB5, respectively, were sampled with standard split spoons in general accordance with the procedures described for SWMU 17. The geologist used field judgement based upon photoionization (PID) readings and visual observations to decide whether continuous or 5-foot spoons were necessary.

4.2.1.4. Sixteen soil borings were advanced at SWMU 54 to bedrock (a maximum depth of 24 feet). Two of the borings, 54SB6 and 54SB14, were completed with the continuous Moss Sampler, the rest were sampled with standard split spoons at 5 foot intervals. 54SB6 was within the lower ash mound and 54SB14 was beside the upper ash mound.

4.2.1.5. Eighteen soil borings were completed for the soil background metals study using small diameter (3.5 inches) hollow stem augers. Samples were collected by continuous split spoon methods so that distinct B and C soil horizons could be identified. Minor modifications to the Work Plan were necessary due to auger refusal, insufficient sample recovery at the desired depth, or identification of the horizon at a depth different than that predicted in the Work Plan. Lithologic logs for the background borings are contained in Appendix C.

4.2.2 Monitoring Wells

4.2.2.1. Eight monitoring wells were installed at two SWMUs, four at SWMU 31 and four at SWMU 48. Well 48MW4 was installed in July 1995; the other seven were installed in December 1994/January 1995. All wells were begun using 6.63 inch inside diameter hollow stem augers (for 4 inch wells). However, where bedrock or tough subsurface conditions were encountered, air rotary methods (6 inch or 8 inch tri-cone rotary bits or a 10 inch air hammer) were employed.

4.2.2.2. At SWMU 31, two wells were installed with augers and two required air rotary techniques for completion. Soil sampling was conducted with split spoons at 5 foot intervals or less based on the geologist's judgement. One monitoring well boring, 31MW3, was sampled continuously with the Moss Sampler to provide detailed lithologic information for SWMU 31.

4.2.2.3. The four wells installed at SWMU 48 were relatively deep, ranging from 120 feet to 154 feet below ground surface, and required air drilling methods beginning at approximately 30 feet to 60 feet down. Soil samples of the overburden of each monitoring well boring were collected by split spoon methods. Temporary 10 inch casing was installed in 48MW2, 48MW3, and 48MW4, to prevent borehole collapse during air drilling.

4.3 MONITORING WELL COMPLETION PROCEDURES

4.3.1 Monitoring Well Construction

4.3.1.1. All monitoring well construction procedures were in accordance with the USAEC's Geotechnical Requirements (USATHAMA,1987) and Commonwealth of Virginia guidelines. Unless otherwise noted below, the wells were constructed as follows: four inch (inside diameter) schedule 40 PVC pipe was installed inside the hollow stem auger; ten feet of 0.10 inch PVC slotted screen, plugged at the bottom, was used; threaded couplings joined the casing and screen; the top of the screen was positioned 1-2 feet above the stabilized groundwater level; the sand filter pack was extended to approximately two feet above the top of the screen; a five foot thick bentonite seal was placed above the filter pack; the remainder of the annulus was filled to ground surface with a cement-bentonite mixture by tremie pipe; the augers were removed slowly to allow settling of the grout; the PVC casing extended 2-3 feet above ground surface; a five foot long, six inch diameter steel casing was installed over the PVC casing; and four steel protective posts were placed around the well. Filter pack sand size and screen slot size were based upon geotechnical data from the applicable geologic formations obtained during previous investigations (Dames & Moore, 1992a and 1992b). A construction diagram of a typical monitoring well is presented as Figure 4.1. Table 4.1 lists the construction details of the eight new wells and the existing wells sampled during this investigation.

4.3.1.2. The wells installed at SWMU 48 were deeper and more difficult than those at SWMU 31. Therefore, some deviations from the Work Plan procedures were necessary. The wells were installed inside temporary steel casings since the hollow stem augers were not large enough to fit some of the air rotary equipment used to penetrate the bedrock. Greater screen lengths were used because of the difficulty of predicting groundwater movement in the bedrock. Since the potential for floating hydrocarbon compounds existed at this SWMU, it was important to position the screen to intercept these compounds. Because the bedrock was relatively tight and the groundwater stabilized level could not be predicted, a 30 foot long screen was installed in the first well drilled (48MW1) at this SWMU. Once the general groundwater level was established, 20 foot screens were used in the three remaining SWMU 48 wells.

FIGURE 4.1

TYPICAL MONITORING WELL CONSTRUCTION

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

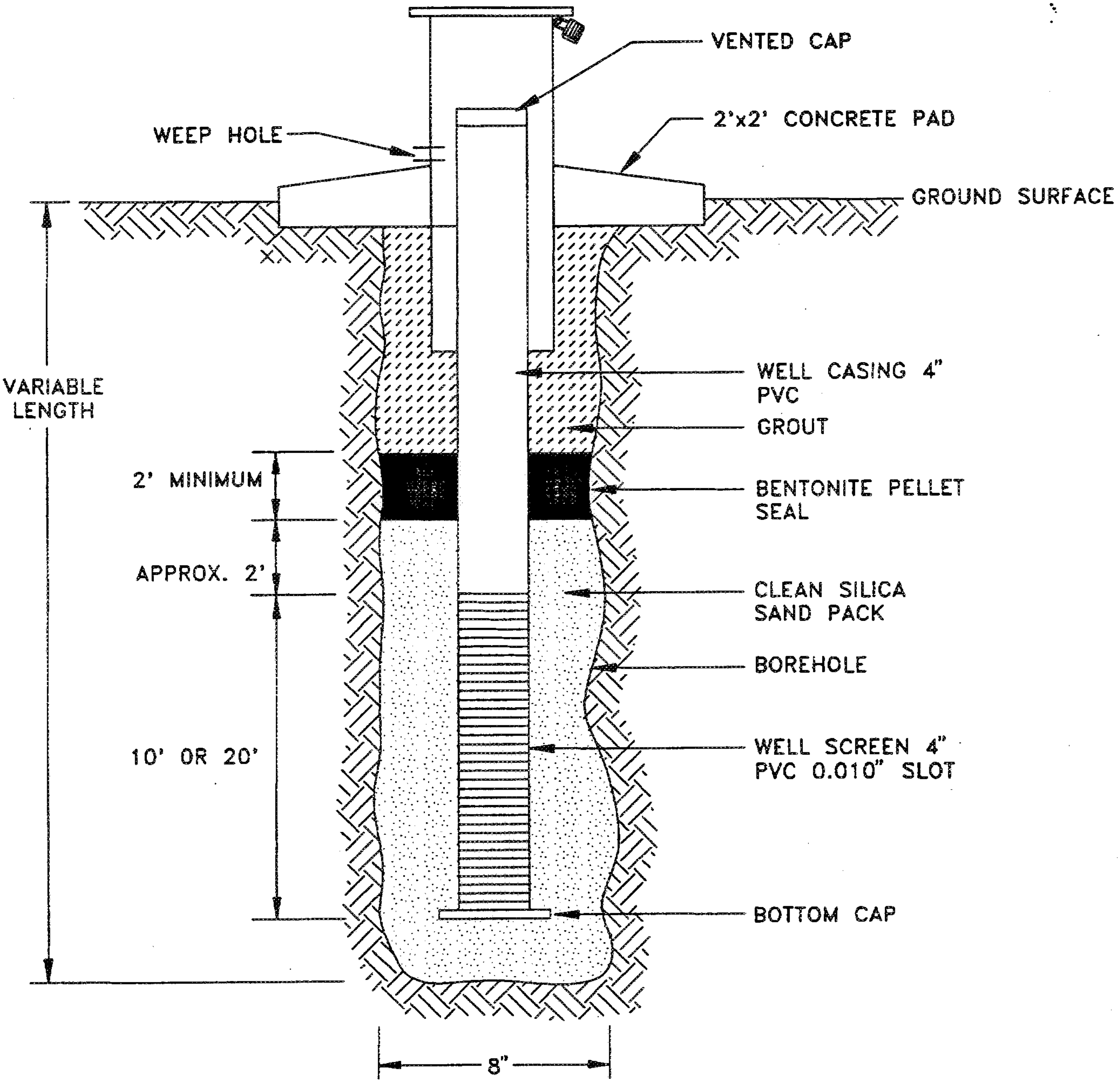

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TABLE 4.1

MONITORING WELL CONSTRUCTION DETAILS

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

Well Name	Well Depth (ft)	Well Elevation At T.O.C. (ft)	Depth To Water (ft)	Water Elevation (Ft)	Screen Length (Ft)	Well Diameter (In)
31MW1	52.40	1715.04	34.43	1680.61	10	4
31MW2	28.50	1699.05	25.82	1673.23	10	4
31MW3	32.43	1698.82	25.04	1673.78	10	4
31MW4	30.45	1698.55	24.92	1673.63	10	4
48MW1	142.00	1819.95	103.86	1716.09	30	4
48MW2	135.70	1818.88	123.86	1695.02	20	2
48MW3	122.30	1812.17	94.46	1717.71	20	4
48MW4	96.06	1832.60	78.30	1754.30	20	4
17MW2	173.00	1906.29	99.76	1806.53	20	4
17MW3	181.50	1906.78	146.91	1759.87	20	4
40MW3	120.00	1858.21	94.44	1763.77	20	4
17PZ1	132.50	1907.02	99.69	1807.33	20	4
40MW2	60.00	1882.51	DRY	DRY	20	4
40MW4	62.80	1908.11	DRY	DRY	20	4
54MW1	52.00	1707.78	18.70	1689.08	20	4
54MW2	28.00	1701.41	22.60	1678.81	10	4
54MW3	30.00	1702.15	23.81	1678.34	10	4

NOTES:

1. Water elevations were taken in July 1995.
2. All wells were constructed of PVC materials.
3. Well name includes the SWMU designation.
4. Elevations are in feet above mean sea level.
5. The SWMU 31 and 48 wells were installed by Parsons ES in January or July 1995; 17MW2, 17MW3, and 40MW3 were installed by Parsons ES in May 1993; the other wells were installed by Dames & Moore in 1991-1992.

4.3.1.3. 48MW2 was completed as a two inch inside diameter well. Drilling difficulties encountered while attempting to install this well included a "dogleg" caused by particularly soft overburden on top of relatively hard bedrock, and a collapsing borehole as downhole equipment tried to negotiate the "dogleg." In order to save the hole, and avoid redrilling approximately 80 feet of overburden and bedrock, a two inch well, which was not obstructed by these conditions, was installed.

4.3.2 Monitoring Well Development

4.3.2.1. Well development procedures were slightly modified from the Work Plan description based on comments from the USEPA. Wells installed by Parsons ES were developed by pumping which was initiated at least 48 hours but no longer than seven days after completion of the well. The entire water column was evacuated by periodically changing the position of the submersible pump during development. At least six well volumes of groundwater were removed. This included the column of static water and the saturated annulus outside of the screen.

4.3.2.2. Monitoring of the physical and chemical characteristics of the groundwater, including, pH, conductivity, temperature, color, odor, and turbidity, was performed throughout the development procedure. After removal of six volumes of groundwater from each well, development continued until pH, conductivity, and temperature readings were reproducible within 20 percent of the prior set of readings. The field data sheets containing the development information are presented in Appendix D.

4.3.2.3. In general, the wells at SWMU 31 were slow in recharging; the bedrock wells at SWMU 48, with the exception of 48MW2, were relatively quick rechargers. The groundwater from all wells was visually clear after completion of development.

4.4 SOIL BACKGROUND METALS STUDY

4.4.0.1. The soil background metals study was conducted in response to USEPA comments concerning inorganic concentrations present in site background soils. The objective of the study was to establish statistically valid background levels of metals in the soil as the basis for comparisons between those levels and concentrations of metals found in the SWMUs. The sampling methodology and statistical analysis summarized below were in accordance with the approved Revised Addendum to the Final RFI Work Plan (Parsons ES, June 1995).

4.4.0.2. In order to establish background soil metals concentrations which could be compared to all soil sampling for metals at any SWMU on the facility, a review of the previous soil sampling procedures was undertaken. It was determined that only three of the ten identified soil types (SCS 1985a, 1985b) across the facility were actually sampled during previous and current investigations. The review also took into account sampling procedures and depths of the previous investigations to ensure that similar samples would be collected during the background study for comparison.

4.4.0.3. The B and C horizons of the three soil types, taken at various depths, were sampled from background areas across the site. Designations of background areas were based on distance from SWMUs or impacted areas, facility history or personnel interviews, and field reconnaissance. Eighteen borings and 36 samples were collected (as described in 4.2 above) and submitted for metals analyses.

4.4.0.4. The data then underwent statistical testing in accordance with the Work Plan. The results are presented in the baseline risk assessment (Section 6).

4.5 DYE TRACING STUDY

4.5.0.1. The dye tracing test was conducted at SWMU 17 in the Fall of 1993 and the Spring of 1994. The Work Plan was completed in May 1993 and the Dye-Tracing Study Report was submitted in March 1994 and amended in September 1994 (Parsons ES, September 1994). This subsection is a summary of the field procedures for the test. The test findings are discussed in the SWMU 17/40 section.

4.5.1 Well Installation

4.5.1.1. As part of the dye-tracing study, three bedrock monitoring wells and two temporary dye-injection wells were installed in the SWMU 17 area. The bedrock wells ranged in depth between 120 feet and 190 feet and were designed to intercept the regional water table associated with the New River. The two dye-injection wells, located in the two major sinkholes of SWMU 17, were installed to a maximum depth of 23.5 feet. The orientation of the injection wells to the New River receptor is shown in Figure 3.10.

major sinkholes of SWMU 17, were installed to a maximum depth of 23.5 feet. The orientation of the injection wells to the New River receptor is shown in Figure 3.10.

4.5.1.2. The bedrock borings were advanced using air-hammer drilling techniques. Prior to well placement, a color television camera was lowered into each borehole to facilitate examination of structural features (bedding planes and fractures) and physical condition (solution features). The wells were then constructed in the borehole with 4-inch inner diameter, flush-joint, schedule 40 PVC pipe and screened over the lower 20 feet.

4.5.1.3. The two temporary dye-injection wells (INJ1 and INJ2) were installed in the southwest corner of the Stage and Burn Area (SWMU 17A) and adjacent to the Runoff Drainage Area (SWMU 17E). The borings were advanced using either air rotary or hollow stem augers drilling methods and were designed to extend through the soil fill material in the bottom of the sinkhole to the bedrock interface. The injection wells were constructed with an open ended 4-inch, inner diameter PVC pipe.

4.5.2 Dye Selection

4.5.2.1. Sodium Fluorescein, Rhodamine WT, and Direct Yellow 96 dyes were chosen for this study. Fluorescein (CI Acid Yellow 73) is a green fluorescent dye that is recovered on activated coconut charcoal. Direct Yellow 96 is a yellow fluorescent dye recovered on unbleached, unwhitened cotton detectors. Rhodamine WT is a pink fluorescent dye recovered on activated coconut charcoal.

4.5.3 Dye Injection

4.5.3.1. Prior to injecting the dye for this study, field reconnaissance activities were conducted of the study area between late May 1993 to early June 1993. These efforts were conducted to locate and verify dye monitoring points and to locate additional monitoring points not previously identified in the Work Plan. During field reconnaissance for the final selection of dye monitoring locations, dye-detector 'bugs' were placed in all prospective monitoring locations that were to be utilized during the dye-trace test. They were retrieved prior to dye injection and tested for background levels of Fluorescein and Direct Yellow dyes. A total of 35 monitoring locations were chosen for the initial dye injections that took place in the fall of 1993. Of these, 27 monitoring locations were used for the second dye injection in the spring of 1994. Approximately one week prior to the second injection, dye-detector 'bugs' were placed at each of the prospective monitoring locations. These bugs were retrieved prior to dye injection and tested for background levels of Rhodamine WT dye.

4.5.3.2. During the initial stage of this investigation, the dyes were introduced on September 23, 1993 during relatively low flow conditions after a storm event. Fluorescein dye was injected into INJ1, located in SWMU 17A. Prior to introduction of the dye, approximately 1,200 gallons of unchlorinated water was pumped into the injection well to saturate the potential flow pathways. The dye was then introduced directly into the well after the slug of water infiltrated into the sinkhole. Following injection, the dye was followed by a chaser of 1,200 gallons of unchlorinated water injected at a moderate and constant rate.

4.5.3.3. A similar injection method was attempted at INJ2, located in the runoff drainage basin (SWMU 17E). Initially, unchlorinated water was pumped into the injection well; however, the water did not infiltrate into the surrounding formation. The remaining 1,150 gallons of water was pumped onto the ground surrounding the injection well in an effort to saturate the entire area. The Direct Yellow dye was then introduced into the well and also poured into the ponded water in the runoff basin. Another 1,200 gallons of unchlorinated water were pumped on the ground at the runoff drainage basin to further saturate the soil overburden and to speed up dye infiltration.

4.5.3.4. During the second stage of this investigation, Rhodamine WT dye was introduced on April 18, 1994 during relatively high flow conditions. Rhodamine WT dye was injected into INJ1, located in SWMU 17A. Prior to introducing the dye, approximately 1,250 gallons of unchlorinated water was pumped into the injection well to saturate the potential flow pathways. The dye was poured directly into the well, after the slug of water infiltrated the sinkhole. Following the injection of the dye, an additional 1,250 gallons of unchlorinated water was pumped into the injection well at a moderate and constant rate.

4.5.4 Dye Monitoring

4.5.4.1. Passive detectors, or "bugs," were used to accumulate dyes for visual examination during this investigation. Fluorometric techniques were used to detect the dye and to provide qualitative and/or semi-quantitative measures of the dye concentration. Visual

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examination was chosen for this study in order to reduce the complexity of the detector processing while still meeting the objectives of the study. Activated charcoal was used to adsorb Fluorescein and Rhodamine WT dye for detection and Direct Yellow was detected on cotton bugs.

4.5.4.2. During both stages of this investigation, both a cotton and a charcoal bug were placed at each monitoring location. Although no dyes were injected in the spring of 1994 that would be detected on a cotton bug, these were used to examine if residual direct yellow dye remained in the groundwater. The bugs were suspended above the stream bed using a weighted, stable stand known as a "gumdrop." Detectors installed in wells were suspended below the water table by a piece of weighted polypropylene rope.

4.5.4.3. A total of 35 locations were monitored for the resurgence of dye during the initial stage of this investigation (15 stream locations, 9 river locations, 7 spring locations, and 4 well locations). A total of 27 locations were monitored for the resurgence of dye during the second stage of this investigation. Seven river monitoring points and one stream monitoring point (SMP 17) were dropped for the second stage of this investigation. These points were dropped based on findings of the initial dye injection which indicated that these were improbable discharge points.

4.5.4.4. During the field reconnaissance phase and prior to each dye injection, detectors were placed at each of the monitoring locations and tested for background levels of the dyes. During the tracing study, the bugs were collected from each monitoring location and analyzed for dye on a daily basis during the first week after dye injection. A biweekly monitoring schedule was implemented during weeks two through twelve of the initial stage of this study. A monthly monitoring schedule was implemented for weeks two through twelve during the second stage of this study. Both the charcoal and cotton bugs were collected from all locations during the monitoring program.

4.6 SURFACE WATER ELEVATION GAUGE INSTALLATION

4.6.0.1. Surface water elevation (staff) guages were installed in each of the three lagoons at SWMU 31, and initially in the New River just beyond the SWMU 31 boundary. The gauges consisted of calibrated steel posts driven by hand into the ground or sediment. The gauges were surveyed to establish water elevations across the SWMU to complete a water balance study of the lagoons and river.

4.6.0.2. The staff gauge installed in the New River was washed away by flooding caused by a heavy rainfall event in January 1995. Therefore, a permanent structure, from which periodic river elevation measurements could be taken, was surveyed and used for the water balance study of the SWMU 31 lagoons. The structure was a concrete abutment at the facility's treatment plant. Measurements were taken with an electronic water level indicator.

4.7 AQUIFER TESTING

4.7.0.1 Slug injection and withdrawal tests were conducted at SWMUs 31 and 48 to determine hydraulic conductivity and transmissivity of the water-bearing strata. The slug tests were performed by subjecting the water-bearing unit in the screened interval of the well to a stress caused by a short-term injection or withdrawal of a known volume (slug). The response of the water-bearing units to the stress was measured by recording the water level rise or fall in the test well as it returned to equilibrium (pre-test) conditions.

4.7.0.2. Seven injection (falling-head) and three withdrawal (rising-head) tests were conducted at the two different SWMUs. Subsection 8.4.3.1 provides results from the four injection tests and two withdrawal test at SWMU 31. Subsection 9.4.3.1 provides results from the three injection tests and one withdrawal test at SWMU 48.

4.7.0.3. Initial static water levels were collected before testing took place. A data logger was then connected to a pressure transducer and placed at the bottom of the well. The water level was allowed to stabilize after insertion of the transducer; this new stabilized water level was recorded in a field log book and then input into the data logger before starting the slug test. Injection tests were performed by rapidly inserting the slug into the well followed by data logger and hand-measurements (for confirmation) of the subsequent water level changes until 98% of the pre-insertion static water level was attained. Withdrawal tests were then performed on the test well by rapidly removing the slug from the well column and monitoring the water level rise to within 98% of the static level, or a period of 24 hours was reached.

4.7.0.4. The slugs used for this investigation were five feet in length and constructed with 2-inch inner diameter PVC pipe. Clean #2 weight gravel pack sand was placed in the PVC pipe to ensure maximum water level displacement. The slugs and other downhole equipment were decontaminated in accordance with Work Plan procedures prior to and after each test to avoid cross-contamination.

4.7.0.5. Note that a modified version of the Work Plan specified procedure was used for the slug tests. The modification from pumping to slug injection was made to eliminate the need to containerize potentially contaminated groundwater.

4.7.0.6. There were two exceptions to the slug test procedures described above. Wells 31MW2 and 48MW2 were not tested using the five foot PVC pipe slugs. Well 31MW2 only contained 3.5 feet of water; the PVC slug would not have displaced a sufficient amount of water for the slug test. Therefore, five gallons of deionized water were added to the well to conduct a falling-head test. Because the water had to be poured into the well, hand-measurements of the water levels could not begin until 30 seconds after the data logger was started. Similarly, 48MW2 was not tested with a PVC slug. 48MW2 is constructed with a 2 inch PVC casing and that diameter is not large enough to accommodate the slug. Five gallons of deionized water were added to this well to conduct a falling-head test. Hand-measurements were taken approximately 40 seconds after the data logger was started.

4.7.0.7. The slug test data were analyzed using the Bouwer and Rice (1976) method. The fitting of data to an "S"-shaped type curve for the Bouwer and Rice straight line (1976) method permits the calculation of hydraulic conductivity and transmissivity for the formation surrounding the well screen. Type curves and calculation sheets are included in Appendix E.

4.8 SURVEYING

4.8.0.1. Surveying activities were completed by Geotrack, Inc., a firm licensed in the state of Virginia. Location coordinates of data points were established within 3.0 feet using the Virginia State Planar Coordinate System of 1927. Elevations were established within 0.01 feet using the National Geodetic Vertical Datum of 1929. Initially, all data points were surveyed with reference to the 1983 State Planar Coordinate System to be compatible with the facility's mapping system. However, these data were then converted to the 1927 coordinate system to be compatible with the USAEC's IRDMIS data base. Geotrack, Inc. used the 1983 data to locate the surveyed points on the facility's electronic files. The SWMU location maps were then produced from the electronic files. Table 4.2 presents the elevations and location coordinates (northings and eastings in the 1927 system format) of the data points surveyed for this investigation.

4.8.0.2. The elevations of all eight monitoring wells installed by Parsons ES were surveyed at the top of the casing (T.O.C.) and at the concrete pad (equivalent to ground surface elevation). Location coordinates were also surveyed for the wells. Although the Work Plan called only for estimates of elevations for all soil borings, elevations of the borings for SWMUs 48 and 54 were surveyed by Geotrack. The elevations of the three staff gauges and the concrete abutment measuring point were surveyed. All other elevation and location coordinate data, including the soil borings at SWMU 17 and the background metals study soil borings, were estimated using data from the nearest surveyed point.

4.9 SAMPLING AND ANALYSIS PROGRAM

4.9.0.1. The sampling and analysis program was designed to meet the objectives stated in Subsection 1.2 of this report. The locations and numbers of samples and the analyses performed were selected to optimize the identification of sources of contaminants, pathways of contaminant migration, and the extent of contamination. The sampling methodologies considered the characteristics of known contaminants as well as the need to identify suspected contaminants. The program was carried out in accordance with the sampling procedures, analytical methodology, and sample nomenclature described in the Work Plans and Quality Assurance Project Plan (QAPP). The following subsections describe what samples were collected, what analyses were performed, and any deviations from the Work Plans or QAPP. The analytical results are discussed in detail in subsequent sections. Sample locations are shown on the location maps for the area of concern in subsequent sections. A summary of all samples collected, including QA/QC samples, and the analyses performed (with USEPA analytical method numbers) is presented in Table 4.3 for aqueous samples and Table 4.4 for solid samples.

4.9.1 Surface Water

4.9.1.1. A total of nine surface water samples were collected from the New River, a spring directly discharging to the river, and Stroubles Creek. Sample SPG3SW1 was from a

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TABLE 4.2
SURVEY DATA
RADFORD ARMY AMMUNITION PLANT

SWMU	Well	Elevation of T.O.C. (1)	Coordinates (2)	
			Northing	Easting
17	INJ1	1872.43	313343	1403827
	INJ2	1866.28	313055	1404221
31	31MW1	1715.04	319116	1397410
	31MW2	1699.05	319485	1397410
	31MW3	1698.82	319382	1397251
	31MW4	1698.55	319208	1397041
48	48MW1	1819.95	319695	1409679
	48MW2	1818.88	319446	1409717
	48MW3	1812.17	319463	1409912
	48MW4	1832.60	319840	1409453

SWMU	Staff Gauge	Elevation of 3.0' mark
31	31SG1	1692.23
	31SG2	1687.54
	31SG3	1685.10

SWMU	Soil Boring	Ground Surface Elevation
48	48SB4	1830.4
	48SB5	1823.5
54	54SB1	1697.3
	54SB2	1699.1
	54SB3	1696.6
	54SB4	1697.0
	54SB5	1697.0
	54SB6	1700.9
	54SB7	1700.1
	54SB8	1699.4
	54SB9	1697.9
	54SB10	1696.6
	54SB11	1697.3
	54SB12	1696.8
	54SB13	1700.0
	54SB14	1699.6
	54SB15	1704.5
	54SB16	1697.0

(1) For monitoring and injection wells elevations are given for the top of casing (T.O.C.).
All elevations are in feet above mean sea level.

(2) Coordinates given in Virginia State Planar System, North American Datum 1927 - CONUS. Clarke, 1866.

NOTE: Only those points surveyed are shown; survey data of other points were estimated in accordance with the Work Plan.

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TABLE 4.3
RFI ANALYTICAL PROGRAM: AQUEOUS SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name	Media(2)	Analytical Parameter (1)												Comments
			Total Metals	Diss. Metals (3)	Explosives	VOCs	SVOCs	TOC	TOX	TPH	Chloride	Hardness	COD	Field Meas. (4)	
SWMU 17															
Contaminated Waste Burning Area	17PZ1	GW	Z	X, Z	X			X	X					X, Z	
	17MW2	GW	Z	X, Z	X			X	X					X, Z	
	17MW3	GW	Z	X, Z	X			X	X					X, Z	
	40MW3	GW	Z	X, Z	X			X	X					X, Z	
SWMU 17															
Discharge Point	SPG3SW1	SW	X		X			X	X					X, Z	
SWMU 31															
Coal Ash Settling Lagoons	31MW1	GW	Z	X, Z				X	X					X, Z	
	31MW2	GW	Z	X, Z				X	X					X, Z	
	31MW3	GW	Z	X, Z				X	X					X, Z	
	31MW4	GW	Z	X, Z				X	X					X, Z	
SWMU 48															
Oily Wastewater Disposal Area	48MW1	GW	Z	X, Z		Z	X	X	X	X	X	X	X	X, Z	
	48MW2	GW	Z	X, Z		Z	X	X	X	X	X	X	X	X, Z	
	48MW3	GW	Z	X, Z		Z	X	X	X	X	X	X	X	X, Z	
	48MW4	GW	Z	Z		Z	Z							Z	
SWMU 54															
Propellant Ash Disposal Area	54MW1	GW	Z	Z	Z			Z	Z					Z	
	54MW2	GW	Z	Z	Z			Z	Z					Z	
	54MW3	GW	Z	Z	Z			Z	Z					Z	
Stroubles Creek	SCSW1	SW	X		X	X	X	X	X		X	X		X	
	SCSW2	SW	X		X	X	X	X	X		X	X		X	
New River	NRSW1	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	
	NRSW2	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	
	NRSW3	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	
	NRSW4	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	
	NRSW5	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	
	NRSW6	SW	Z		Z	Z	Z	Z	Z		Z	Z		Z	

TABLE 4.3 (Contined)
RFI ANALYTICAL PROGRAM: AQUEOUS SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name	Media(2)	Analytical Parameter (1)												Comments
			Total Metals	Diss. Metals (3)	Explosives	VOCs	SVOCs	TOC	TOX	TPH	Chloride	Hardness	COD	Field Meas. (3)	
QA/QC Samples															
SWMU 17 Contaminated Waste Burning Area	17FBAQGW	GW	X		X			X	X						Field Blank
SWMU 17 Discharge Point	SPG3FBAQ	SW	X		X			X	X						Field Blank
SWMU 31 Coal Ash Settling Lagoons	31MW5	GW	X					X	X						Field Duplicate of 31MW3
SWMU 48 Oily Wastewater Disposal Area	48EQGW	GW	X				X	X	X	X	X	X	X		Equipment Blank
	48MWTB	GW				Z									Trip Blank
	48MWTB2	GW				Z									Trip Blank
SWMU 54 Propellant Ash Disposal Area	54MWEQ	GW	Z	Z	Z			Z	Z						Equipment Blank
New River	NRSW8	SW	Z		Z	Z	Z	Z	Z		Z	Z			Field Duplicate of NRSW5
	NRSWTB2	SW				Z									Trip Blank
	NRSWTB3	SW				Z									Trip Blank
	NRSWFB	SW	Z		Z	Z	Z	Z	Z		Z	Z			Field Blank
Stroubles Creek	SCSW3	SW	X		X	X	X	X	X		X	X			Field Duplicate of SCSW 2
	SCTBAQ	SW				X									Trip Blank

(1) ANALYTICAL PARAMETERS

Metals (Total and Dissolved) by SW-846 6010/7000 series.
Explosives by SW-846 8330
Volatile Ogranics (VOCs) by SW-846 8240
Semivolatile Ogr彼nics (SVOCs) by SW-846 8270
Total Organic Carbon (TOC) by MCAWW 415.1
Total Petroleum Hydrocarbons (TPH) by SW-846 3550/MCAWW 418.1
Chloride
Hardness by SM2340-B
COD

(2) MEDIA

GW - Groundwater
SW - Surface Water

(3) FIELD MEASUREMENTS

pH, temperature, and conductivity, measured at the time of collection

NOTES: X indicates January 1995 sampling
Z indicates July 1995 sampling
Dissolved metals were sampled in January and July 1995

TABLE 4.4
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

			Analytical Parameter (1)										
Area	Field Sample Name (2)	Media (3)	Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	Comments
SWMU 17 *(17A)* Stage and Burn Area	17ASB105	SO	X	X	X	X							
	17ASB110	SO	X	X									
	17ASB115	SO	X	X									
	17ASB120	SO	X	X									
	17ASB122	SO	X	X	X	X							
	17ASB1	SO					X			X		X	Composite Sample
	17ASB205	SO	X	X	X	X							
	17ASB210	SO	X	X									
	17ASB215	SO	X	X									
	17ASB220	SO	X	X									
	17ASB225	SO	X	X	X	X							
	17ASB2	SO					X			X		X	Composite Sample
	17ASS3	SO	X	X									
	17ASB305	SO	X	X	X	X							
	17ASB310	SO	X	X									
	17ASB315	SO	X	X									
	17ASB320	SO	X	X									
	17ASB325	SO	X	X	X	X							
	17ASB3	SO					X			X		X	Composite Sample
SWMU 17 *(17B)* ACD Staging Area	17BSS1	SO	X	X									
	17BSS2	SO	X	X									
ACD	17CSB105	SO	X	X									
	17CSB110	SO	X	X									
	17CSB114	SO	X	X									
	17CSB1	SO					X			X		X	Composite Sample
	17CSB205	SO	X	X									
	17CSB210	SO	X	X									
	17CSB215	SO	X	X									
	17CSB2	SO					X			X		X	Composite Sample

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1) Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	Comments
SWMU 17 *17 (D)* ACD Ash Staging Area	17DSB105	SO	X	X									
	17DSB110	SO	X	X									
	17DSB115	SO	X	X									
	17DSB120	SO	X	X									
	17DSB125	SO	X	X									
	17DSB127	SO	X	X									
	17DSB1	SO					X			X		X	Composite Sample
	17DSB205	SO	X	X									
	17DSB210	SO	X	X									
	17DSB215	SO	X	X									
	17DSB220	SO	X	X									
	17DSB225	SO	X	X									
	17DSB2	SO					X			X		X	Composite Sample
SWMU 17 Discharge Point	SPG3SE1	SE	X	X			X	X					
SWMU 31 Coal Ash Settling Lagoons	31MW1A25	SO	X										
	31MW1B35	SO	X										
	31MW2A12	SO	X										
	31MW2B22	SO	X										
	31MW3A10	SO	X										5-10' Interval Sampled
	31MW3B20	SO	X										15-20' Interval Sampled
	31MW4A12	SO	X										
	31MW4B22	SO	X										
	31SE1	SE					X			X		X	Composite Sample
	31SE2	SE								X		X	Composite Sample
	31SE3	SE					X			X		X	Composite Sample
	31SE4	SE								X		X	Composite Sample
	31SE5	SE					X			X		X	Composite Sample
	31SE6	SE								X		X	Composite Sample

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1)										Comments
			Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	
SWMU 48	48SB4A11	SO		X	X	X			X				10-11' Interval Sampled
Oily Wastewater	48SB4B21	SO		X	X	X	X		X				20-21' Interval Sampled
Disposal Area	48SB4	SO								X		X	Composite Sample
	48SB5A19	SO				X			X				
	48SB5B37	SO				X	X		X				
	48SB5	SO								X		X	Composite Sample
	48SS1	SO	X	X	X	X			X				
	48SS2	SO	X	X	X	X			X				
	48SS3	SO	X	X	X	X			X				
	48SS4	SO	X			X			X				
	48SS5	SO	X			X			X				
	48SS6	SO	X			X			X				
	48MW1A22	SO				X			X				
	48MW1B54	SO				X	X		X				
	48MW2A42	SO				X			X				
	48MW2B46	SO				X	X		X				
	48MW3A22	SO				X			X				
	48MW3B32	SO				X	X		X				
SWMU 54													
Propellant Ash	54SS1	WA										X	Composite Sample
Disposal Area	54SS2	WA										X	Composite Sample
	54SB1A2	SO	X	X									
	54SB1B22	SO	X	X			X						
	54SB2A2	SO	X	X									
	54SB2B17	SO	X	X									
	54SB3A2	SO	X	X									
	54SB3B17	SO	X	X									
	54SB4A2	SO	X	X									
	54SB4B17	SO	X	X									
	54SB5A2	SO	X	X									
	54SB5B17	SO	X	X									

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1) Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	Comments
SWMU 54 Propellant Ash Disposal Area	54SB6A2	SO	X	X									
	54SB6B15	SO	X	X									10-15' Interval Sampled
	54SB7A2	SO	X	X									
	54SB7B17	SO	X	X									
	54SB8A2	SO	X	X									
	54SB8B17	SO	X	X									
	54SB9A7	SO	X	X									
	54SB9B17	SO	X	X									
	54SB10A2	SO	X	X									
	54SB10B17	SO	X	X			X						
	54SB11A2	SO	X	X									
	54SB11B17	SO	X	X									
	54SB12A2	SO	X	X									
	54SB12B17	SO	X	X									
	54SB13A2	SO	X	X									
	54SB13B22	SO	X	X									
	54SB14A2	SO	X	X									
	54SB14B15	SO	X	X			X						11-12' Interval Sampled
	54SB15A6	SO	X	X									
	54SB16A2	SO	X	X									
	54SB16B12	SO	X	X			X						
Stroubles Creek	SCSE1	SE	X	X	X	X	X	X					
	SCSE2	SE	X	X	X	X	X	X					
New River	NRSE1	SE	X	X	X	X	X	X					
	NRSE2	SE	X	X	X	X	X	X					
	NRSE3	SE	X	X	X	X	X	X					
	NRSE4	SE	X	X	X	X	X	X					
	NRSE5	SE	X	X	X	X	X	X					
	NRSE6	SE	X	X	X	X	X	X					

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

			Analytical Parameter (1)										
Area	Field Sample Name (2)	Media (3)	Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	Comments
Background Soil Sampling	BG1BUC3	SO	X				X				X		
	BG1CUC8	SO	X										
	BG2BUC5	SO	X										
	BG2CUC11	SO	X										
	BG3BUC3	SO	X										
	BG3CUC22	SO	X										
	BG4BUC5	SO	X										
	BG4CUC17	SO	X				X				X		
	BG5BUC3	SO	X										
	BG5CUC8	SO	X										
	BG6BUC5	SO	X										
	BG6CUC12	SO	X										
	BG7BUC5	SO	X										
	BG7CUC22	SO	X										
	BG8BUC5	SO	X				X				X		
	BG8CUC10	SO	X				X				X		
	BG1BBL4	SO	X				X				X		
	BG1CBL10	SO	X				X				X		
	BG2BBL5	SO	X										
	BG2CBL17	SO	X				X				X		
	BG3BBL3	SO	X										
	BG3CBL22	SO	X										
	BG4BBL5	SO	X				X				X		
	BG4CBL10	SO	X										
	BG1BWL5	SO	X										
	BG1CWL8	SO	X										
	BG2BWL4	SO	X										
	BG2CWL12	SO	X										
	BG3BWL3	SO	X										
	BG3CWL22	SO	X				X				X		
	BG4BWL4	SO	X										
	BG4CWL17	SO	X										
	BG5BWL3	SO	X				X				X		
	BG5CWL8	SO	X				X				X		
	BG6BWL4	SO	X				X				X		
	BG6CWL17	SO	X										

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

Area	Field Sample Name (2)	Media (3)	Analytical Parameter (1)										Comments
			Metals	Explosives	VOCs	SVOCs	TOC	TOX	TPH	BTU	pH	Waste Char.	
QA/QC Samples													
SWMU 17													
Stage and Burn Area 17(A)	17AFBSO	SO	X	X	X	X							Field Blank
	17ASB340	SO	X	X	X	X	X						Field Duplicate of 17ASB315
ACD 17(C)	17CSB240	SO	X	X			X						Field Duplicate of 17CSB210
ACD Ash 17(D) Staging Area	17DSB240	SO	X	X			X						Field Duplicate of 17DSB210
SWMU 17													
Discharge Point	SPG3FBSE	SE	X	X			X	X					Field Blank
SWMU 31													
Coal Ash Settling Lagoons	31MWFBSO	SO	X										Field Blank
	31MWEQSO	SO	X										Equipment Blank
	31MW4C40	SO	X										Field Duplicate of 31MW4A12
SWMU 48													
Oily Wastewater Wastewater Disposal Area	48TBSO	SO			X								Trip Blank
	48EQSO	SO	X	X	X	X	X		X				Equipment Blank
	48SS8	SO	X	X	X	X	X		X				Field Duplicate of 48SS2
SWMU 54													
Propellant Ash Disposal Area	54TBSO	SO			X								Trip Blank
	54EQSO1	SO	X	X			X						Equipment Blank
	54FBSO	SO	X	X			X						Field Blank
	54SB10B20	SO	X	X			X						Field Duplicate of 54SB10B17
	54SB16B25	SO	X	X			X						Field Duplicate of 54SB16B12
	54EQSO2	SO	X	X			X						Equipment Blank
	54EQSOWA	WA	X										Equipment Blank
Stroubles Creek	SCEQSE	SE	X	X	X	X	X	X					Equipment Blank
	SCSE3	SE	X	X	X	X	X	X					Field Duplicate of SCSE2
New River	NRSE8	SE	X	X	X	X	X	X					Field Duplicate of NRSE5
	NRSEEQ	SE	X	X	X	X	X	X					Equipment Blank

TABLE 4.4 (Continued)
RFI ANALYTICAL PROGRAM: SOLID SAMPLES
RADFORD ARMY AMMUNITION PLANT

			Analytical Parameter (1)										
Area	**Field Sample Name (2)**	**Media (3)**	**Metals**	**Explosives**	**VOCs**	**SVOCs**	**TOC**	**TOX**	**TPH**	**BTU**	**pH**	**Waste Char.**	**Comments**
Background Soil Sampling	BG4CUCD	SO	Z				Z				X		Duplicate of BG4CUC17
	BG4BBLD	SO	Z				Z				X		Duplicate of BG4BBL5
	BG5CWLD	SO	Z										Duplicate of BG5CWL8
	FBLK1	SO	Z										Field Blank
	EQBLK	SO	Z										Equipment Blank

(1) ANALYTICAL PARAMETERS

Metals by SW-846 6010/7000 series
Explosives by SW-846 8330
Volatile Organics (VOCs) by SW-846 8240
Semivolatile Organics (SVOCs) by SW-846 8270
Total Organic Carbon (TOC) by MCAWW 415.1
Total Organic Halogens (TOX) lby SW-846 9020
Total Petroleum Hydrocarbons (TPH)
 by SW-846 3350/MCAWW 418.1
British Thermal Units (BTU) by ASTM D240-76
Waste Characterization (Waste Char.) Includes:
 TCLP Metals by SW-846 1211/6010/7000 Series
 Ignitability by SW846 7.1.2.2
 Corrosivity by SW-846 9045
 Reactivity by Chap 7/9030, 9012
 Paint Filter Test by SW-846 9095

(2) FIELD SAMPLE NAME

The Sample Name indicates Area (SWMU or River, etc), Type (SB is a boring sample, ss is a surface soil, BG is a Background Sample), and depth (unless otherwise noted, for "SB" samples, last two digits is botton of 2 ft spoon interval, for "BG" samples, the number following the soil type is the bottom of 2 ft spoon interval).

Soil Types for "BG" SX are:
UC = Unison Urban Complex
BL = Braddock Loam
WL = Whelling Loam

(3) MEDIA

SO - Soil
SE- Sediment

Notes: The Background Soil Samples (BG and the New River Samples (NR) were collected in July 1995. All others were Sampled December 1994 or January 1995.

spring determined to be the discharge point of the dye injected at SWMU 17. It was sampled in January 1995 for metals, explosives, total organic carbon (TOC), and total organic halogens (TOX). This was the only location identified as a discharge point for SWMU 17.

4.9.1.2. Two surface water samples were collected from Stroubles Creek in January 1995. The creek, a main tributary to the New River, was sampled upstream of the facility (SCSW1) and at the point of discharge to the river (SCSW2), for metals, explosives, TOC, TOX, volatile organic compounds (VOCs), semi-volatile compounds (SVOCs), hardness, and chloride. The creek was relatively high and fast moving at the time of sampling.

4.9.1.3. Six surface water samples were collected from the New River in July 1995 for characterization purposes. The samples were analyzed for the same parameters listed in 4.9.1.2 above. The samples, which were intended to provide supplemental risk assessment information, were located near the likely discharge points of SWMU 31 (NRSW6), SWMU 48 (NRSW4), and SWMU 54 (NRSW5), or up river of the facility (NRSW1, 2, and 3).

4.9.1.4. In addition to those samples, associated surface water QA/QC samples were also collected in accordance with the QAPP. Those included a trip blank and field duplicate for the Stroubles Creek samples, a field blank for the spring sample, and a field duplicate, trip blank and field blank associated with the New River samples. Field parameters, including pH, temperature, and conductivity, were collected for all surface water samples.

4.9.2 Groundwater

4.9.2.1. A total of 15 groundwater samples were collected from the eight new monitoring wells and from several existing wells at SWMUs 17/40 and 54. Eleven wells were sampled in January 1995 and all 15 wells were sampled in July 1995 (when 48MW4 was installed and the SWMU 54 wells were added). The sampling procedures followed the Work Plan with only minor deviations as described below.

4.9.2.2. Based upon comments received from the USEPA after completion of the initial round of groundwater sampling, additional sampling was scheduled. Initially, only dissolved metals were collected from all of the wells. In July 1995, it was determined that total metals analyses were also required. Therefore, in July 1995, all of the wells were sampled for total metals and re-sampled for dissolved metals so that the metals data from the two parameters would not be affected by the time passage between sampling events.

4.9.2.3. Purging of the wells was generally completed by hand bailing with PVC bailers for shallow wells and submersible pumps for deeper wells. All groundwater samples were collected in disposable polyethylene bailers. A pressure filter device (0.45 micron) was attached to the bailer for the collection of dissolved metals samples. Field parameters, including pH, temperature, and conductivity, were measured before and after collection of the sample. Table 4.1 includes groundwater elevations recorded in July 1995, when all wells were gauged and sampled.

4.9.2.4. Three monitoring wells at SWMU 17 were sampled for total metals, dissolved metals, explosives, TOC, and TOX. One well at SWMU 40 was sampled for the same parameters. All were bedrock wells. Shallower wells 40MW2 and 40MW4 were dry in January and July 1995 and could not be sampled. Well 17MW3, a deep bedrock well, was purged by hand bailing due to a pump malfunction; the other wells were purged with a pump. In general, all wells recharged quickly enough to remove the required volumes of groundwater, but all were completely dried once or twice before the required purge volume was achieved. Associated QA/QC samples included a field blank.

4.9.2.5. Four monitoring wells were sampled at SWMU 31 for total metals, dissolved metals, TOC, and TOX. All four wells were purged by hand bailing. Only 31MW2 and 31MW3 were purged dry before the required volume was achieved (in the July 1995 event); the others had moderate to good recharge rates. A field duplicate was taken for QA/QC purposes.

4.9.2.6. Three monitoring wells at SWMU 48 were sampled for total metals, dissolved metals, VOCs, SVOCs, TOC, TOX, total petroleum hydrocarbons (TPH), chloride, hardness, and chemical oxygen demand (COD). The well installed in July 1995 (48MW4) was sampled for total and dissolved metals, and VOCs. All four wells were completed in the bedrock. Recharge in these wells ranged from slow to very slow. 48MW4 was purged by hand bailing because of a pump malfunction; 48MW2 was purged by hand because of the small diameter of the well. 48MW1 and 48MW3 were purged by pumping. VOCs were added as an

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analytical parameter (for all four wells) to the July re-sampling event; VOC samples were not collected in January 1995. QA/QC samples included an equipment blank and two trip blanks.

4.9.2.7. Sampling of the monitoring wells at SWMU 54 was not proposed in the Work Plan. However, to supplement risk assessment and site characterization information, the three monitoring wells, which were not sampled in January 1995, were included in the sampling activities during July 1995. The wells were sampled for total metals, dissolved metals, explosives, TOC, and TOX. Wells 54MW1 and 54MW2 were relatively slow rechargers; all were purged by hand bailing. An equipment blank was taken for QA/QC purposes.

4.9.3 Soil

4.9.3.0.1. Surface and subsurface soil samples were collected during the investigation for chemical analysis. In addition, soil samples (generally subsurface) were also submitted for geotechnical analysis in accordance with USAEC requirements. The sample totals discussed below include the subsurface soils taken for the soil metals background study. All samples were collected following the Work Plan procedures unless otherwise noted below.

4.9.3.1 Surface Soils

4.9.3.1.1. A total of nine surface soil samples were collected with a stainless steel bowl and spoon for the investigation. All were sampled in December 1994. Three samples, 17ASS3, 17BSS1, and 17BSS2 were taken at SWMU 17. 17ASS3 was the top layer (0-0.5 feet) of the 17ASB3 boring sample. These surface soil samples were analyzed for total metals and explosives.

4.9.3.1.2. Six surface soil samples were collected at SWMU 48. Three samples were taken from the upper disposal area and analyzed for total metals, explosives, VOCs, SVOCs, and TPH. Three samples were collected from the lower disposal area and submitted for total metals, SVOCs, and TPH analysis. All six samples were obtained with a stainless steel spoon and bowl. A field duplicate sample was taken for QA/QC purposes.

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4.9.3.2 Subsurface Soils

4.9.3.2.1. A total of 126 subsurface soil samples were collected for the investigation. This total includes samples composited for remediation and disposal characterization but does not count samples submitted for geotechnical analysis. All sampling was done by split spoon methodology as described in the Work Plan. The sample name, as shown on Table 4.3 includes the depth. Unless otherwise specified, the depth is indicated by the last one or two digits of the name with the number being the bottom of the two foot spoon interval, e.g., 17ASB105 was taken from a depth of 3-5 feet. Depths were specified in the Work Plan based on a review of previous data or an assessment of site conditions. Any deviations from this plan are based on field observations or physical difficulties in obtaining the sample from the proposed depth.

4.9.3.2.2. A total of 39 subsurface soil samples from seven borings in four separate areas of SWMU 17 were collected. Five samples from boring 17ASB1 were taken at five foot intervals and analyzed for total metals and explosives. Additionally, the shallowest and deepest samples of this boring were submitted for VOCs and SVOCS. A sample composited from the entire hole was analyzed for TOC, British Thermal Units (BTUs), and waste characterization (TCLP-full list, corrosivity, ignitability, reactivity, and the paint filter test). The sample plan was the same for borings 17ASB2 and 17ASB3.

4.9.3.2.3. In a different area of SWMU 17, three subsurface soil samples were collected from boring 17CSB1 at five foot intervals for total metals and explosives analysis. A composite of the entire hole was submitted for TOC, BTU, and waste characterization analysis. The sample plan was the same for boring 17CSB2. Drilling auger refusal was encountered sooner than predicted in this area resulting in two fewer samples being collected from each boring than was proposed in the Work Plan. Auger refusal was at approximately 15 feet.

4.9.3.2.4. Boring 17DSB1 produced six samples and one composite, which were submitted for the same analyses as described in 4.9.3.2.3 above. Bedrock was not reached in this hole until drilling had progressed beyond the depth predicted in the Work Plan. Therefore, an additional sample was taken. Boring 17DSB2 produced five samples and one composite, which were submitted for the same analyses as 17DSB1. SWMU 17 subsurface soil QA/QC samples included a field blank and three field duplicates.

4.9.3.2.5. Eight total subsurface soil samples were collected from SWMU 31, two from each monitoring well boring. The samples were submitted for total metals analysis. The intention of the sampling was to determine migration potential of the metals from the lagoons to the New River. Therefore, the samples were taken from depths at or near the lagoon water levels and at or just below the lagoon bottoms. The 31MW3 boring was sampled continuously with the Moss Sampler; the samples from this boring are a composite of the five foot spoon interval (e.g., 31MW3A10 is the shallow sample composited from 5-10 feet). Associated QA/QC samples included a field blank, equipment blank, and a field duplicate.

4.9.3.2.6. Two subsurface soil samples and one composite of the hole were taken from each of two soil borings at SWMU 48. The shallowest sample from the boring (48SB4) in the upper disposal area was analyzed for explosives, VOCs, SVOCs, and TPH. The deepest sample was analyzed for those parameters plus TOC. The composite from this hole was submitted for BTU and waste characterization analysis. The samples from the boring (48SB5) in the lower disposal area were analyzed for SVOCs and TPH, with the deepest sample from the boring additionally being analyzed for TOC. The composite from this hole was analyzed for BTUs and waste characterization. Sampling depths were based on PID readings and visual observations.

4.9.3.2.7. Two subsurface soil samples were collected from each of three monitoring well borings at SWMU 48 (the 48MW4 boring soils were not sampled since this well was placed adjacent to the 48SB4 boring). The objective was to sample at the deepest level of contamination, based on PID readings and visual evidence, and just below the deepest contamination. The shallower of the two samples from each well boring was analyzed for SVOCs and TPH. The deeper of the two samples was analyzed for those parameters plus TOC. An equipment blank and a trip blank were submitted for QA/QC purposes.

4.9.3.2.8. Two subsurface soil samples from each of sixteen soil borings were proposed for SWMU 54. Due to drilling rig access problems at the north mound, only one subsurface soil sample was taken at 54SB15 (hand augered to a depth of 6 feet). Therefore the total number of samples was 31. The samples were taken from just below visual evidence of propellant ash or from 6-12 inches if no ash was visible, and from any other areas of visible contamination or just above the water table if contamination was not evident. All samples were analyzed for total metals and explosives with borings 54SB1, 54SB10, 54SB14, and

54SB16 also being analyzed for TOC. Associated QA/QC samples included a field blank, a trip blank, an equipment blank, and a field duplicate.

4.9.3.2.9. As described in Subsection 4.4, two subsurface soil samples from each of 18 soil borings advanced in three different soil types were collected for the soil background metals study. The samples were collected using continuous split spoons so that the B and C soil horizons could be identified. One soil sample from each of those horizons was taken from each boring. All samples were analyzed for total metals, Additionally, four samples from each soil type were analyzed for pH and TOC. Three field duplicates (one from each soil type), one field blank, and one equipment blank were collected for QA/QC purposes. The visual manual soil classification system was applied to the samples; a summary of this information is included in Appendix F.

4.9.3.3 Geotechnical Samples

4.9.3.3.1. A total of 31 subsurface soil samples were submitted for geotechnical analysis. The analyses included particle size distribution, Atterberg limits, and Unified Soil Classification System (USCS) categorization. Nineteen of the 31 samples were collected from the various SWMU borings with most of those coming from SWMU 54. The other 12 samples were taken during the background metals study, four from each of the three soil types. Table 4.5 presents a summary of the geotechnical sampling and analysis. The laboratory data for the geotechnical sampling is included in Appendix F.

4.9.3.3.2. All the geotechnical samples were originally intended to be collected using a Shelby tube (a thin walled sampling device). However, due to difficult drilling caused by gravel or hard conditions, little success was achieved with the Shelby tube approach; only one sample, 31MW1, could be obtained with this method. Discussions with the geotechnical laboratory project manager revealed that samples for the above listed parameters could be collected in large jars without an impact to the quality of the results. Therefore, most of the geotechnical samples were collected in two 16 ounce jars for shipment to the laboratory.

4.9.4 Sediment

4.9.4.0.1. A total of 15 sediment samples were taken from surface water bodies (Stroubles Creek and the New River) and lagoons. Surface water samples were associated with

TABLE 4.5
GEOTECHNICAL SAMPLING
RADFORD ARMY AMMUNITION PLANT

AREA	SAMPLE NAME	DEPTH
SWMU 31	31MW1	10-12'
SWMU 48	48MW2	10-12'
	48MW3	10-12'
	48SB5	10-11'
SWMU 54	54SB1	15-17'
	54SB2	10-12'
	54SB3	10-12'
	54SB4	5-7'
	54SB5	15-17'
	54SB6	15-20'
	54SB7	10-12'
	54SB8	15-17'
	54SB9	10-12'
	54SB10	10-12'
	54SB11	15-17'
	54SB12	5-7'
	54SB13	5-7'
	54SB14	7-9'
	54SB16	10-12'
BACKGROUND SOILS	BG1BUC3	3-5'
	BG4CUC17	15-17'
	BG8BUC5	3-5'
	BG8CUC10	8-10'
	BG3CWL22	20-22'
	BG5BWL3	1-3'
	BG5CWL8	6-8'
	BG6BWL4	2-4'
	BG1BBL4	2-4'
	BG1CBL10	8-10'
	BG2CBL17	15-17'
	BG4BBL5	3-5'

All samples were analyzed for particle size distribution, Atterberg limits, and Unified Soil Classification System (USCS) categorization.

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the New River sediments and the Stroubles Creek sediments, but not the SWMU 31 lagoon sediments.

4.9.4.1 Surface Water Bodies

4.9.4.1.1. Two sediment samples were collected from Stroubles Creek. SCSE1 is associated with surface water sample SCSW1 (upstream of the facility) and SCSE2 is associated with SCSW2 (the discharge point of the creek into the New River). The sediments were sampled in January 1995 during relatively high, fast moving water conditions. The samples were submitted for total metals, explosives, VOCs, SVOCs, TOC, and TOX. The spring which was determined by dye tracing to be the discharge point of SWMU 17 into the New River was also sampled in January 1995. Associated with sample SPG3SW1, SPG3SE1 was sampled for total metals, explosives, TOC, and TOX. QA/QC samples included a field blank, an equipment blank, and a field duplicate.

4.9.4.1.2. Six New River sediment samples, associated with the New River surface water samples, were collected in July 1995 (see Subsection 4.9.1). The samples were taken during relatively calm, low water conditions and were analyzed for total metals, explosives, VOCs, SVOCs, TOC, and TOX. A duplicate sample and an equipment blank were collected for QA/QC purposes.

4.9.4.2 Lagoons

4.9.4.2.1. Two sediment samples were collected from each of the three lagoons at SWMU 31. The objective of the sampling was to determine the potential for eventual disposal of the sediments. The samples were analyzed for BTUs and waste characterization, with one of the two from each lagoon also being analyzed for TOC. Each sample was collected by compositing several hand augered borings from one area of the lagoon. The hand auger was advanced as deeply as possible to characterize the total sediment column. Generally, the auger could not penetrate below six feet into the sediment. This procedure was repeated in the opposite corner of the lagoon. The other lagoons were sampled in the same manner.

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4.9.5 Waste

4.9.5.0.1. Two propellant ash waste samples, one from each mound, were taken at SWMU 54. The samples were submitted for waste characterization analysis (TCLP metals, corrosivity, reactivity, ignitability, and the paint filter test). The samples were collected by compositing four discrete samples from around each ash pile in a stainless steel bowl. An equipment blank was also submitted for QA/QC purposes.

4.10 INVESTIGATION DERIVED WASTE

4.10.0.1. All drilling generated fluids, well development or purge water, or general decontamination generated fluids were discharged to the facility's industrial treatment plant in accordance with the Work Plan and past investigation field practices. No fluids were discharged directly to the ground.

4.10.0.2. Soil cuttings were placed on heavy plastic sheeting and covered for protection from the elements, or were placed directly into D.O.T. type-H drums, until the results of the waste characterization sampling were known. When the analyses revealed that no hazardous constituents were present, the soil was spread around the facility. Since the soil background metals borings did not generate much soil (small diameter augers were used), and since the areas were chosen because they had never been impacted by facility activities, none of this soil was containerized.

SECTION 5

DATA MANAGEMENT/DATA QUALITY

5.1 DATA MANAGEMENT

5.1.0.1. The processing of data generated for the Radford RFI is crucial to the overall success of the project. This section outlines the data management approach for submission and conformance to the USACE's requirements.

5.1.0.2. The USAEC's Installation Restoration Data Management Information System (IRDMIS) is the data management system used for the collection, validation, storage, retrieval, and presentation of Installation Restoration and Base Closure data. All the Radford chemical and goetechnical data must be entered using the USAEC coding forms to transmit error free data files to the Installation Restoration (IR) central site for final verification and processing. Parsons ES established a data management program that implemented the requirements of the contract process and conformed to the policies and procedures of the IRDMIS.

5.1.0.3. The Parsons ES data management team was responsible for the implementation of the Radford RFI data management program. The key team members included the data manager and data base administrator, the data coordinator, and the quality control task coordinator. The QA coordinator served in an oversight role to ensure adherence to the IRDMIS requirements through the performance of data and system audits.

5.1.1 Site Identification

5.1.1.1. All of the samples collected for the Radford RFI project were assigned a unique site identification number (IDs) for data identification. The Project Manager and the Field Team Leader assigned the site IDs prior to sampling to ensure proper usage and to prevent duplication. The field team members used sample labels and chain-of-custody records to identify sampling locations. The USAEC coding forms were also used in the field to collect all required IRDMIS information.

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5.1.2 Data and Data File Types

5.1.2.1. The two types of data and data files required for the IRDMIS process were chemical and geotechnical. The geotechnical data files contained information collected by the field sampling team during soil boring, well construction, monitoring and sampling activities using the appropriate IRDMIS coding forms. The chemical data files contained all the data associated with the laboratory certification and analysis of the project samples. Based on the sampling and analysis plan, the following types of data files were developed and used by the data management team and the laboratory:

Geotechnical Files

- GMA - map location coordinates for soil borings and sampling sites;
- GFD - geotechnical field drilling, including boring log and well installation information;
- GWC - geotechnical well construction data; and
- GGS - geotechnical groundwater stabilized level (depth of water table below the surface).

Chemical Data Files

- CGW - chemical groundwater data files;
- CSO - chemical soil data files;
- CSW - chemical surface water data files; and
- CSE - chemical sediment data files

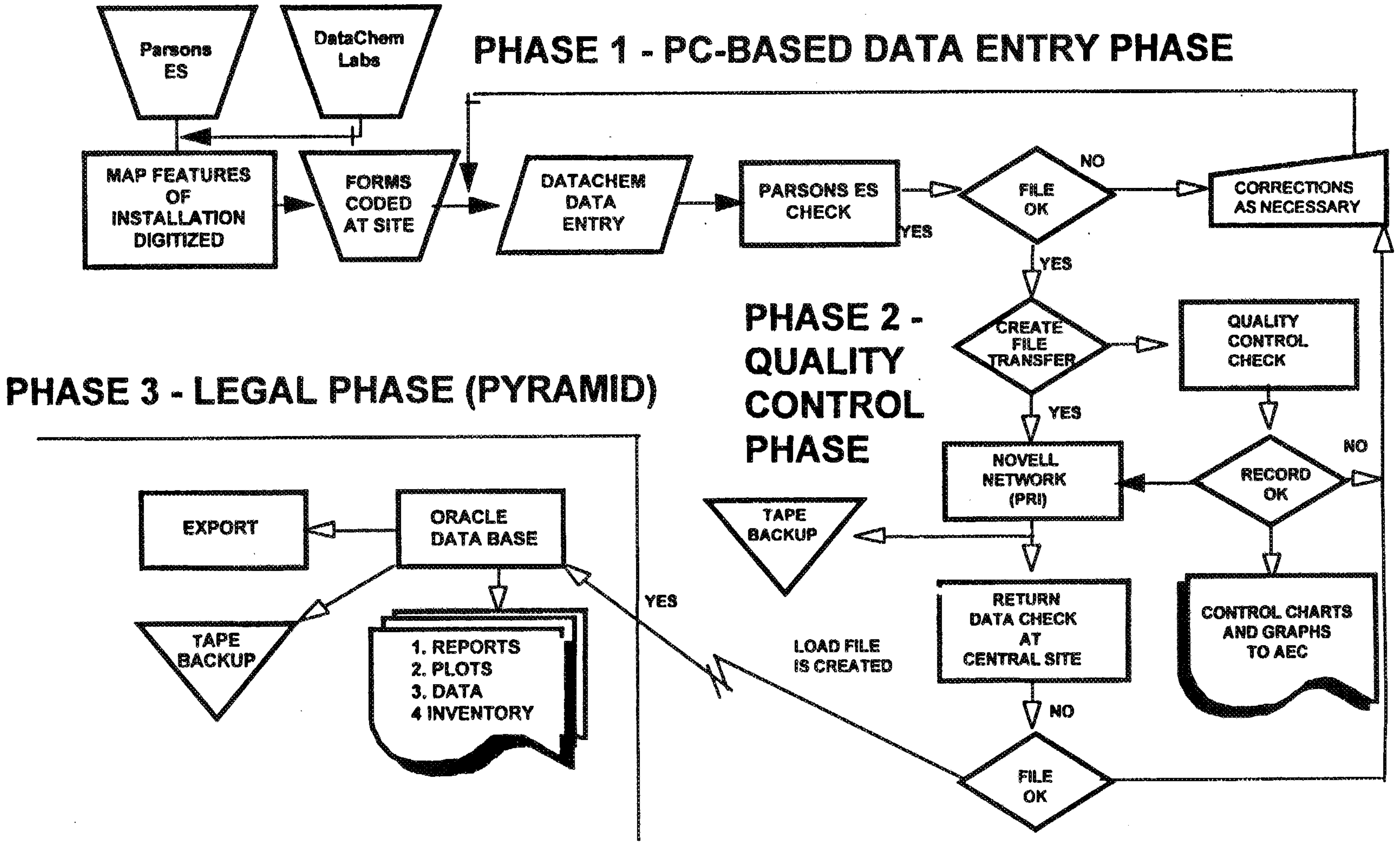
5.1.3 Data Development and Tracking

5.1.3.1. The overall data management was directed by Parsons ES with support from its contract laboratory, Data Chem Laboratories (DCL) of Salt Lake City, Utah. DCL provided the initial chemical and geotechnical electronic data files development while Parsons ES performed the quality control work. Figure 5.1 illustrates the IRDMIS Data Management phases from data entry to final acceptance into the system.

5.1.3.2. In Phase I of the IRDMIS Data Management Process, the chemical, geotechnical and map data is accumulated and entered into the IRDMIS PC-based data entry program. The field sampling team collects the map, geotechnical, and well construction data at the outset of the project. The chemical data files development is performed by DCL using the PC-based IRDMIS data entry and validation system. All the coding forms are

FIGURE 5.1

IRDMIS DATA MANAGEMENT PHASES



developed and submitted to DCL by the Parsons ES field team as part of the field sampling process. The data management team reviews the geotechnical coding forms prior to submittal to DCL. At the completion of the chemical data analysis, DCL submits the chemical data, via hard copy and electronic diskette, to the Parsons ES data management team. The Parsons ES data team then incorporates the MAP, GFD, and GWC files, and completes the IRDMIS QC checks. This completed work effort is then submitted as "Level 1" data. Since there were two rounds of sampling, this process was done twice to complete the Level 1 work effort.

5.1.3.3. In Phase II the data is processed to ensure its integrity prior to final submittal in IRDMIS. The chemical data files were then transmitted by DCL to Parsons ES. The data management team then combined the submissions for all sampling lots, using the IRDMIS data entry and validation system to combine the chemical data with the MAP information collected earlier in the process. This portion of the data management effort constituted the completion of the IRDMIS data set. The data was then run through the IRDMIS group checks and record checks. Any detected errors were corrected in conjunction with DCL and the field sampling teams. The error-free submission was then transmitted on diskette to the USAEC data management subcontractor who uploaded the files into the IRDMIS. At this stage the data is considered at "Level 2" submission . There were two sets of chemical data submitted to USAEC conforming to the two rounds of sampling performed on the project. The first submission consisted of 114 lots of chemical data and was completed in July 1995. The second submission consisted of 67 lots of chemical data and was completed in late September 1995.

5.1.3.4. In Phase III of the IRDMIS process the data was checked by the USAEC database contractor for submission into the "pyramid" or the Oracle data base. If any problems did exist with the Level 2 data it would then be returned to Parsons ES for correction. The two sets of data submitted to USAEC were free of errors and hence were successfully incorporated into IRDMIS (Level 3 data).

5.1.4 Problem Resolution

5.1.4.1. Relatively few difficulties were encountered during the data collection and QC process. The few minor errors were resolved easily in discussions between the Parsons ES data management team and DCL. The submission of the second data set for Level 3

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approval was delayed approximately one-month causing a postponement in the initial report submittal date. Under the existing system, until the chemical data is accepted as part of the IRDMIS data base the analysis of the final data review for the RFI cannot be performed.

5.2 DATA QUALITY

5.2.0.1. Parsons-ES conducted two sampling events at RAAP for the RFI. The sampling events were conducted during January and July 1995. All work was performed in accordance with the Work Plan and Quality Assurance Project Plan (QAPP) to ensure generation of legally defensible data.

5.2.0.2. A total of approximately 245 groundwater, surface water, soil, sediment, and associated field quality control samples were collected during the two sampling events. The field quality control samples collected included the following types: trip blanks, equipment blanks, field blanks, aqueous field duplicates, and soil/sediment field replicates. The samples were analyzed for volatile organics (VOCs), semivolatile organics (SVOCs), metals, explosives, and the following wet chemistry parameters: hardness, total organic halogens (TOX), total petroleum hydrocarbons (TPH), chloride, and total organic carbon (TOC). All analyses were performed by DCL following the analytical methods specified in the QAPP. See Tables 4.3 and 4.4 for a complete list of sample names and analyses.

5.2.0.3. This Data Quality Assurance (QA) Summary Section presents a summary and assessment of the analytical data generated for the two sampling events. All data submitted by the laboratory have been evaluated using the quality assurance objectives and the data validation procedures described in the QAPP. All data were validated after IRDMIS Level 3 was attained. Data Summary Tables are included as Appendix G.

5.2.0.4. This section addresses only those problems affecting the usability of the data. A discussion of data validation qualifiers (flags) applied to the data and reasons for the qualifier is also presented. A glossary of the data validation qualifiers is presented at the end of the section. This report is organized by sampling event. Details concerning the samples, analytical parameters, and quality control problems leading to rejection or qualification of data for each sampling event is presented below.

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5.2.0.5. Any QC problems leading to rejection of data [qualified as unusable ("R")] are discussed in the Summary Section for each sampling event. Deviations from the QAPP or the analytical methods and a discussion of the overall usability of the data are also presented in this section. QC problems leading to qualifying of data as estimated are presented in the Minor Problems Section. Details concerning samples and target analytes affected are also presented in this section.

5.2.1 January 1995 Sampling Event

5.2.1.0.1. A total of approximately 168 samples were collected during the January 1995 sampling event. The samples collected included 31 aqueous (groundwater and surface water) samples and 135 solid (sediment and soil) samples. The aqueous samples included the following field quality control samples: 3 trip blanks, 7 equipment blanks, 4 field blanks, 1 aqueous field duplicate, and 9 solid field replicates.

5.2.1.0.2. The environmental samples were analyzed for one or more of the following parameters: VOCs, SVOCs, explosives, metals, and the wet chemistry parameters listed above, using the analytical methods specified in the QAPP. The field duplicates, and field blanks were analyzed for the same parameters as the associated environmental samples. The trip blank samples were analyzed for VOCs only. The field blank samples included the field blanks and the equipment blanks.

5.2.1.1 Summary

5.2.1.1.1. Except as indicated in this section, the samples were collected, prepared and analyzed following the procedures described in the Work Plan and the QAPP. Except as indicated in this section, all samples were prepared and analyzed within the holding times specified in the QAPP for the respective analytical methods. The types and number of field and laboratory QC samples collected and analyzed met the QA objectives specified in the QAPP.

5.2.1.1.2. No major QC problems leading to rejection of data were found during validation of the data for the January 1995 sampling event. The data as submitted by the laboratory and qualified following data validation are usable for the purposes of this project. The overall completeness for the data generated is greater than 90 percent, the QA objective.

Some samples required dilution due to matrix interferences or levels of target analytes above the calibration range for the analytical method. The reporting limits for affected samples were adjusted by the laboratory to reflect the necessary dilutions. Generally, the reporting limits for undiluted samples met the QAPP objectives for detection limits.

5.2.1.2 Minor Problems

5.2.1.2.1. QC problems leading to qualifying of data (as estimated) included: laboratory and field blank contamination; accuracy (% recovery) and precision (RPD) outliers; outliers and preservation and storage problems. The "J" qualifier is used to indicate estimated results. The flag indicates that the analyte was positively identified but the associated value may be imprecise due to QC problems. Subscripts (e.g., J1, J2, etc.) have been added to the "J" flag to indicate the nature of the QC problem (see data validation qualifiers glossary).

5.2.1.2.2. Specific QC problems encountered included:

Volatile Organics

- Several VOC target analytes were detected in field QC samples associated with the January 1995 samples. Target analytes concerned are 1,1,1-trichloroethane, 1,2-dichloroethane, acetone, and methylene chloride. No data have been qualified since the affected analytes were not detected in any of the associated samples.

Semivolatiles (SVOCs)

- Several target SVOCs were detected in the laboratory blanks associated with these samples: 2,4-dinitrophenol, 2,4-dichlorophenol, diethylphthalate, 2-chlorophenol, di-n-butylphthalate. Of the target analytes listed, only di-n-butylphthalate was detected in associated samples. Reported results for di-n-butylphthalate for samples SCSE2 and SCSE3 have been qualified as estimated and flagged "J1".

Explosives

- The laboratory control samples (LCS) associated with the explosives analysis for these samples contained accuracy outliers for the following target explosives: 2,4,6-trinitrotoluene, 2,4-dinitrotoluene, and cyclonite. Reported results for these analytes in the associated samples have been qualified as estimated and flagged "J4/UJ4".

Metals

- Target metals, barium, lead, and chromium, were detected in soil laboratory blanks associated with these samples. Reported results for these analytes in the associated soil samples have been qualified as estimated and flagged "J1".
- The result reported for beryllium for sample 31MW4 has been flagged "J5". This flag indicates the reported result is greater than the instrument detection limit (IDL) but less than the reporting limit. The reported result should be considered as estimated.
- The laboratory control sample (LCS) associated with the soil and sediment samples contained accuracy (% recovery) outliers for the following target metals: arsenic, mercury, lead, silver, barium, cadmium, chromium, nickel, and thallium. Reported results for these metals in the associated samples have been qualified as estimated and flagged "J4/UJ4" or "J6". Reported results for lead and chromium, already qualified due to blank contamination have been flagged "J6".
- The laboratory control sample (LCS) associated with the aqueous samples in this sampling event contained accuracy (% recovery) outliers for the following target metals: barium, berllium, antimony, and chromium. Reported results for these metals in the aqueous samples have been qualified as estimated and flagged "J4/UJ4".

Wet Chemistry

- The laboratory reported preservation or storage problems associated with reported results for total organic carbon (TOC) and total organic halogens (TOX) for sample SCSW2. The results reported for these analytes for this sample have been qualified as estimated and flagged "J7".

5.2.2 July 1995 Sampling Event

5.2.2.0.1. A total of approximately 77 samples was collected during the second sampling event. The samples were collected in July 1995. The samples collected included 30 aqueous samples and 47 sediment samples. The aqueous samples included the following field quality control samples: 4 trip blanks, 3 equipment blanks, 2 field blanks, 1 surface water field duplicate and 4 soil/sediment field replicates. Surface water sample NRSW8 was collected as a duplicate of sample NRSW5. The following soil/sediment samples were collected in replicate: BG4CUCD/BG4CUC17; BG4BBLD/BG4BBL5; NRSE8/NRSE5; and BG5CWLD/BG5CWL8.

5.2.2.0.2. The environmental samples were analyzed for one or more of the following parameters: VOCs, SVOCs, explosives, metals, and the wet chemistry parameters listed above. The field duplicates, replicates, and field blanks were analyzed for the same parameters as the associated environmental samples. The trip blanks were analyzed for VOCs only.

5.2.2.1 Summary

5.2.2.1.1. Except as indicated in this section, the samples were collected, prepared and analyzed following the procedures described in the Work Plan and the QAPP. Also, except as indicated in this section, all samples were prepared and analyzed within the holding times specified in the QAPP for the respective analytical methods. The number and types of field and laboratory QC samples collected and analyzed met the QA objectives specified in the QAPP. The data as submitted by the laboratories and qualified as indicated are usable for the purposes of this project. The overall completeness for the second sampling event is greater than 90 percent, the QA objective.

5.2.2.1.2. During the sampling event, the laboratory reported that several samples were received above the required temperature. The laboratory indicated the temperature problems were due to preservation or storage problems; however, the field sampling team confirmed that the problem was due to the unusally high temperatures at the site during collection of the samples. The field sampling team undertook several corrective actions to solve the problem including increasing the amount of ice included in the sample coolers as well as collecting the samples as early as possible. Finally, the decision was made to

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recollect those samples which had been received at the laboratory with a temperature greater than 8°C.

5.2.2.1.3. Samples received by the laboratory at or less than 8°C were analyzed as required. Reported results for these samples have been qualified as estimated and flagged "J7/UJ7". Samples affected by this problem are as follows:

- SVOC results reported for the following aqueous samples have been flagged "UJ7/J7" due to the temperature problem: NRSW5, NRSW8, NRSEEQ, and NRSWFB.
- SVOC results reported for the following soil/sediment samples have been flagged "UJ7/J7" due to the temperature problem: NRSE5, and NRSE8.
- TOX results reported for the following samples have been flagged "UJ7/J7" due to the temperature problem: 54MW2, 54MW3, and NRSW8.
- TOC results reported for the following samples have been flagged "UJ7/J7" due to the temperature problem: 54MW2, 54MW3, and NRSW8.
- The result reported for chloride for sample NRSW8 has also been flagged "J7" due to the temperature problem.

5.2.2.2 Minor Problems

5.2.2.2.1. QC problems leading to qualification of data as estimated included: field/laboratory blank contamination, and accuracy outliers. The "J" flag is used to indicate results qualified as estimated due to a QC problem. This flag indicates that the analyte was analyzed for but the reported result (detect or nondetect) may be imprecise due to QC problems. Subscripts have been added to the "J" flag to indicate the nature of the QC problem.

5.2.2.2.2. Specific QC problems encountered included:

Volatiles(VOCs)

- The laboratory reported calibration problems associated with the result reported for total xylenes for the following samples: NRSW1, NRSW2, NRSW3, NRSW4, NRSW5, NRSW8, 48MW1, 48MW2, 48MW3, NRSEEQ, NRSWTB,

NRSWFB, 48MWTB, NRSWTB2, NRSWTB3, NRSE1, NRSE2, NRSE3, NRSE4, NRSE5, and NRSE8. These results have been flagged "UJ8" and should be considered estimates.

- The field blanks associated with these samples contained VOC target analytes: acetone, and methylene chloride. The result reported for methylene chloride for sample 48MW2 has been flagged "J1" due to the blank contamination.

Explosives

- The laboratory reported that results for the target explosives cyclotetramethylenetetranitramine (for sample 54MW3) and 2,4,6-trinitrotoluene (for sample NRSE5) were not confirmed by confirmational analyses. These results have been qualified as estimated and flagged "J10".
- The laboratory reported calibration problems associated with the result reported for the target explosive cyclonite for sample 54MW2. The reported result has been flagged "UJ8" due to the calibration problems.

Metals

- The soil/sediment laboratory blank associated with Lot ATWL contained the target metals barium and chromium. Reported results for these metals in the associated samples have been qualified as estimated and flagged "J1".
- The soil laboratory blank associated with Lot ATWQ contained the target metal barium. Reported results for this metal in the associated samples have been qualified as estimated and flagged "J1".
- The sediment laboratory blank associated with Lot AUCG contained the target metals barium and chromium. Reported results for these metals in the associated sediment samples have been qualified as estimated and flagged "J1".

5.2.3 Glossary Of Data Validation Qualifiers

U	The analyte was analyzed for and is not present above the level of the associated value. The associated numerical value indicates the approximate concentration necessary to detect the analyte in the sample.
J	The analyte was analyzed for and was positively identified, but the associated numerical value may be imprecise due to a QC anomaly. The data is considered

usable for many purposes. A subscript has been appended to the "J" flag to indicate the QC anomaly involved:

J1	Analyte detected in the field or laboratory blank associated with this sample. Reported result should be considered estimated and biased high.
J2	Reported result exceeded the calibration range for the instrument and method and should be considered estimated. Sample should have been diluted and reanalyzed to secure more accurate result.
J3	Holding time violation reported. Sample prepared or analyzed outside the specified holding time for the method. Reported result should be considered biased low.
J4	Accuracy or precision outlier reported for QC results associated with the reported result. Reported result should be considered estimated.
J5	Reported results greater than the MDL but less than the PRL and should be considered estimated.
J6	Multiple QC criteria outside acceptance limits (e.g., precision and accuracy outliers).
J7	Preservation/storage problems reported for this sample. Reported results should be considered estimated.
J8	Calibration or internal standard outliers reported for this sample. Reported results should be considered estimated.
J9	Reported results have been qualified as estimated due to matrix interferences in the affected sample.
J10	The reported result was not confirmed by confirmational analysis. The results on the primary and confirmation columns for this analyte do not agree.
UJ	A combination of the "U" and "J" flags. The analyte was analyzed for but was not detected. The reported detection limit has been qualified due to a QC anomaly. The subscripts defined above for the "J" qualifier also applies to the "UJ" qualifier.
R	The reported result has been qualified as unusable due to gross violations of one or more quality control criteria. This flag does not address the presence or absence of the analyte of concern rather it addressed one or more major QC problems associated with the reported result. If the analyte qualified is critical to the project, resampling and reanalysis of the qualified result may be required.
D	Result reported from diluted sample run. See "J2" above.

SECTION 6

BASELINE RISK ASSESSMENT

6.1 INTRODUCTION

6.1.1 Objectives

6.1.1.1. The objectives of this baseline risk assessment are to help determine the necessity of additional response actions at RAAP; to provide a basis for determining cleanup levels that adequately protect public health and the environment; to provide a basis for comparing various remedial alternatives; and to determine if remediation is warranted (USEPA, 1989c). The focus of this assessment is the human health risk from exposure to chemicals in soil, surface water, sediments and groundwater.

6.1.1.2. Risk assessment is the technical evaluation of the nature and magnitude of potential risk; a baseline risk assessment is an analysis of the potential for adverse effects (current or future) that could be caused by hazardous substance releases from a site in the absence of any action to control or mitigate these releases. The objective of the baseline risk assessment for RAAP is to obtain information that can be used in the following decision processes:

- To document the magnitude of potential risk at a site, and to identify the primary causes of the potential risk;
- To determine whether additional response action is necessary at a particular SWMU; and
- To help support the selection of the "no-action" remedial alternative at appropriate sites.

6.1.1.3. This risk assessment was conducted in accordance with USEPA guidance including the *Risk Assessment Guidance for Superfund Human Health Evaluation Manual* (RAGS) (USEPA, 1989c), the *Supplemental Guidance to RAGS: Calculating the Concentration Term* (USEPA, 1992c), the *CERCLA Compliance with Other Laws Manual*

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(USEPA, 1988) and other supporting documents. These guidance documents provide direction on evaluating the nature of chemical releases from the site, the potential pathways for human exposure, and determining the potential threat to public health and the environment as a result of such releases. A typical RCRA risk assessment normally encompasses a comparison of sampling data to health-based numbers (HBNs) or risk-based concentrations (RBCs) to determine if these concentrations pose a risk of adverse health effects through human exposure. However, RAAP is currently negotiating a Federal Facility Agreement with the USEPA. Once approved, the facility will fall under the guidance of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) division of the USEPA. To avoid any potential future problems with remedial alternatives based upon a RCRA risk assessment, a decision was made by USAEC to follow CERCLA guidance for the assessment of human health risk.

6.1.2 Overview and General Approach

The following steps were completed sequentially for the evaluation for each SWMU:

- Identification of chemicals of potential concern;
- Exposure assessment;
- Toxicity assessment; and
- Risk characterization.

6.1.2.1. The first step of this evaluation consisted of assessing the available sampling data and determining exposure point concentrations for each medium. A preliminary conceptual site model was developed to assist in this analysis. Data collected during the Parsons ES RFI sampling events, as well as from other investigations (as appropriate), were included for evaluation as chemicals of potential concern.

6.1.2.2. The data were evaluated to determine suitability for use in the risk assessment, and were then used to calculate a representative concentration for each chemical of potential concern. The calculated concentration represents a specific medium and predicts the concentration available for intake by potentially exposed populations.

6.1.2.3. The second step is the exposure assessment, which estimates the type and magnitude of exposures to the potential chemicals of concern that are present at or migrating from a site. An exposure pathway describes how a population can be exposed to chemicals at a site. A completed exposure pathway comprises the following elements:

- A source and mechanism for chemical release;
- An environmental transport medium;
- An exposure point; and
- A human receptor and a feasible route of exposure at the exposure point.

A pathway is not complete unless each element is present.

6.1.2.4. The relationship between the toxicity of a chemical, the potential exposure to that chemical, and the potential for or severity of adverse health effects is developed in the third step. Chemicals that do not have toxicity information available are identified and evaluated qualitatively when possible. Additionally, adjustments are made to oral toxicity information to quantitatively evaluate, where possible, potential dermal exposures.

6.1.2.5. The exposure assessment and the toxicity evaluation are coupled and a quantitative representation of the nature and magnitude of risk is derived in the final step. Also, the uncertainties inherent in the data evaluation, in the exposure assumptions, in the available toxicity information, and in the risk quantitation are assessed in this step.

6.2 SELECTION OF CHEMICALS OF CONCERN

6.2.0.1. The positive results from the 1995 field investigation effort at RAAP are summarized by site (SWMU, New River or Stroubles Creek) in Tables 6.1 through 6.4. The results from these investigations are used as the basis for selecting chemicals of potential concern at the areas under investigation during this RFI. Chemicals of potential concern are chemicals identified at a site that may be hazardous to human health.

6.2.0.2. The objectives of the data evaluation and the identification of chemicals of potential concern are:

Table 6.1
Maximum Soil Concentrations[1,2]
0 - 10 Feet Sample Depth
Radford Army Ammunition Plant

CAS No.	Parameter	Max. (ppm)	Location	No. Detects	No. Samples
	Metals				
7440-38-2	Arsenic	127.72	17BSS1	28	97
7439-92-1	Lead	5256.41	17ASB105	87	97
7440-22-4	Silver	42.31	17ASB105	31	97
7440-39-3	Barium	5128.21	17ASB105	87	97
7440-41-7	Beryllium	7.39	17ASB310	81	97
7440-43-9	Cadmium	13.72	17ASB105	6	97
7440-47-3	Chromium	2051.28	17ASB105	87	97
7440-02-0	Nickel	902.56	17ASB105	87	97
7440-36-0	Antimony	77.95	17ASB105	1	97
7439-97-6	Mercury	72.13	54SB6A2	27	97
7782-49-2	Selenium	0.79	48SS4	2	97
	Semivolatiles				
117-81-7	Bis(2ethylhexyl)phthalate	10.13	17ASB105	18	55
56-55-3	Benzo(a)anthracene	0.99	17ASB105	2	55
205-99-2	Benzo(b)fluoranthene	1.92	17ASB105	1	55
191-24-2	Benzo(g,h,i)perylene	1.23	17ASB105	7	55
207-08-9	Benzo(k)fluoranthene	0.56	17ASB105	2	55
218-01-9	Chrysene	1.04	17ASB105	6	55
206-44-0	Fluoranthene	0.81	17ASB105	2	55
85-01-8	Phenanthrene	1.67	17ASB105	6	55
129-00-0	Pyrene	1.54	17ASB105	3	55
84-74-2	Di-n-butyl phthalate	12.27	48SS2	4	55
	Explosives				
121-14-2	2,4-Dinitrotoluene	25.31	54SB6A2	3	33
2691-41-0	HMX	4.68	54SB3A2	2	33
121-82-4	RDX	1.98	54SB3A2	1	33
118-96-7	2,4,6-Trinitrotoluene	2988.51	54SB3A2	8	33

1 - Analyte detection limits are listed in Table A-7 in the Quality Assurance Project Plan, Parsons ES, 1994.

2 - Soil sampling locations are listed by SWMU in the RCRA Facility Investigation Work Plan for Solid Waste, Parsons ES, 1994

Table 6.2
Maximum Groundwater Concentrations[1,2]
Radford Army Ammunition Plant

CAS No.	Parameter	Max. (ppb)	Location	No. Detects	No. Samples
	Metals				
7440-38-2	Arsenic	15.10	54MW1	1	15
7439-92-1	Lead	6.33	54MW1	1	15
7440-39-3	Barium	816.00	48MW2	12	15
7440-41-7	Beryllium	13.20	54MW1	10	15
7440-47-3	Chromium	26.60	54MW1	1	15
7440-36-0	Antimony	97.50	54MW1	1	15
	Volatiles				
71-55-6	1,1,1-Trichloroethane	4.10	48MW1	2	15
75-34-3	1,1-Dichloroethane	2.30	48MW1	1	15
75-35-4	1,1-Dichloroethylene	1.10	48MW1	1	15
56-23-5	Carbon Tetrachloride	100.00	48MW3	2	15
75-09-2	Methylene Chloride	1.10	48MW2	1	15
67-66-3	Chloroform	30.00	48MW3	2	15
127-18-4	Tetrachloroethylene	1.20	48MW1	1	15
79-01-6	Trichloroethylene	37.00	48MW3	3	15
	Semivolatiles				
117-81-7	Bis(2ethylhexyl)phthalate	23.00	48MW3	2	15
	Explosives				
2691-41-0	HMX	4.63	54MW2	2	15

1 - Analyte detection limits are listed in Table A-7 in the Quality Assurance Project Plan, Parsons ES, 1994.

2 - Soil sampling locations are listed by SWMU in the RCRA Facility Investigation Work Plan for Solid Waste, Parsons ES, 1

Table 6.3
Maximum Sediment Concentrations[1]
Radford Army Ammunition Plant

CAS No.	Parameter	Max. (ppm)	Location	No. Detects	No. Samples
	Metals				
7440-38-2	Arsenic	10.59	SCSE1	3	10
7439-92-1	Lead	4415.58	NRSE4	10	10
7440-22-4	Silver	0.21	SCSE3	10	10
7440-39-3	Barium	415.00	NRSE3	10	10
7440-41-7	Beryllium	3.03	NRSE3	7	10
7440-47-3	Chromium	77.33	NRSE3	10	10
7440-02-0	Nickel	41.83	NRSE3	10	10
7439-97-6	Mercury	0.16	NRSE4	1	10
7782-49-2	Selenium	1.85	NRSE3	1	10
	Semivolatiles				
117-81-7	Bis(2ethylhexyl)phthalate	5.10	NRSE4	1	10
56-55-3	Benzo(a)anthracene	0.72	NRSE3	4	10
84-66-2	Diethyl phthalate	6.40	NRSE4	1	10
131-11-3	Dimethyl phthalate	6.40	NRSE4	1	10
84-74-2	Di-n-butyl phthalate	10.00	NRSE$	3	10
218-01-9	Chrysene	0.90	NRSE1	5	10
206-44-0	Fluoranthene	0.80	NRSE3	6	10
85-01-8	Phenanthrene	0.82	NRSE3	6	10
129-00-0	Pyrene	1.00	NRSE3	4	10
86-30-6	N-Nitrosodiphenylamine	2.00	NRSE4	1	10
	Explosives				
118-96-7	2,4,6-Trinitrotoluene	28.89	NRSE5	1	10

1 - Analyte detection limits are listed in Table A-7 in the Quality Assurance Project Plan, Parsons ES, 1994.

Table 6.4
Maximum Surface Water Concentrations[1]
Radford Army Ammunition Plant

CAS No.	Parameter	Max. (ppb)	Location	No. Detects	No. Samples
	Metals				
7439-92-1	Lead	9.80	NRSW4	1	10
7440-39-3	Barium	48.00	SCSW3	10	10
7440-47-3	Chromium	30.90	SCSW2	1	10
	Explosives				
2691-41-0	HMX	5.30	SCSW1,2,3	3	10

1 - Analyte detection limits are listed in Table A-7 in the Quality Assurance Project Plan, Parsons ES, 1994.

- To determine the presence and levels of contamination at individual SWMUs;
- To determine whether the levels of site-related chemicals differ from background levels; and
- To determine whether the analytical data are adequate to evaluate exposure concentrations.

6.2.0.3. The analytical data were organized into a summary format appropriate for this baseline risk assessment according to the following steps:

- Gather all data available from the site investigation and sort by medium;
- Evaluate the quality of the data with respect to sample quantitation limits;
- Evaluate any tentatively identified compounds (TICs);
- Compare the potential site-related contamination with background; and
- Develop a set of data for use in the risk assessment.

6.2.1 Evaluation of Analytical Data

6.2.1.1. All available and relevant analytical data from the 1995 sampling events were collected and sorted by media. The media for which analytical data are available include: groundwater, surface water, sediments and soils. The soil analytical data were sorted into two categories: surface soils and subsurface soils. The surface soil data includes all soil samples taken from 0 to 1.5 feet below ground surface (bgs), and the subsurface soil data includes all data deeper than 1.5 feet bgs. These depth intervals were chosen to account for shallow depths that may expose site workers and deeper areas likely only to directly expose construction workers. The 0 to 1.5 foot depth interval was also chosen because a large number of soil samples collected were in this depth range, and it was determined that this would be representative of surface soils at RAAP.

6.2.1.2. The data were evaluated to determine if quality and certainty of analysis are similar between sampling periods. Under RAGS guidance (USEPA 1989c), all compatible data are used for risk assessment purposes. Groundwater data for metals from the January 1995 sampling event were replaced with the July 1995 data since only dissolved metals were analyzed in January. The exception to this selection was if a dissolved metals concentration detected during the January, 1995 sampling event was not detected during the July 1995 sampling event. Therefore, unless a significant concentration of a compound was found in a

January dissolved metals sample, only groundwater data for metals from the July 1995 sampling event were retained for analysis.

6.2.1.3. Certain analytes were not detected in every sample collected and analyzed at RAAP. The data set contains some samples with positive results and others with non-detected results. Chemicals that have not been detected in any samples of a particular medium at a SWMU were eliminated from evaluation.

6.2.2 Comparison to Background

6.2.2.0.1. As described in Subsection 4.4 of this report, Parsons ES conducted a soil background metals study as part of the RFI sampling at RAAP. This study was conducted to determine the potential presence and extent of inorganic chemical contamination at RAAP. SWMU soil metals samples were characterized and compared to background soil metals concentrations using statistical analyses to determine whether SWMU data were significantly greater than background. A previous surface soil background study was conducted at RAAP (Dames & Moore, 1992a). However, data from this study are not used in the statistical analysis presented below because of the USEPA identified deficiencies in the soil types sampled and the validity of making comparisons with samples taken at depth (SCS 1985a; 1985b). Therefore, the Dames & Moore derived soil background levels will only be used for qualitative comparisons to SWMU surface soil samples.

6.2.2.0.2. For each subset of data described below, background distributions were characterized for each metal, a tolerance limit was constructed for that metal from the background distribution, and the SWMU samples were individually compared to the tolerance limit. These calculations and data tables are presented in Appendix H. If any individual SWMU sample exceeded the calculated tolerance limit for a metal, then that SWMU was considered contaminated by that metal. Because many soil metals concentrations follow lognormal distributions, all distribution-dependent, parametric analyses (such as the Shapiro Wilk test for normality and the normal tolerance limit) are conducted using lognormally-transformed data unless otherwise noted. All summary results, however, are presented as untransformed data. The testing methodology and the results are summarized below.

6.2.2.1 Methodology

6.2.2.1.2. The first step in the analytical process was to characterize the SWMU soil metals and background data. The soil samples collected during this sampling event were from three soil types (Unison-Urban Land Complex, Wheeling Loam, and Braddock Loam) and from two soil horizons (B and C; see Subsection 3.4 of this document for a discussion of the physical characteristics of these soils and Subsection 4.4 for a description of sampling procedures); therefore, the statistical analyses were tailored to these soil types/horizons. In addition, the four sampling locations at SWMU 17 (17A, 17B, 17C, and 17D) were grouped for analysis. In this grouping, sampling area 17A was considered separately from sampling areas 17B, 17C, and 17D, which were considered as one group for the purposes of this analysis. These determinations were based on usage history and the relative proximity and similarity of 17B, 17C, and 17D, and their relative distance from 17A. All background and SWMU sample data were first grouped by soil type and soil horizon, creating 10 subsets of SWMU data and 6 subsets of background data (See Table 6.5). Each subset of SWMU data was then analyzed against the appropriate subset of background data, ensuring that each SWMU sample was compared to a background distribution from a similar soil type and soil horizon.

6.2.2.1.3. The background distribution of each metal was characterized for each soil type for each soil horizon. Preliminary tests were used to determine whether the background samples were normally distributed, and thus which method of calculating the tolerance limit was appropriate. If the assumptions of normality were met, then the SWMU data were compared to the background distribution using the normal tolerance limit. If the assumptions of normality were not met for background, then the SWMU data were compared to background using a Poisson-based tolerance limit.

6.2.2.1.4. The first normality screen was the percentage of nondetects in the background distribution. Following EPA guidance (USEPA 1989b, USEPA 1992b, and telephone conversations with J. Brown, EPA Headquarters), if the background distribution had >50% nondetect (ND) values, then it was assumed to be nonnormal and SWMU data comparisons were conducted using the Poisson-based tolerance limits. For distributions where $0 \leq ND\% \leq 15$, all nondetect values were replaced with half of their sample quantitation limits and the distributions were tested for normality using the Shapiro Wilk normality test. If this test indicated that the background data were normally distributed, then comparisons were conducted using normal tolerance limits.

TABLE 6.5
Background Sample Matrix
Radford Army Ammunition Plant

Soil Type	Soil Horizon	SWMU To Be Compared	# Background Samples	# SWMU Samples
Braddock Loam	B	48	4	0
Braddock Loam	C	48	4	0
Unison-Urban Land Complex	B	17A	8	3
Unison-Urban Land Complex	B	17BCD	8	13
Unison-Urban Land Complex	C	17A	8	4
Unison-Urban Land Complex	C	17BCD	8	15
Wheeling Sandy Loam	B	31	6	0
Wheeling Sandy Loam	C	31	6	9
Wheeling Sandy Loam	B	54	6	14
Wheeling Sandy Loam	C	54	6	19

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6.2.2.1.5. If the percentage of nondetects was $15 \leq ND\% \leq 50$, then the normality of the background data was tested using the Shapiro Wilk test of normality on only detected values. If the Shapiro Wilk test determined that the distribution of the detected values was non-normal, then the comparisons were conducted using Poisson-based tolerance limits as discussed above. However, if the Shapiro Wilk test determined that the distribution of the detected values was normal, then the mean and standard deviation of the distribution were adjusted using either Cohen's adjustment or Aitchison's adjustment. The appropriateness of these adjustments was determined using censored vs. detects-only probability plots, and determining which plot was most linear (See USEPA 1992b for a discussion of these methodologies). In only two cases was the percentage of nondetects for a metal between 15 and 50% (arsenic for soil horizons B and C for the Urban Complex soil type), and, in these cases, neither the detects-only nor the censored probability plot appeared linear. Therefore, the data were analyzed using Poisson-based tolerance limits.

6.2.2.1.6. Upper tolerance limits were then calculated for each background metal distribution using either the normal upper tolerance limit formula or the Poisson-based tolerance limit formula according to the criteria discussed above (See USEPA 1989b and USEPA 1992b). The limits calculated were 95% upper tolerance limits at the 95% confidence level. Analysis at this level indicates a 95% confidence level that 95% of the values of the background distribution would lie below the tolerance limit. SWMU metals values falling above these limits are considered to be significantly different from background, and thus are considered in the risk assessment.

6.2.2.1.7. Following EPA guidance, (USEPA 1989b and USEPA 1992b) the tolerance limit tests for each metal are applied by comparing each SWMU sampling point against the upper tolerance limit calculated for that soil type and soil horizon. If any one of the SWMU sampling values lies above the upper tolerance limit, then this value is considered in the risk assessment.

6.2.2.2 Results

6.2.2.2.1. The results are summarized in Tables 6.6 through 6.12. The following results are subdivided by SWMU, and then by soil horizon. Sample locations are shown by SWMU in the Final RCRA Facility Investigation Work Plan (Parsons ES, 1994).

6.2.2.2.2. **SWMU 17A**: Three samples were taken in soil horizon B at SWMU 17A. Comparison to Unison-Urban Land Complex data indicated that SWMU samples exceeded background for antimony, arsenic, cadmium, chromium, nickel, and silver. 17ASB1 contributed the highest metals concentrations for each of the metals which exceeded background. Thirteen samples were taken in soil horizon C at SWMU 17A. The only exceedances of background in soil horizon C were arsenic, lead, and silver, possibly due to the fact that the soil contamination characterized by 17ASB1 was localized in soil horizon B.

6.2.2.2.3. **SWMUs 17B,C,D**: Four samples were taken in soil horizon B at SWMU 17B,C,D. The only exceedance of background was 1 of 4 samples exceeding for arsenic. Fifteen samples were taken in soil horizon C at this SWMU. Beryllium, cadmium, and lead exceeded background in 1 of the 15 samples (17CSB210) this soil horizon. Although one surface soil sample was collected at SWMU 17A and two surface soil samples were collected at SWMU 17B, appropriate background samples are not available for statistically rigorous comparisons. However, existing background surface soil data (Dames & Moore, 1992a) are used for qualitative comparisons in Subsection 7.5 of this report.

6.2.2.2.4. **SWMU 31**: No soil samples were taken in soil horizon B. Nine samples were taken in soil horizon C. Beryllium exceeded background.

6.2.2.2.5. **SWMU 48**: Samples collected in soil horizons B and C were not analyzed for metals. Although several surface soil samples were collected, appropriate background samples were not available for statistically rigorous comparison. However, background surface soil samples (Dames & Moore, 1992a) are used for qualitiative comparisons in Subsection 9.5 of this report.

6.2.2.2.6. **SWMU 54**: Fourteen samples were taken in soil horizon B at SWMU 54. Comparison to Wheeling Loam background data indicated cadmium, lead, and mercury exceed background in this soil horizon. Nineteen samples were taken in soil horizon C at SWMU 54, and only beryllium and lead exceeded background.

TABLE 6.6
SWMU 17A, Soil Horizon B
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17ASB105	17ASB205	17ASB305	Limit	Limit Exceeded?
METALS (ug/g)					
Antimony	77.95			21	Yes
Arsenic	94.87	7.33	6.70	5.5	Yes
Barium	5128.21	64.38	71.26	16,349.6	No
Beryllium	1.65	2.23	3.40	4.5	No
Cadmium	13.72			3.5	Yes
Chromium	2051.28	46.82	53.71	164.4	Yes
Lead	5256.41	26.28	27.08	6002.6	No
Mercury	0.29	0.18	0.18	1.5	No
Nickel	902.56	26.15	34.64	406.6	Yes
Selenium				2.5	No
Silver	42.31			1.5	Yes
Thallium				33.5	No

TABLE 6.7
SWMU 17A, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17ASB310	17ASB315	17ASB320	17ASB325	17ASB340	Limit	Limit Exceeded?
METALS (ug/g)							
Antimony						21.5	No
Arsenic	7.51	4.64	3.75		3.30	11.5	Yes
Barium	126.39	45.16	52.97	54.71	34.58	1,014.7	No
Beryllium	7.39	2.20	0.57	0.77	1.55	10	No
Cadmium						3.5	No
Chromium	79.33	75.99	17.25	22.59	45.44	148.1	No
Lead	23.02	21.83	30.77	9.23	15.70	64.9	Yes
Mercury	0.13					1.5	No
Nickel	71.26	36.43	6.30	10.90	23.71	231.6	No
Selenium						2.5	No
Silver						1.5	Yes
Thallium						33.5	No

TABLE 6.7
SWMU 17A, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17ASB110	17ASB115	17ASB120	17ASB122	17ASB210	17ASB215	17ASB220	17ASB225
METALS (ug/g)								
Antimony								
Arsenic	9.30	13.50	16.69			8.98		
Barium	63.12	69.20	69.36	71.50	75.69	86.91	134.26	9.56
Beryllium	2.22	2.11	1.77	2.13	2.06	4.52	6.82	
Cadmium								
Chromium	55.51	54.72	54.92	68.50	49.70	86.04	122.27	7.56
Lead	101.39	56.44	273.97	11.79	14.13	69.06	41.78	77.36
Mercury	0.14	0.16	0.11	0.09		0.12		
Nickel	24.84	29.20	24.28	28.37	27.78	56.83	78.96	6.12
Selenium								
Silver	0.39		2.12					
Thallium								

TABLE 6.8
SWMU 17BCD, Soil Horizon B
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17CSB105	17CSB205	17DSB105	17DSB205	Limit	Limit Exceeded?
METALS (ug/g)						
Antimony					21	No
Arsenic	11.98				5.5	Yes
Barium	29.40	36.74	68.93	65.89	16,349.6	No
Beryllium	3.23	1.56	1.83	1.42	4.5	No
Cadmium					3.5	No
Chromium	61.87	33.62	29.92	31.28	164.4	No
Lead	41.82	12.20	20.08	20.81	6002.6	No
Mercury					1.5	No
Nickel	25.95	18.68	14.58	11.18	406.6	No
Selenium					2.5	No
Silver			0.03		1.5	No
Thallium					33.5	No

TABLE 6.9
SWMU 17BCD, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17CSB110	17CSB114	17CSB210	17CSB215	17CSB240	17DSB110	17DSB115	17DSB120	17DSB125
METALS (ug/g)									
Antimony									
Arsenic				4.59					
Barium	78.55	84.33	70.12	104.70	86.49	60.40	67.05	69.69	72.73
Beryllium	5.19	3.61	5.77	2.52	6.21	2.02	3.21	3.04	4.77
Cadmium				4.73					
Chromium	72.81	59.89	54.29	71.92	74.38	43.94	67.82	56.07	86.92
Lead	18.44	18.73	13.68	190.60	17.24	17.95	26.54	12.36	28.23
Mercury	0.10								
Nickel	46.17	35.33	46.60	45.62	56.83	16.21	28.97	45.53	50.40
Selenium									
Silver				0.04					
Thallium									

TABLE 6.9
SWMU 17BCD, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	17DSB127	17DSB210	17DSB215	17DSB220	17DSB225	17DSB240	Limit	Limit Exceeded?
METALS (ug/g)								
Antimony							21.5	No
Arsenic		6.32	11.32			8.03	11.5	No
Barium	111.48	80.98	142.65	111.91	55.95	68.85	1,014.7	No
Beryllium	5.89	2.48	7.88	5.48	11.84	2.23	10	Yes
Cadmium							3.5	Yes
Chromium	77.87	56.30	97.09	63.30	77.76	49.18	148.1	No
Lead	23.46	17.87	23.10	11.31	8.43	14.63	64.9	Yes
Mercury	0.15		0.24				1.5	No
Nickel	66.39	28.79	72.05	57.42	87.82	23.33	23.6	No
Selenium							2.5	No
Silver	0.07						1.5	No
Thallium							33.5	No

TABLE 6.10
SWMU 31, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	31MW1A25	31MW1B35	31MW2A	31MW2B	31MW3A10	31MW3B20	31MW4A12	31MW4B22	31MW4C40	Limit	Limit Exceeded?
METALS (ug/g)											
Antimony										20.5	No
Arsenic				4.40						7	No
Barium	28.11	58.39	134.90	97.33	134.00	75.10	136.78	82.68	140.53	1186.1	No
Beryllium	0.94	1.18	1.00	1.06	0.95	0.75	1.18	0.83	1.22	1	Yes
Cadmium										3.5	No
Chromium	18.50	24.10	43.94	34.00	26.80	19.50	43.91	32.03	44.13	122.7	No
Lead	0.63	7.32	21.16	20.86	31.54	40.00	17.70	13.96	19.98	57.7	No
Mercury				0.07	0.18					2	No
Nickel	23.62	30.89	13.37	22.78	12.60	13.30	20.23	18.18	21.49	122.7	No
Selenium										2.5	No
Silver		0.02				0.11				1.5	No
Thallium										31.5	No

TABLE 6.11
SWMU 54, Soil Horizon B
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	54SB10A	54SB11A	54SB12A	54SB13A	54SB14A	54SB16A	54SB1A	54SB2A	54SB3A	54SB4A	54SB5A	54SB6A	54SB7A	54SB8A	Limit	Limit Exceeded?
METALS (ug/g)																
Antimony															20.5	No
Arsenic	4.28							3.27				4.08			6.5	No
Barium	319.23	223.57	235.96	226.99	153.30	231.33	164.51	224.22	178.16	313.51	281.80	1077.02	138.29	188.63	1710	No
Beryllium	1.81	1.49	1.54	1.42	0.89	1.47	0.93	1.76	1.11	1.78	1.55	1.11	0.82	1.15	5	No
Cadmium							2.40					11.75			3.5	Yes
Chromium	33.86	33.17	36.08	31.29	20.52	34.27	25.38	27.91	28.16	35.56	34.54	136.92	24.00	27.69	149.4	No
Lead	205.56	91.13	21.22	134.97	36.56	31.82	716.80	2354.26	321.84	84.26	39.90	3789.73	50.29	229.75	108.9	Yes
Mercury							0.09	0.13	5.06			72.13			1.5	Yes
Nickel	19.71	20.05	20.10	18.90	12.38	20.56	11.66	10.25	13.45	21.44	21.20	16.99	12.34	15.60	154.9	No
Selenium															2.5	No
Silver	0.07			0.07			0.07	0.03	0.03	0.04	0.04	0.30			2	No
Thallium															32	No

TABLE 6.12
SWMU 54, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	54SB10B	54SB10D	54SB11B	54SB12B	54SB13B	54SB14B	54SB15A	54SB16B	54SB16D	54SB1B	54SB2B	54SB3B	54SB4B
METALS (ug/g)													
Antimony													
Arsenic													
Barium	158.09	141.88	175.55	248.34	118.64	166.27	338.27	203.70	237.56	307.44	175.46	87.63	108.30
Beryllium	1.20	1.03	1.34	1.82		1.08	1.93	1.48	1.77		1.33		
Cadmium													
Chromium	29.78	27.23	32.93	46.48	32.32	34.10	45.93	34.20	43.53	9.80	29.45	37.76	21.30
Lead	11.69	13.16	12.11	13.28	8.23	13.25	28.40	14.81	13.68	5.77	14.23	14.74	8.36
Mercury	0.12											0.21	
Nickel	18.01	15.45	18.89	26.43	13.20	20.12	26.05	20.12	24.25	6.23	16.69	10.26	9.19
Selenium													
Silver	0.03	0.03									0.03	0.04	0.03
Thallium													

TABLE 6.12
SWMU 54, Soil Horizon C
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	54SB5B	54SB6B	54SB7B	54SB8B	54SB9A	54SB9B	Limit	Limit Exceeded?
METALS (ug/g)								
Antimony							20.5	No
Arsenic							7	No
Barium	244.59	362.50	420.91	243.14	193.90	201.01	1186.1	No
Beryllium	1.61	2.43	2.47	1.72	1.39	1.53	1.6	Yes
Cadmium							3.5	No
Chromium	40.64	70.14	57.10	40.15	27.93	37.56	122.7	No
Lead	16.82	430.56	22.79	21.20	20.85	15.83	57.7	Yes
Mercury							2	No
Nickel	24.46	30.14	34.72	25.56	17.68	22.61	154.9	No
Selenium							2.5	No
Silver	0.05					0.04	1.5	No
Thallium							31.5	No

6.2.3 Summary of Chemicals of Potential Concern

6.2.3.1. The chemicals of potential concern for each media at each site was compiled as a result of the tasks outlined in Section 6.2. This list included chemicals that meet the following criteria:

- Chemical was positively identified in at least 1 sample collected from the specific medium at the SWMU;
- Inorganic chemicals were detected at a concentration greater than the established background level for the specific medium;
- Chemical is a target analyte that is reported with an acceptable level of certainty associated with the chemical identification.

6.2.3.2. Thirty seven chemicals were evaluated in this risk assessment in soils, groundwater, surface water and sediment. The types of chemicals are as follows: 9 volatiles, 13 semi-volatiles, 11 metals and 4 explosives.

6.3 COMPLIANCE WITH ENVIRONMENTAL STANDARDS

6.3.1 Chemical-Specific ARARs and TBC Criteria

6.3.1.0.1. The primary guidance for identifying and evaluating the requirements of environmental statutes for Superfund sites is the *CERCLA Compliance with Other Laws Manual* (USEPA, 1988). This guidance is intended to assist in the selection of on-site remedial actions that meet the applicable, or relevant and appropriate requirements (ARARs) of the Resource Conservation and Recovery Act (RCRA), the Safe Drinking Water Act (SDWA), the Clean Air Act (CAA), the Clean Water Act (CWA), and other Federal and State environmental laws as required by CERCLA Section 121.

6.3.1.0.2. According to the manual, a requirement under other environmental laws may be either applicable or relevant and appropriate. Cleanup standards, standards of control and other substantive environmental protection requirements are considered applicable. These standards specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site. Relevant and appropriate requirements are not directly "applicable" to a specific hazardous substance at a CERCLA site, but address significantly similar situations and merit consideration.

6.3.1.0.3. ARARs can be classified as ambient or chemical-specific requirements, performance, design or other action-specific requirements, or location-specific requirements. Chemical-specific requirements are numerical values or methodologies which result in the establishment of numerical values that represent an acceptable concentration of chemical that may be discharged to the environment. Action-specific requirements are generally technology- or activity-based requirements on remedial actions at CERCLA sites. Location-specific requirements are restrictions placed on the concentration of hazardous substances or the conduct of activities due to the criticality of a type of habitat. For the purposes of this risk assessment, chemical-specific requirements will be analyzed.

6.3.1.0.4. A second level of "to-be-considered" criteria (TBCs) includes federal and state environmental criteria, advisories, guidance and proposed standards. TBCs are not legally binding and do not have the status of potential ARARs; however, appropriate TBCs may be considered as part of the site risk assessment and may be useful in determining the cleanup level for the protection of the environment and human health.

6.3.1.0.5. ARARs and TBCs identified for these SWMUs are discussed for human receptors with respect to the different media below. Table 6.13 lists appropriate ARARs evaluated for this risk assessment.

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Table 6.13

Water Quality Criteria (mg/L)

Analyte	FWQC - Acute	FWQC - Chronic	VAWQC - Public
Lead	83	3.2	0.015
Barium	1	N/A	2
Chromium	1,700	210	0.17
HMX	0.4	N/A	N/A

FWQC - Federal Water Quality Criteria
VAWQC - Virginia Water Quality Criteria

6.3.1.1 Groundwater

6.3.1.1.1. Groundwater conditions at RAAP are complex in terms of defining the water table and the availability of groundwater. In general, in the lower areas of alluvial deposition located along the New River, the water table approximates the depth of the river. In the higher elevation areas, where the groundwater resides in bedrock, the water table is extremely variable. Because of the presence of karst features like solution cavities and collapse structures, and areas that are severely fractured, there is a significant potential for variable movement of groundwater through these features. Groundwater occurrence and movement is discussed in detail in Subsection 3.7 and in the SWMU-specific sections (7 through 10).

6.3.1.1.2. Groundwater at RAAP is not currently used as a public water supply serving 25 or more people. According to this criteria, MCLs (Maximum Contaminant Levels) and MCLGs (Maximum Contaminant Level Goals) for drinking water, which are promulgated under the Safe Drinking Water Act would not be appropriate as ARARs for this investigation (USEPA, 1988a).

6.3.1.2 Surface Water and Sediments

6.3.1.2.1. The New River is the main surface water feature at RAAP, with approximately 13 miles of shoreline within the boundaries of the installation. RAAP discharges approximately 25 million gallons per day (mgd) into the New River from 15 locations along the New River and Stroubles Creek (Parsons ES, 1994a). Effluent from RAAP consists of various treated process waters, wash waters, cooling waters, stormwater runoff and sanitary wastewater. Stroubles Creek, the largest tributary of the New River, originates in the southeast sector of RAAP and consists primarily of stormwater runoff and effluent from the Blacksburg, Virginia Municipal Wastewater Treatment Plant. In addition, groundwater discharging from the karst bedrock may contribute significantly to the stream flow. The wastewater effluent consists primarily of domestic and industrial wastewaters.

6.3.1.2.2. Under the authority of the Clean Water Act, the USEPA has developed Federal Water Quality Criteria (FWQC). These numerical ambient criteria are provided to protect marine and freshwater animals from chronic (long term) and acute (short term) toxicities. Since FWQCs are non-enforceable guidelines, they are considered TBCs for cleanup goals. States are required under section 303 of the Clean Water Act to adopt water quality standards based on use classifications. The state WQCs establish a maximum allowed concentration for various parameters which typically parallel the acute and chronic concentration levels of the FWQCs and are used as standards for aquatic receptors. These minimum standards are considered state ARARs. Since the New River has been classified by Virginia as suitable for use as a public water supply and the SWMUs under investigation have the potential to influence the quality of the water used for this purpose, Federal and State WQCs will be considered in this risk assessment (See Table 6.13).

6.3.1.3 Soils

6.3.1.3.1. Soil ARARs are generally applied to terrestrial flora and wildlife. There are no established Federal or Commonwealth of Virginia standards relating chemical concentrations in surface soils to toxic effects on vegetation or wildlife. Therefore there are no TBCs that could be considered as appropriate to apply to human receptors. As this risk assessment is solely concerned with human health and does not consider the potential ecological effects of the chemicals of concern, no further analysis of these standards is necessary.

6.3.2 Location and Action-Specific ARARs

6.3.2.0.1. As mentioned above, location-specific ARARs are restrictions placed on concentrations of chemicals solely because of their presence in a specific location, such as a wetland or other type of critical habitat. Action-specific requirements are technology- or activity-based requirements or remedial actions at CERCLA sites. Because RAAP does not currently fall under CERCLA regulations, action-specific requirements will not be examined in this section. These ARARs may be examined in more detail in the Corrective Measures Study (CMS) as potential remedial actions are considered.

6.3.2.1 Wetlands

6.3.2.1.1. Wetland communities may be unique or sensitive environments. Research from previous and current investigative activities indicates that jurisdictional wetlands do not occur on the SWMUs under investigation for this RFI, with the exception of drainage features extending to the New River and Stroubles Creek. If a wetland is considered to be under the jurisdictional review of the Clean Water Act, Section 404(b)(1) of the act specifies conditions permitting wetland alterations. These guidelines specifically prohibit activities that cause or contribute to violations of any applicable state water quality standard or that cause significant adverse effects to aquatic life or wildlife from the spread of pollutants through physical, chemical or biological processes.

6.3.2.1.2. General risks to wetland-associated organisms are used as indicators of possible population-level and habitat-level impacts from chemicals of potential concern. There are no chemical-specific standards established specifically for wetlands; however, surface water and sediment criteria used for aquatic communities can be applied to wetlands in the assessment area.

6.3.2.2 Wildlife

6.3.2.2.1. Currently, there are no promulgated or established Federal or Virginia standards relating specific chemical concentrations in soil, sediment or surface water directly to toxic effects on wildlife species. There are abundant toxicological testing data that relate known chemical doses in either food or surface water to acute and chronic effects on test species.

6.4 FATE AND TRANSPORT OF THE CHEMICALS OF POTENTIAL CONCERN

6.4.1 Potential Routes of Migration

6.4.1.1. The primary source for potential release of contaminants to the environment at the RAAP is through the past and present use of SWMUs for waste disposal. The primary release mechanisms from SWMU 17 are the staging and burning of large metallic items in need of explosives decontamination. Release mechanisms for SWMU 31 are deposition of fly ash or bottom ash from former coal burning operations in the settling lagoons. SWMU 48 was used for disposal of oily wastewaters from oil/water separators. The release mechanisms at SWMU 54 are former land disposal of propellant ash and periodic flooding of this area by the New River. These activities have resulted in possible downward infiltration/percolation of rainfall through potentially contaminated surface and subsurface soils, possible surface runoff of contaminated waters, or possible emissions of contaminated fugitive dust. Contaminant infiltration to the subsurface environment can result in groundwater and subsurface soil becoming secondary sources of contamination. Soil in the vadose (unsaturated) and saturated zones can be contaminated by the vertical and horizontal migration of contaminants from surface spills, land application of wastes, or other disposal practices. After migrating through the vadose zone, contaminants can then enter the groundwater where contaminants may undergo hydrolysis, oxidation, reduction, or other processes resulting in the chemical transformation of a contaminant. The contaminants are also attenuated mechanically as they migrate through the subsurface by processes such as dilution, dispersion, diffusion, and absorption. Potential secondary release mechanisms include infiltration and/or percolation of water through contaminated subsurface soil and the discharge of contaminated groundwater to the surface in the form of leachate/seeps. Potential contaminated media can include surficial soil, groundwater, surface water, sediment, or leachate/seeps.

6.4.1.2. Contaminants released to surface water can be transported downstream, dissolved in water or adsorbed on suspended sediment, or can be transported to the atmosphere. Surface runoff can transport contaminants to surface water; fugitive dust generation can transport contaminants to the air; contaminated soil can be tracked from one location to another; plant life may absorb soil contaminants; and wildlife may ingest plants that have assimilated contaminants in leaf and stem tissue. In addition, contaminants can be conveyed by surface water and/or sediments to aquatic life that may be ingested by wildlife.

6.4.1.3. Finally, contaminants can be physically transformed through volatilization or biodegradation or can accumulate in a specific medium. The potential for specific contaminants to migrate from one medium to another or to be transformed is dependent on the physical and chemical properties of each contaminant.

6.4.2 Contaminant Characteristics

6.4.2.1. Evaluating the environmental fate and transport of the chemicals of concern at the SWMUs under investigation was performed to determine the potential for migration in the environment and the potential for human and environmental exposure. The environmental fate and transport of chemicals is dependent upon the physical and chemical properties of the compounds, the environmental transformation processes affecting them, and the media through which they migrate. In this section, the chemical and physical properties of the chemicals of interest are presented, and the relevance of these properties to environmental fate and transport are discussed. Table 6.14 summarizes relevant physical properties of all the chemicals of interest at the RAAP.

6.4.2.2. The water solubility of a substance is a critical property affecting environmental fate. Highly soluble chemicals can be leached rapidly from soils and are generally mobile in groundwater. Solubilities can range from less than 1 mg/L to totally soluble (Lyman et al., 1982). The solubility of chemicals that are not readily soluble in water may be enhanced by the presence of organic solvents (e.g., acetone), which are more soluble in water.

6.4.2.3. The volatilization of a compound depends on its vapor pressure and water solubility. Vapor pressure, a relative measure of the volatility of chemicals in their pure state, varies from approximately 0.001 millimeters of mercury (mm Hg) to 759 mm Hg for liquids. The higher the vapor pressure the greater the volatility. Henry's Law is used to estimate equilibrium vapor pressures of dilute contaminants in water. Compounds with Henry's Law Constants greater than 10^{-3} atmospheres - cubic meter per mole (atm-m^3/mole) can be expected to volatilize readily from water; those with values ranging from 10^{-3} to 10^{-5} atm-m^3/mole are associated with possibly significant volatilization; while compounds with values less than 10^{-5} atm-m^3/mole will volatilize from water only to a limited extent (Lyman et al., 1982).

6.4.2.4. The octanol-water partitioning coefficient (K_{ow}) provides a measure of the extent of chemical partitioning between water and octanol at equilibrium. The greater the K_{ow}, the more likely a chemical is to partition to octanol than to remain in water. Octanol is used as a surrogate for lipids (fat); therefore, K_{ow} is used to predict bioconcentration in aquatic organisms.

6.4.2.5. The bioconcentration factor (BCF) measures the extent of chemical partitioning at equilibrium between biological media (e.g., fish or plant tissue) and external environmental media (e.g., water). The higher the BCF, the greater the accumulation in living tissue is likely to be. The organic carbon partition coefficient (K_{oc}) reflects the propensity of a compound to sorb to organic matter found in soil. The normal range of K_{oc} values is 1 to 107 milliliters per gram (ml/g), with higher values indicating greater sorption potential. Chemicals that have a strong tendency to sorb to organic matter (i.e., chemicals with a high K_{oc}) will move more slowly between environmental compartments than chemicals with a low K_{oc}.

6.4.2.6. The molecular weight of a chemical is the sum of the atomic weights of its constituent elements. This property is used in performing calculations for the dermal exposure routes. The specific gravity is the ratio of the mass of a solid or liquid to the mass of an equal volume of distilled water at 4°C.

6.4.2.7. The media-specific half-lives in the last four columns of Table 6.14 provide a relative measure of chemical persistence in a given medium, although actual values can vary greatly depending on site-specific conditions. The greater the half-life, the more persistent the chemical. Half-life properties can be valuable in examining the long-term risks from chemicals at a site and developing remediation alternatives.

6.4.3 Contaminant Migration and Persistence

6.4.3.1. Chemicals detected (explosives, metals, VOCs, polynuclear aromatic hydrocarbons [PAHs]) at RAAP were classified into several categories according to their similarity in chemical structure and/or physiochemical properties (factors that would influence mobility in the environment). The chemical categories and some of the associated elements/compounds within each category are the following:

- Explosives: 2,4,6-trinitrotoluene, HMX, 2,4-dinitrotoluene, and RDX.
- Metals: antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, and silver.
- Polynuclear Aromatic Hydrocarbons (PAHs): benzo(a)anthracene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, di-n-butyl phthalate, diethylphthalate, dimethylphthalate, fluoranthene, N-nitrosodiphenylamine, phenanthrene and pyrene.
- Volatile Aromatic Hydrocarbons: carbon tetrachloride, chloroform, 1,1-dichloroethane, 1,1-dichloroethylene, methylene chloride, tetrachloroethane, 1,1,1-trichloroethane, and trichloroethylene.

6.4.3.2. Based on the chemical and physical characteristics of chemicals potentially present at the RAAP, the following generalizations regarding environmental fate and transport can be made to provide a relative comparison to other chemical categories.

6.4.3.3. PAHs and explosives have a high affinity for organic matter and low water solubility. Water solubility tends to decrease, and affinity for organic material tends to increase with increasing molecular weight. When present in soil or sediments, PAHs and explosives tend to remain bound to the soil particles and dissolve only slowly into groundwater or the overlying water column. Because of the high affinity for organic matter, the physical fate of these chemicals is usually controlled by the transport of particulates. Thus, soil, sediment, and suspended particulate matter (in air) represent important media for chemical transport. Furthermore, because of their high affinity for organic matter, PAHs are readily bioaccumulated by living organisms; whereas, explosives are not as readily bioaccumulated.

6.4.3.4. Metals of potential concern identified at the RAAP are generally immobile under the subsurface conditions at the site. Soils and geological maps discussed in Section 3 of this report generally show that the upland regions of this facility are underlain by clay-rich residuum. Slightly acid to neutral soil pH and oxidizing conditions are expected for soils throughout the RAAP.

6.4.3.5. Under such conditions, cadmium exists as cations and can be adsorbed onto the clays. Chromium and selenium have several oxidation states and form anionic complexes; these complexes readily precipitate by reaction with iron and other cations. These chemical properties result in these metals being immobile under the environmental conditions present at the RAAP.

6.4.3.6. In groundwater or wet soils in the unsaturated zone under the site conditions, antimony is expected to behave like arsenic (Hem, 1985). A low solubility is expected due to coprecipitation of the arsenate anion with iron species in the soil. Therefore, antimony is also considered to be relatively immobile under site conditions.

6.4.3.7. The equilibrium solubility of beryllium in dilute water at pH 6 is very low, near 100 µg/L (Hem, 1985). The behavior of mercury in the soil is impossible to predict without knowledge of the local environment. In the absence of chloride ions, the most probable dissolved species is the relatively soluble $Hg(OH)_2$, a neutral species (Stumm and Morgan, 1981). However, if the mercury occurs as the metallic element, it readily volatilizes or it precipitates in the presence of sulfur.

6.4.3.8. Volatile organic compounds tend to have a low residence time in surface soil and surface water environments. These chemicals can be persistent in groundwater. However, there is evidence that non-chlorinated volatile organic compounds may degrade rapidly in the vadose zone above groundwater plumes.

6.5 RISK ASSESSMENT METHODOLOGY

6.5.1 Exposure Assessment

6.5.1.0.1. Under current USEPA guidelines (USEPA, 1989c), the assessment of human exposure to the selected chemicals of concern at sites contaminated with potentially toxic constituents is carried out in three steps:

- Characterization of exposure setting (i.e., relevant physical characteristics of the site and potentially exposed populations);
- Identification and evaluation of pathways by which the previously identified populations may become exposed; and
- Quantification of the exposure (i.e., estimation of exposure point concentrations and human intake of contaminants).

6.5.1.0.2. Relevant physical characteristics of each SWMU or area of concern are discussed in Sections 7 through 12. The remaining items are discussed below.

6.5.1.1 Identification of Potential Receptors

6.5.1.1.1. Demographics, groundwater and surface water use, and ecological characteristics of each SWMU are necessary to identify potential receptors and pathways of contamination exposure. Land use at RAAP will be assumed to remain industrial for future exposure assessment. This is due primarily to RAAP being the only active propellant and explosive manufacturing facility in the United States. Therefore, future receptors will not differ from the current receptors.

6.5.1.1.2 **Local Demographics** - The area surrounding RAAP is mostly rural with the natural terrain prohibiting extensive development. The closest residential community is Fairlawn, located approximately 3 miles southwest of RAAP. The City of Radford is located approximately 5 miles southwest of the facility, and has an estimated 1990 population of 15,940 (Virginia Population Projections, 1993). For a more complete discussion of demographics, refer to Table 3.3 in Section 3.3.

6.5.1.1.3. The 4 SWMUs under investigation at RAAP under this RFI are located within the facility boundaries, which at present limits access to these areas to official visitors. However, the general public has access to the New River which flows through the installation and near several SWMUs under investigation (31, 48 and 54). The New River is separated from RAAP by a security fence which limits direct contact between recreational users of the river and potentially contaminated soils and waters at these SWMUs; however, SWMU 54 lies outside of this fence and is accessible from the New River. People boating, fishing or swimming in the river could be exposed to contaminants migrating through surface water runoff. In addition, burning operations conducted at SWMU 17 may contribute to the inhalation of airborne contaminants by human receptors.

6.5.1.1.4 **Groundwater Receptors** - According to previous investigations at this facility (ES, 1994a), there are two known supply wells at this installation. Well number 1 is located within the Horseshoe adjacent to the New River Bridge and is currently not in use. Well number 2 is located in the southeast corner of the site and is inactive, but may be used as a backup potable water supply for the U.S. Army Research, Development and Acquisition Information Systems Agency.

6.5.1.1.5. At SWMU 17, the direction of groundwater flow is generally toward the New River. Groundwater which recharges the aquifer at the SWMU 17 area discharges into the New River. Groundwater has been shown to flow westward through a direct conduit linking SWMU 17A with a spring at the New River, as discussed in Subsection 7.4 of this report. The closest supply well is over one mile away and upgradient. The other supply well is separated from SWMU 17 by the New River. At SWMUs 31, 48 and 54, potentiometric surface maps indicate that groundwater flows toward the New River. The wells are positioned such that no SWMU is located between a supply well and the New River. Some residents of Blacksburg rely on groundwater as their potable water supply, but these supply wells are located approximately 5 miles east of RAAP. The shallow groundwater for many of the SWMUs flows toward the New River and would not likely migrate toward any users in the vicinity of RAAP.

6.5.1.1.6 **Surface Water Receptors** - Drinking water used at RAAP comes from two surface water intakes on the New River: one located approximately 2 miles upstream of the mouth of Stroubles Creek and the other approximately 6 miles downstream of Stroubles Creek. The Commonwealth of Virginia has classified Stroubles Creek and the portion of the New River flowing through RAAP as generally satisfactory for beneficial use, which includes public or municipal water supply, secondary contact recreation and propagation of fish and wildlife. All water used at RAAP is taken from the New River. Current surface water receptors include recreational users of this stretch of the New River and plant personnel.

6.5.1.1.7. **Soil Receptors** - Receptors could be exposed to surface soils through inhalation of particulates and volatiles, incidental ingestion and dermal contact. Exposure to surface soils at these sites may be limited where there is excessive vegetative cover or the site is paved or covered. Most of SWMU 17 is neither paved nor vegetated which provides a potentially complete pathway for current site workers. Human exposure may be limited at SWMU 48 because the site is currently inactive. SWMU 54 is partially vegetated, but there are areas where ash is exposed through the soil. Current soil receptors include site workers and hunters who may travel across contaminated soils. Future soil receptors include site workers.

6.5.1.1.8 **Air Receptors** - Since SWMU 17 is an active waste burning area, air emissions are a concern from this site. These emissions and contaminated dust would likely be carried over human receptors at RAAP and the surrounding communities. However, ambient air monitoring data during burning operations is unavailable and therefore risks associated with this activity are not quantifiable. Air emissions from SWMUs 40, 48 and 54 would be limited to volatilization of contaminants from the surface soils and fugitive dust emissions. Currently, due to the location of these SWMUs, this would affect mainly site workers and official visitors to RAAP. The sediments at SWMU 31 are covered with water and this limits fugitive emissions from this site.

6.5.1.2 Identification of Exposure Pathways

6.5.1.2.1. An assessment of exposure pathways is based on the current and potential future site conditions, an evaluation of the contaminants of concern, and an evaluation of the potential current and future receptors. An exposure pathway describes how a population can be exposed to chemicals at a site. As stated in Section 6.1.2, a completed exposure pathway comprises the following elements:

- A source and mechanism for chemical release;
- An environmental transport medium;
- An exposure point; and
- A human receptor and a feasible route of exposure at the exposure point.

A pathway is not complete unless each element is present.

6.5.1.2.2. Exposure point concentrations and daily uptake for each contaminant of concern are estimated for each potential exposure pathway. The pathways selected for quantitative analysis include those that are considered to represent the greatest potential for human exposure. Pathways that are less significant are identified and discussed, but not quantified.

6.5.1.2.3. The pathways evaluated were potential current exposure of site workers, construction workers, recreational users, hunters and fishermen to surface water, sediments and surface soils, and future exposure of site workers to groundwater. Current site workers were evaluated for exposure to surface soils through ingestion, dermal contact, and inhalation of volatiles and particulates, and surface water and sediments through ingestion and dermal contact. Current construction workers were evaluated for exposure to surface and subsurface soils through ingestion, dermal contact and inhalation of volatiles and particulates, and surface waters and sediments through ingestion and dermal contact. Current recreational users and fishermen were evaluated for incidental ingestion and dermal contact with surface waters. Current hunters were evaluated for incidental ingestion and dermal contact with surface soils.

6.5.1.2.4. In order to be consistent with the assumptions concerning future land use at RAAP, the only future exposure scenario evaluated that differs from current exposure scenarios was future site worker exposure to groundwater through ingestion, dermal contact and inhalation of volatiles while showering. Although this exposure scenario is unlikely because all drinking water used at RAAP is obtained from the New River, this scenario allows a quantification of the risks from exposure to site groundwater.

6.5.1.3 Quantification of Exposure Pathways

6.5.1.3.1. Exposure-point concentrations were estimated for pathways selected for quantitative evaluation and pathway-specific human intakes were quantified. Exposure-point concentrations can be based on measured monitoring data or on modeling results. For this risk assessment, exposure-point concentrations were calculated from monitoring data. To provide a conservative basis for the risk assessment, steady-state conditions were assumed. Therefore, current and future chemical concentrations were assumed to be identical.

6.5.1.3.2. Intakes are normally expressed as the amount of chemical intake in milligrams of chemical per kilogram of body weight per day (mg/kg-day), which represents an intake normalized for body weight over time. The total exposure is divided by the time period of interest to obtain an average exposure over time. The averaging time is a function of the toxic endpoint: for non-carcinogenic effects it is the exposure duration multiplied by 365 days per year, and for carcinogenic effects it is the lifetime (70 years) multiplied by 365 days per year.

6.5.1.3.3. Exposure/intake variables were used to estimate the reasonable maximum exposure (RME). As defined by USEPA, the RME is considered the highest reasonable exposure that is to be expected to occur at the site. The intent of the RME is to estimate a conservative exposure case which is above the average exposure and within the range of possible exposures. The selection of the parameters to evaluate all exposure scenarios is based on the current use of each site and the potential future use of the sites. These estimates of exposure should not be mistaken for actual exposures occurring at each site. RME values presented in Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors (USEPA, 1991) are used when available for all scenarios. Examples of these default parameters include 1) a 70 year life span, 2) a body weight of 70 kg, and 3) an inhalation rate of 20 cubic meters per day. In the absence of standard assumptions and site-specific information, exposure was estimated using best professional judgment and available site information. Detailed intake algorithms for each exposure scenario, by media and exposure route, are shown in Tables 6.15 through 6.35.

6.5.1.3.4 In addition to evaluating receptors for RME scenarios, the Central Tendency (CT) exposure scenarios were also evaluated. CT default exposure parameters are values that are based on average exposure values and are considered most representative of an exposure that would be contacted at a site over an extended period of time. Therefore, these exposure scenarios can be evaluated based upon average and maximum site contact.

6.5.1.3.5. The emphasis in risk assessments conducted under USEPA Superfund guidance is on chronic exposures unless specific conditions warrant a short-term or an acute assessment. The focus of this evaluation is long-term exposure to relatively low chemical concentrations (i.e., chronic exposure).

TABLE 6.15

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: SURFACE SOIL INGESTION

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF \times FI}{BW \times AT}$$

		Parameter	CT	RME
C	=	Chemical Concentration in Soil (mg/kg)	(a)	(b)
IR	=	Ingestion Rate (mg/day)	50	100
EF	=	Exposure Frequency (days/year)	125(c)	250
ED	=	Exposure Duration (years)	5(d)	25
CF	=	Conversion Factor (kg/mg)	10^{-6}	10^{-6}
FI	=	Fraction Ingested (unitless)	1	1
BW	=	Body Weight (kg)	70	70
AT	=	Averaging Time (days)		
		Noncarcinogenic	1,825	9,125
		Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment based on Virginia climate; outside work was assumed likely for 1/2 of year.
(d) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.16

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: SURFACE SOIL DERMAL CONTACT

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times AF \times EF \times ED \times CF}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Soil (mg/kg)	(a)	(b)
SA = Skin Area (cm2/event) (c)	3,160	4,100
AF = Sin Adherence Factor (mg/cm^2)	1	1
EF = Exposure Frequency (days/year)	125(d)	250
ED = Exposure Duration (years)	5(e)	25
CF = Conversion Factor (kg/mg)	10^{-6}	10^{-6}
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	1,825	9,125
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Head, forearms and hands: CT = Mean values and Upper Bound = Maximum values.
(d) = Best professional judgment based on Virginia climate; work outdoors was assumed likely 1/2 of the year.
(e) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.17

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: INHALATION OF SURFACE SOIL VOLATILES AND PARTICULATES

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times [1/PEF \text{ or } 1/VF]}{BW \times AT}$$

Parameter			CT	RME
C	=	Chemical Concentration in Soil (mg/kg)	(a)	(b)
IR	=	Inhalation Rate (m^3/hour)	2.0	3.5
ET	=	Exposure Time (hours/day)	8	8
EF	=	Exposure Frequency (days/year)	125(c)	250
ED	=	Exposure Duration (years)	5(d)	25
PEF	=	Particulate Emission Factor (m^3/kg)	site specific	site specific
VF	=	Volatilization Factor (m^3/kg)	chemical specific	chemical specific
BW	=	Body Weight (kg)	70	70
AT	=	Averaging Time (days)		
		Noncarcinogenic	1,825	9,125
		Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment based on Virginia climate; work outdoors was assumed likely 1/2 of the year.
(d) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.18

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: INGESTION OF SURFACE WATER

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT}$$

Parameter			CT	RME
C	=	Chemical Concentration in Water (mg/L)	(a)	(b)
IR	=	Ingestion Rate (L/day)	0.05(c)	0.05(c)
CF	=	Conversion Factor (L/L)	1	1
EF	=	Exposure Frequency - New River (days/year)	25(d)	50(e)
EF	=	Exposure Frequency - Stroubles Creek (days/year)	25(d)	50(e)
ED	=	Exposure Duration (years)	5(f)	25
BW	=	Body Weight (kg)	70	70
AT	=	Averaging Time (days)		
		Noncarcinogenic	1,825	9,125
		Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency.
RME = Reasonable Maximum Exposure.
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment.
(d) = Best professional judgment. Assume work near creek or river once per week.
(e) = Best professional judgment. Assume work near creek or river twice per week.
(f) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.19

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: DERMAL CONTACT WITH SURFACE WATER

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times EF \times PC \times ED \times ET \times CF}{BW \times AT}$$

		Parameter	CT	RME
C	=	Chemical Concentration in Water (mg/L)	(a)	(b)
SA	=	Skin Surface Area (cm^2)	840(c)	1,130(c)
CF	=	Conversion Factor (L/cm^3)	0.001	0.001
EF	=	Exposure Frequency - New River (days/year)	25(d)	50(e)
EF	=	Exposure Frequency - Stroubles Creek (days/year)	25(d)	50(e)
PC	=	Permeability Constant (cm/hr)	chemical -specific	chemical-specific
ED	=	Exposure Duration (years)	5(f)	25
ET	=	Exposure Time (hrs/day)	0.15(g)	0.15(g)
BW	=	Body Weight (kg)	70	70
AT	=	Averaging Time (days)		
		Noncarcinogenic	1,825	9,125
		Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Hands: CT = Mean values and RME = Maximum values.
(d) = Best professional judgment. Assume work near creek or river once per week.
(e) = Best professional judgment. Assume work near creek or river twice per week.
(f) = Bureau of Labor Statistics (USEPA, 1990).
(g) = Best Professional Judgment.

TABLE 6.20

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: SEDIMENT INGESTION

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF \times FI}{BW \times AT}$$

Parameter		CT	RME
C =	Chemical Concentration in Sediment (mg/kg)	(a)	(b)
IR =	Ingestion Rate (mg/day)	50	100
EF =	Exposure Frequency - New River (days/year)	25(c)	50(d)
EF =	Exposure Frequency - Stroubles Creek (days/year)	25(c)	50(d)
ED =	Exposure Duration (years)	5(e)	25
CF =	Conversion Factor (kg/mg)	10^{-6}	10^{-6}
FI =	Fraction Ingested (unitless)	1	1
BW =	Body Weight (kg)	70	70
AT =	Averaging Time (days)		
	Noncarcinogenic	1,825	9,125
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment. Assume work near creek or river once per week.
(d) = Best professional judgment. Assume work near creek or river twice per week
(e) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.21

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT SITE WORKER EXPOSURE: SEDIMENT DERMAL CONTACT

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times AF \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	CT	RME
C	=	Chemical Concentration in Sediment (mg/kg)	(a)	(b)
SA	=	Skin Area (cm2/event) (c)	840(c)	1,130(c)
AF	=	Skin Adherence Factor (mg/cm^2)	1	1
EF	=	Exposure Frequency - New River (days/year)	25(d)	50(e)
EF	=	Exposure Frequency - Stroubles Creek (days/year)	25(d)	50(e)
ED	=	Exposure Duration (years)	5(f)	25
CF	=	Conversion Factor (kg/mg)	10^{-6}	10^{-6}
BW	=	Body Weight (kg)	70	70
AT	=	Averaging Time (days)		
		Noncarcinogenic	1,825	9,125
		Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Upper Bound Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Hands: CT = Mean values and RME = Maximum values.
(d) = Best professional judgment. Assume work near creek or river once per week.
(e) = Best professional judgment. Assume work near creek or river twice per week.
(f) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.22

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT RECREATIONAL SURFACE WATER USERS: INGESTION OF CHEMICALS IN SURFACE WATER WHILE SWIMMING

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times CR \times ET \times EF \times ED}{BW \times AT}$$

	Parameter	CT	RME
C	= Chemical Concentration in Water (mg/L)	(a)	(b)
CR	= Contact Rate (L/hr)	0.05(c)	0.05(c)
ET	= Exposure Time (hr/day)(d)	0.013(e)	0.11(f)
EF	= Exposure Frequency (day/yr)	3(g)	7(h)
ED	= Exposure Duration (years)	9(i)	30
BW	= Body Weight (kg)	70	70
AT	= Averaging Time (days)		
	Noncarcinogenic	3,285	10,950
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = USEPA 1989d.
(d) = Based on total outdoor leisure time for men and women. USEPA 1989.
(e) = 10% of mean active leisure time outdoors.
(f) = 10% of upper bound active leisure time outdoors computed as mean + 2 standard deviations.
(g) = Best professional judgment.
(h) = National swimming average, USEPA 1989d
(i) = National median time at one residence USEPA 1989.

TABLE 6.23

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT RECREATIONAL SURFACE WATER USERS: DERMAL CONTACT WITH CHEMICALS IN SURFACE WATER WHILE SWIMMING

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times ET \times PC \times EF \times ED \times CF}{BW \times AT}$$

Parameter		CT	RME
C	= Chemical Concentration in Water (mg/L)	(a)	(b)
SA	= Skin Surface Area (cm^2)	19,400(c)	22,800(c)
ET	= Exposure Time (hours/day) (d)	0.013(e)	0.11(f)
EF	= Exposure Frequency (days/yr)	3(g)	7(h)
PC	= Permeability Constant (cm/hr)	chemical-specific	chemical-specific
ED	= Exposure Duration (years)	9(i)	30
CF	= Volumetric Conversion Factor (liter/cm^3)	0.001	0.001
BW	= Body Weight (Kg)	70	70
AT	= Averaging Time (days)		
	Noncarcinogenic	3,285	10,950
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (1993).

CT = Central Tendency

RME = Reasonable Maximum Exposure

TABLE 6.24

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR INCIDENTAL INGESTION OF SURFACE WATER BY FISHERMAN

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times CR \times ET \times EF \times ED}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Water (mg/L)	(a)	(b)
CR = Contact Rate (L/hr)	0.0005(c)	0.0005(c)
ET = Exposure Time (hr/day)(d)	1(d)	8(d)
EF = Exposure Frequency (day/yr)	32(e)	144(f)
ED = Exposure Duration (years)	9(g)	50(d)
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	3,285	18,250
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment - 1% of water ingestion rate for swimming.
(d) = Best professional judgment.
(e) = Best professional judgment. 1 day/week for 6 months/yr + 1 day/month for 6 months/yr.
(f) = Best professional judgment. 5 days/week for 6 months/yr + 1 day/wk for 6 months/yr.
(g) = National median time at one residence USEPA 1989.

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TABLE 6.25

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR DERMAL CONTACT WITH SURFACE WATER BY FISHERMAN

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times ET \times PC \times EF \times ED \times CF}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Water (mg/L)	(a)	(b)
SA = Skin Surface Area (cm^2)	3,160(c)	4,100(c)
ET = Exposure Time (hours/day) (d)	1(d)	8(d)
EF = Exposure Frequency (days/yr)	32(e)	144(f)
PC = Permeability Constant (cm/hr)	chemical-specific	chemical-specific
ED = Exposure Duration (years)	9(g)	50(d)
CF = Volumetric Conversion Factor (liter/cm^3)	0.001	0.001
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	3,285	18,250
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Head, forearms and hands: CT = Mean values, RME = Maximum values.
(d) = Best professional judgment.
(e) = Best professional judgment. 1 day/week for 6 months/yr + 1 day/month for 6 months/yr.
(f) = Best professional judgment. 5 days/week for 6 months/yr + 1 day/wk for 6 months/yr.
(g) = National median time at one residence USEPA 1989.

TABLE 6.26

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR RECREATIONAL HUNTER EXPOSURE: SURFACE SOIL INGESTION

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF \times FI}{BW \times AT}$$

	Parameter	CT	RME
C	= Chemical Concentration in Soil (mg/kg)	(a)	(b)
IR	= Ingestion Rate (mg/day)	50	100
EF	= Exposure Frequency (days/year)	25(c)	39(d)
ED	= Exposure Duration (years)	9(e)	50(f)
CF	= Conversion Factor (kg/mg)	10^{-6}	10^{-6}
FI	= Fraction Ingested (unitless)	1	1
BW	= Body Weight (kg)	70	70
AT	= Averaging Time (days)		
	Noncarcinogenic	3,285	18,250
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Assumption of 1 day/week for duration of bow season for deer hunting which lasts for 5 months.
(d) = Assumption of 2 weeks vacation and 1 day/week for 5 months.
(e) = National median time at one residence USEPA 1989.
(f) = Best professional judgment.

TABLE 6.27

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR RECREATIONAL HUNTER EXPOSURE: SURFACE SOIL DERMAL CONTACT

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times AF \times EF \times ED \times CF}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Soil (mg/kg)	(a)	(b)
SA = Skin Area (cm^2/event)	3,160(c)	4,100(c)
AF = Skin Adherence Factor (mg/cm^2)	1	1
EF = Exposure Frequency (days/year)	25(d)	39(e)
ED = Exposure Duration (years)	9(f)	50(g)
CF = Conversion Factor (kg/mg)	10^{-6}	10^{-6}
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	3,285	18,250
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Head, arms and hands. CT = Mean values, RME = Maximum values.
(d) = Assumption of 1 day/week for duration of bow season for deer hunting which lasts for 5 months.
(e) = Assumption of 2 weeks vacation and 1 day/week for 5 months.
(f) = National median time at one residence USEPA 1989.
(g) = Best professional judgment.

TABLE 6.28

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR FUTURE SITE WORKER EXPOSURE: INGESTION OF GROUNDWATER

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT}$$

Parameter			CT	RME
C	=	Chemical Concentration in Water (mg/L)	(a)	(b)
IR	=	Ingestion Rate (L/day)	0.5	1
CF	=	Conversion Factor (L/L)	1	1
EF	=	Exposure Frequency (days/year)	125	250
ED	=	Exposure Duration (years)	5(c)	25
BW	=	Body Weight (kg)	70	70
AT	=	Averaging Time (days)		
		Noncarcinogenic	1,825	9,125
		Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Bureau of Labor Statistics (USEPA, 1990).

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TABLE 6.29

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR FUTURE SITE WORKER EXPOSURE: DERMAL CONTACT WITH GROUNDWATER

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times EF \times PC \times ED \times ET \times CF}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Water (mg/L)	(a)	(b)
SA = Skin Surface Area (cm^2)	19,400(c)	22,800(c)
CF = Volumetric Conversion Factor (L/cm^3)	0.001	0.001
EF = Exposure Frequency (days/year)	125	250
PC = Permeability Constant (cm/hr)	chemical-specific	chemical-specific
ED = Exposure Duration (years)	5(d)	25
ET = Exposure Time (hrs/day)	0.117(e)	0.2(f)
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	1,825	9,125
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Upper Bound Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Entire Body. CT = Mean values, RME = Maximum values.
(d) = Bureau of Labor Statistics (USEPA, 1990).
(e) = Best Professional Judgment: Assumption of a 7 Minute Shower.
(f) = Best Professional Judgment: Assumption of a 12 Minute Shower.

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TABLE 6.30

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR FUTURE SITE WORKER EXPOSURE: INHALATION OF GROUNDWATER WHILE SHOWERING

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times ET \times EF \times ED \times CF}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Water (mg/L)	(a)	(b)
IR = Inhalation Rate (m^3/hr)	1.4	2
CF = Conversion Factor (L/m^3)	1	1
ET = Exposure Time (hrs/day)	0.117(c)	0.2(d)
EF = Exposure Frequency (days/year)	125	250
ED = Exposure Duration (years)	5(e)	25
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	1,825	9,125
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Chemical concentration in air is based on the Andelman Shower Model.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best Professional Judgment: Assumption of a 7 Minute Shower
(d) = Best Professional Judgment: Assumption of a 12 Minute Shower
(e) = Bureau of Labor Statistics (USEPA, 1990).

TABLE 6.31

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT CONSTRUCTION WORKER EXPOSURE: SURFACE/SUBSURFACE SOIL INGESTION

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF \times FI}{BW \times AT}$$

Parameter			CT	RME
C	=	Chemical Concentration in Soil (mg/kg)	(a)	(b)
IR	=	Ingestion Rate (mg/day)	100	480
EF	=	Exposure Frequency (days/year)	125	250
ED	=	Exposure Duration (years)	0.5(c)	2(c)
CF	=	Conversion Factor (kg/mg)	10^{-6}	10^{-6}
FI	=	Fraction Ingested (unitless)	1	1
BW	=	Body Weight (kg)	70	70
AT	=	Averaging Time (days)		
		Noncarcinogenic	182.5	730
		Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment.

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TABLE 6.32

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT CONSTRUCTION WORKER EXPOSURE: SURFACE/SUBSURFACE SOIL DERMAL CONTACT

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times AF \times EF \times ED \times CF}{BW \times AT}$$

	Parameter	CT	R
C	= Chemical Concentration in Soil (mg/kg)	(a)	(b)
SA	= Skin Area (cm2/event) (c)	3,160	4,100
AF	= Skin Adherence Factor (mg/cm2)	1	1
EF	= Exposure Frequency (days/year)	125	250
ED	= Exposure Duration (years)	0.5(d)	2(d)
CF	= Conversion Factor (kg/mg)	10^{-6}	10^{-6}
BW	= Body Weight (kg)	70	70
AT	= Averaging Time (days)		
	Noncarcinogenic	182.5	730
	Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Head, forearms and hands: CT = Mean values and Upper Bound = Maximum values.
(d) = Best professional judgment.

TABLE 6.33

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT CONSTRUCTION WORKER EXPOSURE: INHALATION OF SURFACE/SUBSURFACE SOIL VOLATILES AND PARTICULATES

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times [1/PEF \text{ or } 1/VF]}{BW \times AT}$$

Parameter			CT	RME
C	=	Chemical Concentration in Soil (mg/kg)	(a)	(b)
IR	=	Inhalation Rate (m^3/hour)	2.0	3.5
ET	=	Exposure Time (hours/day)	8	8
EF	=	Exposure Frequency (days/year)	125	250
ED	=	Exposure Duration (years)	0.5(c)	2(c)
PEF	=	Particulate Emission Factor (kg/m^3)	site specific	site specific
VF	=	Volatilization Factor (kg/m^3)	chemical specific	chemical specific
BW	=	Body Weight (kg)	70	70
AT	=	Averaging Time (days)		
		Noncarcinogenic	182.5	730
		Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment.

TABLE 6.34

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT CONSTRUCTION WORKER EXPOSURE: INGESTION OF SURFACE WATER

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT}$$

Parameter	CT	RME
C = Chemical Concentration in Water (mg/L)	(a)	(b)
IR = Ingestion Rate (L/day)	0.05(c)	0.05(c)
CF = Conversion Factor (L/L)	1	1
EF = Exposure Frequency (days/year)	125	250
ED = Exposure Duration (years)	0.5(c)	2(c)
BW = Body Weight (kg)	70	70
AT = Averaging Time (days)		
Noncarcinogenic	182.5	730
Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (USEPA, 1993).

CT = Central Tendency.
RME = Reasonable Maximum Exposure.
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Best professional judgment.

TABLE 6.35

EXPOSURE PARAMETERS AND INTAKE ALGORITHM FOR CURRENT CONSTRUCTION WORKER EXPOSURE: DERMAL CONTACT WITH SURFACE WATER

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

$$\text{Intake (mg/kg-day)} = \frac{C \times SA \times EF \times PC \times ED \times ET \times CF}{BW \times AT}$$

		Parameter	CT	RME
C	=	Chemical Concentration in Water (mg/L)	(a)	(b)
SA	=	Skin Surface Area (cm^2) (c)	3,160	4,100
CF	=	Conversion Factor (L/cm^3)	0.001	0.001
EF	=	Exposure Frequency (days/year)	125	250
PC	=	Permeability Constant (cm/hr)	chemical-specific	chemical-specific
ED	=	Exposure Duration (years)	0.5(d)	2(d)
ET	=	Exposure Time (hrs/day)	0.15(e)	0.15(e)
BW	=	Body Weight (kg)	70	70
AT	=	Averaging Time (days)		
		Noncarcinogenic	182.5	730
		Carcinogenic	25,550	25,550

Source: Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure (1993).

CT = Central Tendency
RME = Reasonable Maximum Exposure
(a) = Lower of the 95% upper confidence limit of the mean or the maximum detected value.
(b) = Higher of the 95% upper confidence limit of the mean or the maximum detected value.
(c) = Hands, Face Forearms. CT = Mean values and Upper Bound = Maximum values.
(d) = Best Professional Judgment.
(e) = Best Professional Judgment.

6.5.1.4 Determination of Exposure Point Concentration

6.5.1.4.1. The exposure point concentrations are calculated as the 95 percent upper confidence limit on the arithmetic mean of the analytical results for the representative analytes (USEPA, 1989c). There are two exceptions to this guidance. When a contaminant is detected in only one sample or if only one sample was collected for a certain medium, the single concentration is reported as the exposure point concentration. The second exception occurs when the 95 percent confidence limit exceeds the maximum detected value for a group of samples. In this case, the maximum detected concentration is considered to be the RME and is used as the exposure point concentration.

6.5.1.4.2. The 95% upper confidence limit was calculated per supplemental guidance to RAGS (USEPA, 1992c) using the following equation:

$$95\%\ UCL = e^{(x + 0.5s^2 + sH\,(n-1)^{0.5})}$$

where:

UCL = upper confidence limit;
e = constant (base of the natural log equal to approximately 2.718);
x = mean of the transformed data;
s = standard deviation of the transformed data;
H = H-statistic from Table A12 of USEPA (1992c); and
n = sample size.

6.5.2 Toxicity Assessment

6.5.2.0.1. The toxicity assessment evaluates the available evidence regarding the potential for particular contaminants to cause adverse effects in exposed individuals and provides, where possible, an estimate of the relationship between the extent of exposure to a contaminant and the increased likelihood and/or severity of adverse effects. Toxicity information considered in this assessment includes the reference dose (RfD), which is used to evaluate non-carcinogenic effects and the slope factor (SF), which is used to evaluate carcinogenic potential.

6.5.2.0.2. The values used in the toxicity assessment are found in the given hierarchy of sources:

1) DTSC guidance through either personal or written communication on cancer potency slope factors;
2) USEPA's Integrated Risk Information System (USEPA, 1995a); and
3) The most current edition of USEPA's Health Effects Assessment Summary Tables (HEAST) (USEPA, 1995b);

6.5.2.0.3. Determining toxicity values for some classes of chemicals can be complicated and is beyond the scope of the preliminary screening. When slope factors and unit risks are not available for all potentially carcinogenic members of a chemical class, toxicity values may be calculated using toxicity equivalency factors (TEFs). These are values that compare the carcinogenic potential of a given chemical in a class to the carcinogenic potential of a chemical in the class that has a verified slope factor and/or unit risk. USEPA has provided TEFs for polyaromatic hydrocarbons (PAHs) (USEPA, 1993) as follows:

TEF VALUES

PAH	TEF
Benzo(a)pyrene	1.0
Benzo(a)anthracene	0.1
Benzo(b)fluoroanthene	0.1
Benzo(k)fluoroanthene	0.01
Chrysene	0.001

6.5.2.0.4. To calculate a slope factor for a given PAH, the appropriate TEF value is multiplied by the slope factor for benzo(a)pyrene. Using the TEF approach, carcinogenic risks resulting from exposure to all carcinogenic PAHs can be quantified.

6.5.2.1 Health Criteria for Non-Carcinogenic Effects

6.5.2.1.1. For chemicals that exhibit non-carcinogenic (e.g., systemic) effects, authorities consider organisms to have repair and detoxification capabilities that must be exceeded by some critical concentration (threshold) before the health effect is manifested. This threshold view holds that a range of exposures from slightly above zero to some finite value can be tolerated by the organism with no appreciable risk of adverse effects.

6.5.2.1.2. Health criteria for chemicals exhibiting non-carcinogenic effects for use in risk assessment are generally developed using USEPA RfDs developed by the Reference Dose/Reference Concentration (RfD/RfC) Work Group and included in the IRIS (USEPA, 1995a). In general, the RfD is an estimate of an average daily exposure to an individual (including sensitive individuals) below which there will not be an appreciable risk of adverse health effects. The RfD accounts for uncertainty factors (e.g., to adjust from animals to humans and to protect sensitive subpopulations) which ensure that it is unlikely to underestimate the potential for adverse non-carcinogenic effects to occur. The purpose of the RfD is to provide a bench mark against which the sum of other doses (i.e., those projected from human exposure to various environmental conditions) might be compared. Doses that are significantly higher than the RfD may indicate that an inadequate margin of safety could exist for exposure to that substance and an adverse health effect could occur. A summary of non-carcinogenic chemical-specific toxicity values is presented in Table 6.36.

6.5.2.1.3. The potential chemicals of concern may affect different target organs in the body. Under RAGS guidance, dose additivity is assumed which implies the same toxic endpoint or target organ.

6.5.2.2 Health Criteria for Carcinogenic Effects

6.5.2.2.1. For chemicals that exhibit carcinogenic effects, most authorities recognize that one or more molecular events can evoke changes in a single cell or a small number of cells that can lead to tumor formation. This is the non-threshold theory of carcinogenesis purporting that any level of exposure to a carcinogen can result in some finite possibility of generating the disease. Generally, regulatory agencies assume the non-threshold hypothesis for carcinogens in the absence of information concerning the mechanisms of action for the chemical.

Table 6.36
Chemical Specific Toxicity Values
Noncarcinogenic Effects (1)
Radford Army Ammunition Plant

CAS No.	Chemical	Oral RfD (mg/kg-day)	RfD Conf. (2)	RfD Critical Effect/Species	Oral Absorption Factor (3)	Dermal RfD (mg/kg-day) (4)	Inhalation RfC (mg/m³)	RfC Conf. (2)	RfC Critical Effect/Species
	Volatiles								
56-23-5	Carbon Tetrachloride	7.00E-04	Med	Liver effects/ rats	0.85	5.95E-04	NR	-	-
67-66-3	Chloroform	1.00E-02	Med	Fatty cysts in liver/dogs	1.00	1.00E-02	NR	-	-
107-06-2	1,1-Dichloroethane	NR	NR	-	0.90	NA	NR	-	-
75-35-4	1,1-Dichloroethene	9.00E-03	Med	Liver lesions/rats	0.90	8.10E-03	NR	-	-
75-09-2	Methylene Chloride	6.00E-02	Med	Liver toxicity/rats	0.98	5.88E-02	3.00E+00 *	NR	Liver toxicity/rats
98-95-3	Nitrobenzene	5.00E-04	Low	Liver lesions/rats	0.90 #	4.50E-04	NR	-	-
127-18-4	Tetrachloroethene	1.00E-02	Med	Liver tox/mice; weight gain/rats	0.90	9.00E-03	NR	-	-
71-55-6	1,1,1-Trichloroethane	NR	NR	-	0.90 #	NA	NR	-	-
79-01-6	Trichloroethene	NR	NR	-	0.90	NA	NR	-	-
	Semivolatiles								
56-55-3	Benzo(a)anthracene	3.00E-01	Low	No observed effects/mice	0.20 #	6.00E-02	NR	-	-
205-99-2	Benzo(b)fluoranthene	NR	NR	-	0.20 #	NA	NR	-	-
191-24-2	Benzo(g,h,i)perylene	NR	NR	-	0.20 #	NA	NR	-	-
207-08-9	Benz0(k)fluoranthene	NR	NR	-	0.20 #	NA	NR	-	-
117-81-7	Bis(2-ethylhexyl)phthalate	2.00E-02	Med	Increased liver weight/guinea pigs	0.50	1.00E-02	NR	-	-
218-01-9	Chrysene	NR	NR	-	0.60	NA	NR	-	-
84-74-2	Di-n-butylphthalate	1.00E-01	Low	Increased mortality/rats	0.90	9.00E-02	NR	-	-
534-52-1	4,6-dinitro-2-cresol	NR	NR	-	NR	NA	NR	-	-
84-66-2	Diethylphthalate	8.00E-01	Low	Weight, growth decrease/rats	0.50 #	4.00E-01	NR	-	-
131-11-3	Dimethylphthalate	1.00E+01 *	NR	Kidney effects/rats	0.50 #	5.00E+00	NR	-	-
206-44-0	Fluoranthene	4.00E-02	Low	Liver, kidney, blood	0.20 #	8.00E-03	NR	-	-
86-30-6	N-Nitrosodiphenylamine	NR	NR	-	0.20 #	NA	NR	-	-
85-01-8	Phenanthrene	NR	NR	-	0.20 #	NA	NR	-	-
129-00-0	Pyrene	3.00E-02	Low	Kidney effects/mice	0.20 #	6.00E-03	NR	-	-
	Inorganics								
7440-36-0	Antimony	4.00E-04	Low	Longevity, blood effects/rats	0.01	4.00E-06	NR	-	-
7440-38-2	Arsenic	3.00E-04	Med	Skin lesions/humans	0.01	2.40E-04	NR	-	-
7440-39-3	Barium	7.00E-02	Med	Increased blood pressure/humans	0.05	3.50E-03	5.00E-04 *	NR	Fetotoxicity/rats
7440-41-7	Beryllium	5.00E-03	Low	Heart, kidney, spleen effects/ rats	0.01 #	5.00E-05	NR	-	-
7440-43-9	Cadmium	5.00E-04 (5)	High	Significant proteinuria/humans	0.02	1.00E-05	NR	-	-
7440-47-3	Chromium III	5.00E-03	Low	No observed effects/rats	0.02	1.00E-04	NR	-	-
7439-92-1	Lead	NR	NR	-	0.15	NA	NR	-	-
7439-97-6	Mercury	3.00E-04 *	NR	Kidney effects/rats	0.01	3.00E-06	3.00E-04 *	NR	Neurotoxicity/humans
7440-02-0	Nickel	2.00E-02	Med	Decreased body and organ wt/rats	0.04	8.00E-04	NR	-	-
7782-49-2	Selenium	5.00E-03	High	Reproductive effects/ mice	0.90	4.50E-03	NR	-	-
7440-22-4	Silver	5.00E-03	Low	Argyria/humans	0.20	1.00E-03	NR	-	-
	Explosives								
2691-41-0	HMX	5.00E-02	Low	Liver effects/ mice	0.20 #	1.00E-02	NR	-	-
121-14-2	2,4-Dinitrotoluene	2.00E-03	High	-	0.20 #	4.00E-04	NR	-	-
121-82-4	RDX	3.00E-03	High	Decreased body weight/ rats	0.20 #	6.00E-04	NR	-	-
118-96-7	2,4,6-Trinitrotoluene	5.00E-04	Med	Liver effects/ mice	0.20 #	1.00E-04	NR	-	-

(1) From IRIS (USEPA, 1994a). When IRIS values were unavailable, HEAST (USEPA, 1994b) was used. An asterisk (*) indicates that values taken from HEAST.
A double asterisk (**) indicates that value from USEPA (1994c - personal communication with the Superfund Technical Support Center).
RfD = reference dose, NR = not reported, UR = under review, NV = nonverifiable, NA = not applicable
A dash ("-") indicates that this item is not applicable, or that there is no entry in either IRIS or HEAST.

(2) USEPA-assigned level of confidence in toxicity value. Med = medium.

(3) The absorption values were cited in the appropriate ATSDR Profiles. The pound sign (#) indicates that the ATSDR Profiles were not available and default values were used as follows: 0.9 for volatiles, 0.2 for semi-volatiles, pesticides, wet chemistry analytes and explosives, 0.5 for phthalates 0.01 for metals and 1.0 for 1,3-dichlorobenzene (by analogy to 1,4-dichlorobenzene).

(4) Dermal-RfD = Oral-RfD x oral absorption factor.

(5) Two RfD values are available for cadmium and the most conservative is presented.

6.5.2.2.2. USEPA's Carcinogen Risk Assessment Verification Endeavor (CRAVE) has developed slope factors and unit risks (i.e., dose-response values) for estimating excess lifetime cancer risks associated with various levels of lifetime exposure to potential human carcinogens. The carcinogenic slope factors can be used to estimate the lifetime excess incremental cancer risk associated with exposure to a potential carcinogen. Risks estimated using slope factors are considered unlikely to underestimate actual risks, but they may overestimate actual risks. Excess lifetime cancer risks are generally expressed in scientific notation and are probabilities. For example, an excess risk of 1×10^{-6} (one in one million) represents the added probability of an individual developing cancer over a lifetime as a result of exposure to the specific carcinogenic chemical under the exposure conditions used for the analysis. USEPA has suggested developing remedial alternatives for cleanup of Superfund sites using a target total excess lifetime cancer risk ranging from 10^{-4} (one in ten thousand) to 10^{-6} (one in one million) (USEPA, 1990). A summary of carcinogenic chemical-specific toxicity values is presented in Table 6.37.

6.5.2.2.3. In addition, there are varying degrees of confidence in the weight-of-evidence for carcinogenicity of a given chemical. The USEPA's system involves characterizing the overall weight-of-evidence for a chemical's carcinogenicity based on the availability of animal, human, and other supportive data. The weight-of-evidence classification is an attempt to determine the likelihood that the agent is a human carcinogen, and thus qualitatively affects the estimation of potential health risks. Three major factors are considered in characterizing the overall weight-of-evidence for carcinogenicity: (1) the quality of evidence from human studies; (2) the quality of evidence from animal studies, which are combined into a characterization of overall weight of evidence for human carcinogenicity; and (3) other supportive information that is assessed to determine whether the overall weight-of-evidence should be modified. Uncertainty values are not associated with carcinogenic toxicity values because the uncertainty is reflected by the category to which the chemical is assigned. USEPA's final classification of the overall weight-of-evidence includes the following five categories:

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Table 6.37
Chemical Specific Toxicity Values
Carcinogenic Effects (1)
Radford Army Ammunition Plant

CAS No.	Chemical	CAG Group (2)	Oral Slope Factor $(mg/kg\text{-}day)^{-1}$	Oral Slope Factor Target Organ (Tumor Type)/Species	Oral Absorption Factor (3)	Dermal Slope Factor $(mg/kg\text{-}day)^{-1}$ (4)	Inhalation Unit Risk $(mg/kg\text{-}day)^{-1}$	Inhalation Unit Risk Target Organ (Tumor Type)/Species
	Volatiles							
56-23-5	Carbon Tetrachloride	B2	1.30E-01	Liver (Adenoma)/Rats	0.90	1.53E-01	1.50E-05	-
67-66-3	Chloroform	B2	3.10E-02 **	-	1.00	3.10E-02	5.43E-06 **	-
107-06-2	1,1-Dichloroethane	B1	7.00E-02 **	-	0.90	7.78E-02	2.00E-05 **	-
75-35-4	1,1-Dichloroethene	C	6.00E-01	Adrenal gland (tumors)/ Rats	0.90	6.67E-01	5.14E-05	Kidney (adenocarcinoma): mice
75-09-2	Methylene Chloride	B2	1.40E-02 **	-	0.98	1.43E-02	1.00E-06 **	-
98-95-3	Nitrobenzene	D	NR	-	0.90	NA	NR	-
127-18-4	Tetrachloroethene	NR	5.10E-02 **	-	0.90	5.67E-02	1.46E-05 **	-
71-55-6	1,1,1-Trichloroethane	D	NR	-	0.90 #	NA	NR	-
79-01-6	Trichloroethene	NR	1.30E-02 **	-	0.90	1.67E-02	2.86E-06 **	-
	Semivolatiles							
56-55-3	Benzo(a)anthracene	B2	7.30E-01 (5)	Forestomach (carcinomas)/ Mice	0.20 #	3.65E+00	NR	-
205-99-2	Benzo(b)fluoranthene	B2	7.30E-01	Lung (adenoma)/ Rats	0.20 #	3.65E+00	2.38E-04	-
191-24-2	Benzo(g,h,i)perylene	D	NR	Lung (adenoma)/ Mice	0.20 #	NA	NR	-
207-08-9	Benzo(k)fluoranthene	B2	7.30E-01	Lung (adenoma)/ Rats	0.20 #	3.65E-01	1.12E-04	-
117-81-7	Bis(2-ethylhexyl) phthalate	B2	8.40E-03 **	Liver (adenoma and carcinoma)/ Mice	0.50	1.68E-02	2.40E-06 **	-
218-01-9	Chrysene	B2	7.30E-03 (5)	Forestomach (carcinomas)/ Mice	0.60	1.22E-02	NR	-
84-74-2	Di-n-butylphthalate	D	NR	-	0.90	NA	NR	-
534-52-1	4,6-dinitro-2-cresol	NR	NR	-	NR	NA	NR	-
84-66-2	Diethylphthalate	NA	NR	-	NA	NA	NR	-
131-11-3	Dimethylphthalate	D	NR	-	0.50 #	NA	NR	-
206-44-0	Fluoranthene	D	NR	-	0.20 #	NA	NR	-
86-30-6	N-Nitrosodiphenylamine	B2	4.90E-03	Urinary bladder (carcinoma)/ Rats	0.20 #	2.45E-02	NR	-
85-01-8	Phenanthrene	D	NR	-	0.20 #	NA	NR	-
129-00-0	Pyrene	D	NR	-	0.20 #	NA	NR	-
	Inorganics							
7440-36-0	Antimony	NR	NR	-	0.01	NA	NR	-
7440-38-2	Arsenic	A	1.80E+00	Skin(carcinoma)/Humans	0.01	2.19E+00	1.23E-06	Lung (carcinoma)/humans
7440-39-3	Barium	NR	NR	-	0.05	NA	NR	-
7440-41-7	Beryllium	B2	4.30E+00	Leukemia/ Rats	0.01 #	4.30E+02	1.61E-03	-
7440-43-9	Cadmium	B1	NR	-	0.02	NA	4.29E-03 **	-
7440-47-3	Chromium III	A	4.20E-01 **	-	0.02	2.10E+01	1.46E-01 **	-
7439-92-1	Lead	B2	NR	-	0.15	NA	NR	-
7439-97-6	Mercury	D	NR	-	0.01	NA	NR	-
7440-02-0	Nickel	NR	NR	-	0.04	NA	2.60E-04 **	-
7782-49-2	Selenium	D	NR	-	0.01 #	NA	NR	-
7440-22-4	Silver	D	NR	-	0.20	NA	NR	-
	Explosives							
2691-41-0	HMX	D	NR	-	0.20 #	NA	NR	-
121-14-2	2,4-Dinitrotoluene	NR	NR	-	0.20 #	NA	NR	-
121-82-4	RDX	C	3.00E-03	Liver (adenoma)/ Mice	0.20 #	5.50E-01	NR	-
118-96-7	2,4,6-Trinitrotoluene	C	3.00E-02	Urinary Bladder (papilloma)/ Mice	0.20 #	1.50E-01	NR	-

(1) From IRIS (USEPA, 1994a). When IRIS values were unavailable, HEAST (USEPA, 1994b) was used. An asterisk (*) indicates that values taken from HEAST.
A double asterisk (**) indicates that value from USEPA (1992 - personal communication with the Superfund Technical Support Center).
NR = not reported, UR = under review
A dash ("-") indicates that this item is not applicable, or that there is no entry in either IRIS or HEAST.

(2) CAG = USEPA Carcinogen Assessment Group (see text).

(3) The absorption values were cited in the appropriate ATSDR Profiles. The pound sign (#) indicates that the ATSDR Profiles were not available and default values were used as follows: 0.9 for volatiles, 0.2 for semi-volatiles, pesticides, wet chemistry analytes and explosives, 0.5 for phthalates 0.01 for metals and 1.0 for 1,3-dichlorobenzene (by analogy to 1,4-dichlorobenzene).

(4) Dermal-SF = Oral-SF/oral absorption factor.

(5) The slope factor is for the mixture of 2,4/2,6-dinitrotoluene.

(6) The slope factor for arsenic was derived from an oral unit risk of 5E-05 (L/ug).

- **Group A - Human Carcinogen** - This category indicates that there is sufficient evidence from epidemiological studies to support a causal association between an agent and cancer.
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- **Group B - Probable Human Carcinogen** - This category indicates that there is at least limited evidence from epidemiological studies of carcinogenicity to humans (Group B1) or that, in the absence of adequate data on humans, there is sufficient evidence of carcinogenicity in animals (Group B2).
- **Group C - Possible Human Carcinogen** - This category indicates that there is limited evidence of carcinogenicity in animals in the absence of data on humans.
- **Group D - Not Classified** - This category indicates that the evidence for carcinogenicity in animals is inadequate.
- **Group E - No Evidence of Carcinogenicity to Humans** - This category indicates that there is no evidence for carcinogenicity in at least two adequate animal test in different species, or in both epidemiological and animal studies.

6.5.2.2.4. Slope factors and unit risks are developed by the USEPA based on epidemiological or animal bioassay data for a specific route of exposure (oral or inhalation). The slope factor is the upper 95th percentile confidence limit of the slope of the dose response curve and is expressed as $(mg/kg\text{-}day)^{-1}$. The dose response relationship is linear only in the low dose region and therefore the slope factor is more accurate in this region. There is a high degree of uncertainty when extrapolating from high dose to low dose and from animal doses to human doses. For some chemicals, sufficient data are available to develop route-specific slope factors for inhalation and ingestion.

6.5.2.3 Identified Carcinogens in Chemical of Concern List

6.5.2.3.1. Arsenic and chromium III have been classified as human carcinogens by USEPA and have been assigned a carcinogenicity weight-of-evidence category of Group A.

6.5.2.3.2. 1,1-dichloroethane and cadmium have been classified as probable human carcinogens by USEPA and have been assigned a carcinogenicity weight-of-evidence category of Group B1.

6.5.2.3.3. Carbon tetrachloride, chloroform, methylene chloride, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, bis(2-ethylhexyl)phthalate, chrysene, N-nitrosodiphenylamine, beryllium and lead have been classified as a probable human carcinogens by USEPA, and have also been assigned a carcinogenicity weight-of-evidence category of Group B2.

6.5.2.3.4. The USEPA has placed lead in the weight-of-evidence group B2, indicating that it is a probable human carcinogen. There is sufficient animal evidence that lead is carcinogenic, however the human evidence is inadequate. Quantifying lead's cancer risk involves many uncertainties, some of which may be unique to lead. Age, health, nutritional state, body burden and exposure duration influence the absorption, release and excretion of lead. In addition, current knowledge of lead pharmacokinetics indicates that an estimate derived by existing standard procedures would not truly describe the potential risk. Therefore, a numerical estimate is not used to describe carcinogenic effects of lead.

6.5.2.3.5. 1,1-Dichloroethylene, butylbenzyl-phthalate, RDX and 2,4,6-trinitrotoluene have been classified as possible human carcinogens by USEPA and have been assigned a carcinogenicity weight-of-evidence category of Group C.

6.5.2.4 Inhalation Exposure

6.5.2.4.1 **Conversion of RfCs and IURs** - For inhalation pathways, reference concentrations (RfCs) and inhalation unit risks (IURs) should be used when available to calculate inhalation reference doses (IRfDs) and inhalation slope factors (ISFs) to assess risks via inhalation.

RfCs should be converted to the reference dose using the following equation:

$$\text{IRfD (mg/kg-day)} = \text{RfC (mg/m}^3\text{)} \times 20\ \text{m}^3 \text{ per day per 70 kg.}$$

Inhalation Unit Risks (IURs) should be converted to ISFs using the following equation:

$$\text{ISFs (kg-day/mg)} = \text{IUR (m}^3\text{/ug)} \times 70\ \text{kg} \times 20\ \text{m}^3 \text{ per day} \times 1000 \text{ ug per mg}$$

6.5.2.4.2 **Determination of Volatility** - Based on the physical characteristics of the detected contaminants (Table 6.14), a determination was made concerning the volatility of each compound. Chemicals having a Henry's Law constant greater than 10^{-5} and a molecular weight greater than 200 were considered to be volatile (USEPA, 1991). Chemicals not meeting these criteria were considered to be non-volatile. Chemicals without information concerning either the Henry's Law Constant or the molecular weight were not evaluated for the inhalation pathway. It should be noted that each chemical is represented only once as either a volatile or particulate (nonvolatile).

6.5.2.4.3 **Calculation of the PEF** - The particulate emission factor (PEF) relates the soil contaminant concentration to the air concentration of respirable particles due to fugitive dust emissions. This relationship is applicable to typical hazardous waste sites and is dependent on the assumption that the site will provide a relatively continuous and constant potential for emission over an extended period of time. Particulate emissions are generated by wind erosion and are dependent on the type of surface material and the vegetative cover. PEF values are generated using the following equation:

$$\text{PEF} = (\text{LS} \times \text{V} \times \text{DH} \times \text{Cfa} \times \text{Cfb}) - (\text{A} \times \text{RF} \times (1\text{-G}) \times (\text{UM/UT})^3 \times \text{Fx})$$

where:

PEF = particulate emission factor (m^3/kg)
LS = length of side of contaminated area (site specific, meters)
V = wind speed in mixing zone (2.25 m/sec, default)
DH = diffusion height (2 meters = average human height)
A = area of contamination (site specific, m^2)
RF = respirable fraction (constant = 0.4 g/m^3-hr)
G = fraction of vegetative cover (site specific, unitless)
UT = equivalent threshold value of wind speed at 10 m (12.8 m/sec, default)
UM = mean annual wind speed (6 m/sec - data from Defense Priority Model, 1993)
Fx = constant (0.5, unitless)
Cfa = conversion factor (3,600 sec/hr)
Cfb = conversion factor (1,000 g/kg)

6.5.2.4.4. Certain variables require site specific inputs (i.e. area of contamination and fraction of vegetative cover); where site specific information is not available, default values provided by RAGS (EPA, 1989c) were used. Site specific information used in this calculation includes the length of the contaminated side of the SWMU, the area of contamination, the fraction of vegetative cover, and the mean annual wind speed in this area.

6.5.2.4.5. The length of the contaminated side of each SWMU was measured from scale drawings showing the known and suspected contaminated locations. As a conservative measure, the longest side of each SWMU was used to approximate this distance to account for potential unknown contaminated areas. The area of contamination was also calculated from scale drawings of the study area.

6.5.2.4.6. The fraction of vegetative cover is a qualitative estimate expressed as a percentage for the site. Background information for each SWMU from the RCRA Facility Investigation Work Plan (Engineering Science, 1994a) was used to determine this parameter. The mean annual wind speed for this calculation was determined using meteorological data from the RAAP monitoring station.

6.5.2.4.7 **Calculation of the VF** - A volatilization factor was calculated to arrive at an estimation of soil - to - air volatilization. The volatilization factor is based on a number of site-specific and chemical-specific properties and is calculated as follows:

$$VF = (LS \times V \times DH \times (3.14 \times d \times T)^{0.5})/(A \times 2Dei \times E \times Kas \times CF)$$

where:

VF = volatilization factor (m^3/kg)
LS = length of side of contaminated area (site-specific, meters)
V = wind speed in mixing zone (2.25 m/sec, default)
DH = diffusion height (2 meters = average human height)
d = $(Dei \times E)/(E + Ps)(1 - E)/Kas$
T = the exposure interval (7.9×10^{-8} seconds, default)
A = area of contamination (site specific, m^2)
Dei = the effective diffusivity of the chemical (cm^2/sec)

E = true soil porosity (0.135 used Basewide for silty clay)
Ps = true soil density (2.65 g/cm^3 Basewide for silty clay)
Kas = (H/Kd) x 41 (g soil/cm^3 air)
H = Henry's Law Constant (atm-m^3/mol)
Kd = Koc x OC (cm^3/g)
CF = Conversion factor (0.001 kg/g)
Koc = organic carbon partition coefficient for each chemical (cm^3/g)
OC = fraction of organic carbon (0.2 - default)

6.5.2.4.8 **Volatilization During Showering Indoor Air Model** - Exposure point concentrations for VOCs released from water during showering were modeled on the basis of work conducted by Andelman (1984, 1985a, and 1985b). In the model, the air concentration is determined by a balance between the rate of release from the shower water ant the rate of air exchange between the shower and the rest of the house. The constants occurring in the model have been set to match the observed efficiency of volatilization of trichloroethylene (TCE) in model showers, and to fit the observed shower air concentrations of TCE in several homes with contaminated water where measurements have been made. Scaling to other compounds is accomplished by assuming the rate of volatilization from shower water to air is proportional to the Henry's Law Constant. The time-weighted average concentration of a volatile compound in the shower air over a period of t_s minutes is:

$$C_s = C_{inf}\,[(1 + (1/Kt_s))\,(\exp(-kt_s)-1)] \quad \text{for } t_s > 0$$

where:

C_s = average concentration of a volatile compound in the shower air (mg/m^3) over a duration of t_s (min)
t_s = time in shower (default value 12 min.)
K = rate constant for exponential function, defined below (1/min)
k = F_a/V_b (unitless)
F_a = flow rate of air in shower (2.4 m^3/min, default)
V_b = volume of bathroom (12 m^3, default)
C_{inf} = asymptotic concentration in air (mg/m^3) for shower running longer than 5 min.
C_{inf} = $[(E)(F_w)(C_t/1{,}000)]F_a$ (mg/m^3)

C_t = concentration in shower water (mg/L)
E = efficiency of release of compounds from water to air, defined below (unitless)
$E = (E_{TCE})(H)(H_{TCE})$
F_w = Flow rate of water in shower (8 L/min, default)
E_{TCE} = efficiency of release of TCE from water to air (0.6, default)
H = Henry's Law Constant (m^3 - atm/mol)
H_{TCE} = Henry's Law Constant for TCE (9.1×10^{-3} m^3 - atm/mol)

6.5.2.4.9. The concentration of VOCs in the water were based on the groundwater concentrations. The concentration of VOCs in the shower air will be modeled for the adult resident.

6.5.2.5 Dermal Exposure

6.5.2.5.1. Currently, USEPA has not identified toxicity reference values for dermal exposure and information is limited for determining uptake of chemicals across intact skin. USEPA RAGS guidance allows for an adjustment of oral toxicity information to quantitatively evaluate potential dermal exposures (USEPA, 1989c). Since most RfDs and slope factors are expressed as the amount of substance administered per unit time and unit body weight, it may be necessary to adjust oral toxicity values from administered doses to absorbed doses. Oral absorption factors are taken from the appropriate Agency for Toxic Substances and Disease Registry (ATSDR) profile; when these profiles are unavailable, default values based on the chemical classification are used.

6.5.2.5.2. Of the nineteen chemicals for which there are no dermal RfDs and slope factors available, only one study has been conducted concerning the dermal effects. The dermal effects of phenanthrene has been studied on laboratory animals. While the results are inconclusive, there are indications that chronic exposures will result in adverse effects. Chronic dermal exposures to these chemicals have not been examined for human subjects.

6.5.3 Risk Characterization

6.5.3.0.1. To characterize risk, toxicity and exposure assessments are summarized and integrated into quantitative and qualitative expressions of risk. To characterize potential non-

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carcinogenic effects, comparisons are made between projected intakes of substances and reference dose values. To characterize potential carcinogenic effects, probabilities that an individual will develop cancer over a lifetime of exposure are estimated for projected intakes and chemical-specific slope factors.

6.5.3.1 Non-Carcinogenic Effects

6.5.3.1.1. The potential for non-carcinogenic effects is evaluated by comparing an exposure level over a specified time period (e.g., lifetime) with an RfD derived for a similar exposure period. This ratio of exposure to toxicity is called a hazard quotient according to the following equation:

$$\text{Noncancer Hazard Quotient} = E/RfD$$

Where:

E = Exposure level or intake, and
RfD = Reference dose.

6.5.3.1.2. The noncancer hazard quotient assumes that there is a level of exposure below which it is unlikely that even sensitive individuals will experience adverse health effects (i.e., an RfD). If the exposure level (E) exceeds the threshold (i.e., if E/RfD exceeds unity), there may be concern for potential noncancer effects.

6.5.3.1.3. To assess the overall potential for non-carcinogenic effects posed by more than one chemical, a hazard index (HI) approach has been developed by USEPA. This approach assumes that simultaneous sub-threshold exposures to several chemicals could result in an adverse health effect. It also assumes that the magnitude of the adverse effect will be proportional to the sum of the ratios of the subthreshold exposures. This is expressed as:

$$HI = E_1 \backslash RfD_1, + E_2/RfD_2 + \ldots + E_i/RfD_i$$
$$\text{or } HI = HQ_1 + HQ_2 + \ldots + HQ_i$$

Where:

E_i = the exposure level or intake of the i^{th} toxicant, and
RfD_i = reference dose for the i^{th} toxicant
HQ_i = hazard quotient for the i^{th} toxicant.

6.5.3.1.4. Any single chemical with an exposure level greater than the toxicity threshold will cause the HI to exceed unity. For multiple chemical exposures, the HI can also exceed unity even if no single chemical exposure exceeds its RfD. The assumption of dose additivity reflected in the HI is best applied to compounds that induce the same effects by the same mechanisms. Applying the HI to cases where the known compounds do not induce the same effect may overestimate the potential for effects. To assess the overall potential for non-carcinogenic effects posed by several exposure pathways, the total HI for chronic exposure is the sum of the HIs for each pathway.

6.5.3.2 Carcinogenic Effects

6.5.3.2.1. Carcinogenic risks are estimated as the incremental excess probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (i.e., excess individual lifetime cancer risk). The slope factor converts estimated daily intakes (averaged over a lifetime of exposure) directly to incremental risk of an individual developing cancer. In general, it can be assumed that the dose-response relationship will be linear in the low-dose portion of the multistage model dose-response curve. Under this assumption, the slope factor is a constant and risk will be directly related to intake. Thus, the following linear low-dose equation was used in this assessment:

$$\text{Risk} = \text{CDI} \times \text{SF}$$

Where:

Risk = A unitless probability of an individual developing cancer a result of exposure,
CDI = Chronic Daily Intake averaged over 70 years (mg/kg-day), and
SF = Slope Factor $(\text{mg/kg-day})^{-1}$.

6.5.3.2.2. Because the slope factor is often an upper 95th-percentile confidence limit of the probability of a response and is based on experimental animal data used in the multistage

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model, the carcinogenic risk will generally be an upper-bound estimate. This means that the "true risk" is not likely to exceed the risk estimate derived through this model and is likely to be less than predicted.

6.5.3.2.3. For simultaneous exposure to several carcinogens, USEPA assumes that the risks are additive (USEPA, 1989b). That is to say:

$$Risk_T = Risk_1 + Risk_2 \ldots + Risk_i$$

Where:

$Risk_T$ = Total cancer risk, expressed as a unitless probability, and
$Risk_i$ = Risk estimate for the i^{th} substance.

Addition of the carcinogenic risks is valid when the following assumptions are met:

- doses are low;
- no synergistic or antagonistic interactions occur; and
- similar endpoints are evaluated.

6.5.3.2.4. According to the National Contingency Plan guidance (USEPA, 1990), the acceptable target carcinogenic risk levels are for a lifetime cancer risk range between 10^{-4} to 10^{-6}. This represents a target risk range, and actual risk levels are developed on a site-specific basis.

6.5.3.3 Uncertainty Analysis

6.5.3.3.1. All risk assessments involve the use of assumptions, judgments, and imperfect data to varying degrees. This results in uncertainty in the final estimates of risk. There are several categories of uncertainty associated with risk assessments. One is the initial selection of substances selected for analysis and therefore used to characterize exposures. Uncertainties are inherent in the exposure assessments for individual substances and individual exposures. These uncertainties are usually driven by uncertainty in the chemical monitoring data, but can also be driven by population intake parameters. Another source of uncertainty is the availability of toxicity information for the chemicals detected at

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the RAAP. Other sources of uncertainty are inherent in the toxicity values for each substance used to characterize risk. Finally, additional uncertainties are incorporated into the risk assessment when exposures to several substances across multiple pathways are summed and linear additivity is assumed.

6.5.3.3.2. **Uncertainty in Data Collection and Evaluation** - Uncertainties in the data collection/evaluation step of the risk assessment focus on determining whether enough samples were collected to adequately characterize the risk, and if sample analyses were conducted in a qualified manner to maximize the confidence in the results. Because the Work Plans and Quality Assurance Project Plans were developed to collect samples from zones most likely to have been affected by site activities, the samples were collected randomly from areas of suspected contamination. This biased sampling effort may tend to overestimate the risk at certain SWMUs. In addition, the distinction between surface and subsurface soils was based upon differences in soil horizons when inorganic background sample analysis was performed. This may lead to uncertainty in determining differences between surface and subsurface exposure, and may over- or underestimate risk.

6.5.3.3.3. Chemicals that were never detected were eliminated from the assessment. It is possible, but unlikely, that some chemicals were present below the sample quantitation limit (SQL) and not retained in the assessment. Since samples were collected at areas where concentrations were most likely to be high, it is very unlikely that any chemicals were present at a site at health-significant levels and not detected in at least one sample. However, if this did occur, this assumption would underestimate risk.

6.5.3.3.4. If an inorganic chemical was detected above background, it was retained in the risk assessment regardless of how frequently it was detected. All organic chemicals were retained in the risk assessment. To calculate the exposure concentrations, chemicals were assumed to be present in all samples within a media. When the chemical was not detected in a sample, one-half of the SQL was used. Especially for chemicals that were detected in only a few samples, the 95 percent upper confidence interval or maximum value probably greatly overestimates the amount of the chemical present and, consequently, overestimates the risk from the chemical.

6.5.3.3.5. Chromium exists in two oxidation states: trivalent (chromium III) and hexavalent (chromium VI). Each has a screening Risk Based Concentration (RBC) specific to that oxidation state. Sample analysis provided results for total chromium and did not identify oxidation states. However, chromium occurs in nature principally as the trivalent form. Trivalent chromium is the most stable form; hexavalent chromium is a moderately strong oxidizing agent that reacts with organic materials and is reduced to trivalent chromium. In addition, the main source of hexavalent chromium is chromate and dichromate used in the manufacture of chrome steels and alloys or in plating operations. These types of activities did not occur at the RAAP. Therefore, trivalent chromium is the expected oxidation state at the RAAP.

6.5.3.3.6. The data also include a number of data validation flags, as detailed in Subsection 5.2. Qualified data were retained following RAGS guidance. A common qualifier used in risk assessment is the J qualifier. J-qualified data indicates uncertainty in the reported concentration of the chemical, but not in the assigned identity. RAGS guidance (USEPA, 1989) allows for the retention of J-qualified chemical concentrations the same way as positive data without the J qualifier. The uncertainty in the reported chemical concentration can over- or underestimate risk.

6.5.3.3.7. **Uncertainty in Exposure Assessment** - A large part of the risk assessment is estimating risks that are conditional upon the existence of exposure conditions analyzed. If exposure does not occur, no risks are present. Once pathways are identified, exposure point concentrations must be estimated. There is always some doubt as to how well an exposure model approximates the actual conditions receptors will be exposed to at a given site. Key assumptions in estimating exposure point concentrations and exposure assumptions and their potential impact on the assessment are described in the following paragraphs.

6.5.3.3.8. Exposure point concentrations were based on steady state conditions; therefore, future concentrations are assumed to be identical to current concentrations. This assumption may tend to overestimate long-term exposure concentrations because chemical concentrations are likely to decrease over time from natural processes such as dispersion, attenuation, and dilution during migration to potential receptors.

6.5.3.3.9. One of the main areas of uncertainty in exposure assessment is determining land use. At the RAAP, most of the area is industrial and current access is limited to official visitors. As a conservative measure, future land use within RAAP was assumed to be developed for residential use. This may tend to over- or underestimate risks at the RAAP.

6.5.3.3.3.9.1. Another uncertainty in exposure assessment is the particulate emission factor (PEF) used to quantify the generation of fugitive dusts from surface contamination. The PEF calculation is not chemical-specific and therefore, it does not account for the different physical characteristics of the contaminants. In this respect, all chemicals were assumed to have the same behavior when adsorbed to fugitive dust particles. This may tend to over- or underestimate risk. Additionally there is always uncertainty associated with modeled concentrations. Models were used to estimate volatilization from soils, particulate generation and volatilization during showering. Assumptions were made in each of these models that may over- or underestimate risk.

6.5.3.3.3.9.2. **Uncertainty in Toxicity Assessment** - Some uncertainty is inherent in the toxicity values for the duration of exposure assessed. Many of the studies are based on animals and extrapolated to humans, and in some cases, subchronic studies may be used to assess chronic effects. As stated in the toxicity assessment section, several uncertainties apply in these extrapolations. Because slope factors are generally based on the upper limit of the 95th-percentile confidence interval, chemical-specific risks may be overestimated. Reference doses are also chosen conservatively and make use of safety factors.

6.5.3.3.3.9.3. USEPA has not published dermal toxicity values and therefore, adjustments are made to the oral toxicity values in order to quantitatively evaluate risks through dermal exposure. There is also uncertainty associated with the lack of toxicity data and studies for some of the chemicals of concern. These chemicals are unable to be quantitatively assessed in the risk assessment. This lack of data and adjusted oral data may tend to over- or underestimate risk.

6.5.3.3.3.9.4. Risks to construction workers were assessed as though their exposure were chronic or long-term rather than subchronic or short-term. Using a chronic exposure is a conservative assumption and tends to overestimate risks.

6.5.3.3.3.9.5. **Uncertainty In Risk Characterization** - Uncertainties in the toxicity assessment are compounded under the assumption of dose additivity for multiple substance exposure. That assumption ignores possible synergisms and antagonisms among chemicals and assumes similarity in mechanisms of action and metabolism. For noncarcinogens the assumption of dose additivity, established by RAGS guidance and reflected in the HI, is best applied to compounds that induce the same target organ effects by the same mechanisms. Applying the HI to cases where the known compounds do not induce the same effect or where positive synergism between chemicals is apparent may under- or overestimate the potential for effects. Similarly, risks summed for chemicals having various weight-of-evidence classifications as well as different target organs may also tend to overestimate risk.

SECTION 7

SITE CHARACTERIZATION OF SWMU 17 AND SWMU 40 (CONTAMINATED WASTE BURNING AREAS AND SANITARY LANDFILL)

7.1 HISTORY AND OPERATIONS

7.1.0.1. SWMU 17 is used for burning wastes potentially contaminated with explosives or propellants and is subdivided into five separate areas (A through E) based on history and operations. The general SWMU 17 (Vicinity) discussions address the monitoring wells placed in and around the unit and the groundwater discharge point at the New River as determined by the dye tracing study. The discharge point is approximately 4,800 feet west of the SWMU 17 boundary. SWMU 40 is included with SWMU 17 because of their proximity and similar subsurface conditions.

7.1.0.2. SWMU 17 is located in the south-central part of the Main Manufacturing Area. Plate 1 shows SWMU 17 and SWMU 40 in relation to the rest of the facility. A detailed location map of SWMU 17/SWMU 40 is presented as Figure 7.1.

7.1.1 SWMU 17A: Stage and Burn Area

7.1.1.1. SWMU 17A is situated within the westernmost of the two prominent sinkholes which form the dominant geomorphological feature of SWMU 17. The sinkhole is approximately 30 feet deep by 200 feet wide by 400 feet long.

7.1.1.2. Materials consisting mostly of large metallic items and large combustible items contaminated with propellants and explosives are accumulated into large piles in the Stage and Burn Area. The materials are piled on the ground by crane to a height of approximately 30 feet and then ignited. Facility representatives reported that waste oil and diesel fuel are used to fuel the burning operations. Wood, paper, and cardboard contaminated with propellants and explosives are often added to the piles to increase combustion. Waste oil used for these operations was stored in the two waste oil USTs (SWMU 76 on Figure 7.1) formerly located along the Stage and Burn Area embankment east of the waste pile. Following burning of the waste pile, scrap metal is removed from the

Table 6.14
Environmental Properties, Fate, and Transport Data[(a)]
Radford Army Ammunition Plant

CAS#	Chemical	Class	Formula	Mol Wt	Solubility (mg/L)	Vapor Pressure (mm Hg)	Henry's Law K (atm-m3/mole)	Log Kow (mL/g)	Log BCF	Log Koc (mL/g)	Spec Grav	Gas Diff[(b)] (g/cm^2)	SoilHalflife (days)	AirHalflife (days)	SfWtrHalflife (days)	GdWtrHalflife (days)	Derm ABS	PC
7440-38-2	Arsenic	M	As	74.9	NR	1.00E+00	NR	NR	NR	NR	5.72	NA	Pers	Pers	Pers	Pers	1% (c)	1.00E-03 (c)
7440-39-3	Barium	M	Ba	137.0	NR	NR	NR	NR	1.00	NR	3.60	NA	Pers	Pers	Pers	Pers	1% (c)	1.00E-03 (c)
7440-41-7	Beryllium	M	Be		Insol	1.00E+01	NR	NR	NR	NR	1.85	NA	Pers	Pers	Pers	Pers	1% (c)	1.00E-03 (c)
7440-43-9	Cadmium	M	Cd	112.0	NR	NR	NR	NR	1.91	NR	8.65	NA	Pers	Pers	Pers	Pers	1% (c)	1.00E-03 (c)
7440-47-3	Chromium III	M	Cr$^{(+3)}$	52.0	NR	NR	NR	NR	1.20	NR	7.14	NA	Pers	Pers	Pers	Pers	1% (c)	1.00E-03 (c)
74399-21-1	Lead	M	Pb	207.0	NR	NR	NR	NR	1.69	4.01	11.34	NA	Pers	Pers	Pers	Pers	1% (c)	1.00E-03 (c)
7439-97-6	Mercury	M	Hg	201.0	2.00E+03	2.00E-03	NR	0.71	3.74	1.83	13.53	NA	Pers	Pers	Pers	Pers	1% (c)	1.00E-03 (c)
7440-02-0	Nickel	M	Ni	59.0	Insol	NR	NR	NR	1.67	NR	8.90	NA	Pers	Pers	Pers	Pers	1% (c)	1.00E-03 (c)
7782-49-2	Selenium	M	Se	78.9	Insol	1.00E-03	NR	NR	NR	NR	4.80	NA	Pers	Pers	Pers	Pers	1% (c)	1.00E-03 (c)
7440-22-4	Silver	M	Ag	108.0	Insol	NR	NR	NR	3.49	NR	10.49	NA	Pers	Pers	Pers	Pers	1% (c)	1.00E-03 (c)
56-55-3	Benzo(a)anthracene	S	C18 H12	228.0	1.40E-02	1.10E-07	8.00E-06	5.91	4.00	6.14	1.27	5.08E-02	102.0 - 680.0	0.04 - 0.13	0.04 - 0.13	204.0 - 1360.0	10% (c)	8.10E-01 (c)
205-99-2	Benzo(b)fluoranthene	S	C20 H12	252.0	1.20E-03	5.00E-07	1.20E-05	6.57	4.38	5.74	NR	4.83E-02	360.0 - 610.0	0.06 - 0.6	0.36 - 30.0	720.0 - 1220.0	10% (c)	1.20E+00 (c)
191-24-2	Benzo(g,h,i)perylene	S	C22 H12	252.0	2.60E-04	1.01E-10	1.40E-07	7.10	4.70	6.89	NR	4.83E-02	590.0 - 650.0	0.01 - 0.13	590.0 - 650.0	1180.0 - 1300.0	10% (c)	2.19E+00 (c)
207-08-9	Benzo(k)fluoranthene	S	C20 H12	252.0	5.50E-04	9.59E-11	1.04E-03	6.85	4.53	6.64	NR	4.83E-02	910.0 - 2140.0	0.05 - 0.46	0.16 - 20.8	1778.0 - 4280.0	10% (c)	4.00E+00 (c)
117-81-7	Bis(2-ethylhexyl)phthalate	S	C24 H38 O	391.0	4.00E-01	6.20E-08	1.10E-05	4.20	4.14	5.00	0.99	3.88E-02	5.0 - 22.9	0.12 - 1.21	5.0 - 22.9	10.0 - 389.0	10% (c)	3.30E-02 (c)
218-01-9	Chrysene	S	C18 H12	228.0	6.00E-03	6.30E-09	7.26E-20	5.91	4.07	5.39	1.27	5.08E-02	371.0 - 1000.0	0.03 - 0.33	0.18 - 0.54	722.0 - 2000.0	10% (c)	8.10E-01 (c)
84-74-2	Di-n-butylphthalate	S	C16 H22 O4	278.0	4.50E+03	1.40E-05	6.30E-05	4.79	2.78	3.14	1.04	4.60E-02	2.0 - 23.0	0.31 - 3.08	1.0 - 14.0	2.0 - 23.0	10% (c)	3.30E-02 (c)
534-52-1	4,6-dinitro-2-cresol	S	C7 H6 N2 O5	198.1	1.30E+01	1.05E-04	4.80E-11	2.56	1.72	2.48	NR	5.44E-02	-	0.3 - 50.0	0.25 - 38.0	-	10% (c)	NR
88-99-3	Diethylphthalate	S	C12 H14 O4	222.0	1.20E+03	3.50E-03	8.46E-07	3.00	2.07	1.84	1.12	5.14E-02	3.0 - 56.0	0.88 - 8.83	3.0 - 56.0	6.0 - 112.0	10% (c)	4.80E-03 (c)
131-11-3	Dimethylphthalate	S	C10 H10 O4	194.0	4.50E+04	1.00E-02	2.15E-06	2.00	1.76	2.28	1.19	5.50E-02	1.0 - 7.0	4.67 - 46.7	1.0 - 7.0	2.0 - 14.0	10% (c)	1.60E-03 (c)
206-44-0	Fluoranthene	S	C16 H10	202.0	3.73E-01	5.00E-06	1.69E-02	5.22	3.06	4.62	1.25	5.39E-02	140.0 - 440.0	0.08 - 0.84	0.88 - 2.63	280.0 - 880.0	10% (c)	3.60E-01 (c)
86-30-6	N-Nitrosodiphenylamine	S	C12 H10 N2 O	198.2	4.00E+01	1.00E-01	6.40E-04	3.13	2.34	3.13	1.23	5.44E-02	-	0.25 - 1.0	-	-	10% (c)	6.70E-01 (c)
85-01-8	Phenanthrene	S	C14 H10	178.0	1.29E+00	6.80E-04	2.56E-05	4.57	3.42	4.59	1.18	5.74E-02	16.0 - 200.0	0.08 - 0.84	0.13 - 1.04	32.0 - 400.0	10% (c)	2.70E-01 (c)
129-00-0	Pyrene	S	C16 H10	202.0	1.71E-01	2.50E-06	1.87E-05	5.32	2.66	5.13	1.27	5.39E-02	210.0 - 1900.0	0.03 - 0.09	0.03 - 0.09	420.0 - 3800.0	10% (c)	6.70E-01 (c)
56-23-5	Carbon Tetrachloride	V	C Cl4	153.2	1.16E+03	9.13E+01	3.04E-02	2.83	1.26	1.85	1.59	6.19E-02	-	10950.0 - 18250.0	3.0 - 30.0	-	25% (c)	1.00E-03 (c)
67-66-3	Chloroform	V	C H Cl3	119.0	9.30E+03	1.98E+02	3.20E-03	1.97	0.57	1.64	1.48	7.02E-02	28.0 - 180.0	26.0 - 260.0	28.0 - 180.0	56.0 - 1800.0	25% (c)	8.90E-03 (c)
75-34-3	1,1-Dichloroethane	V	C2 H4 Cl2	99.0	8.65E+03	8.70E+01	1.31E-03	1.48	0.08	1.28	1.25	7.70E-02	100.0 - 180.0	12.2 - 121.5	100.0 - 180.0	100.0 - 360.0	25% (c)	5.30E-03 (c)
75-35-4	1,1-Dichloroethene	V	C2 H2 Cl2	97.0	6.40E+03	5.91E+02	1.90E-01	2.13	0.75	1.81	1.22	7.78E-02	28.0 - 180.0	0.41 - 4.11	28.0 - 180.0	56.0 - 132.0	25% (c)	1.60E-02 (c)
75-09-2	Methylene chloride	V	C H2 Cl2	85.0	1.94E+04	4.40E+02	2.69E-03	1.30	0.70	0.94	1.33	8.31E-02	7.0 - 28.0	19.9 - 191.0	7.0 - 28.0	14.0 - 56.0	25% (c)	4.50E-03 (c)
98-95-3	Nitrobenzene	V	C6 H5 N O2	123.1	2.00E+03	1.00E+00	2.20E-05	1.85	0.78	1.84	1.20	6.91E-02	-	0.5 - 111.0	1.0 - 3.8	-	25% (c)	1.00E-03 (c)
127-18-4	Tetrachloroethene	V	C2 Cl4	165.8	1.50E+01	1.85E+01	ND	3.40	2.35	ND	1.62	5.95E-02	-	1.0 - 60.0	0.1 - 14.0	-	25% (c)	1.00E-03 (c)
71-55-6	1,1,1-Trichloroethane	V	C2 H3 Cl3	134.0	1.33E+03	1.24E+02	1.62E-02	2.49	0.75	2.18	1.34	6.62E-02	28.0 - 180.0	226.7 - 2247.0	140.0 - 273.0	140.0 - 546.0	25% (c)	1.70E-02 (c)
79-01-6	Trichloroethene	V	C3 H Cl3	132.0	1.47E+03	7.40E+01	1.17E-02	3.30	1.03	2.10	1.46	6.67E-02	180.0 - 360.0	1.13 - 11.3	180.0 - 360.0	321.0 - 1653.0	25% (c)	1.60E-02 (c)
2691-41-0	HMX	X	C4 H8 N8 O8	296.2	NR	NR	NR	NR	NR	NR	NR	4.45E-02	-	-	17.0 - 7900.0	-	1% (c)	1.00E-03 (c)
121-14-2	2,4-Dinitrotoluene	X	C7 H6 N2 O4	182.1	3.00E+01	1.40E-04	8.79E-08	1.98	2.31	NR	1.32	5.68E-02	-	1.0 - 71.0	1.7 - 438.0	-	1% (c)	1.00E-03 (c)
121-82-4	RDX	X	C3 H6 N6 O6	222.3	Insol	NR	2.60E-11	0.87	1.39	2.22	1.82	5.14E-02	-	0.05 - 1.0	9.0 - 112.0	-	1% (c)	1.00E-03 (c)
118-96-7	2,4,6-Trinitrotoluene	X	C7 H5 N2 O4	227.1	ND	1.90E-04	4.57E-07	1.60	ND	3.20	1.65	5.09E-02	-	110.0 - 150.0	25.0 - 64.0	-	1% (c)	1.00E-03 (c)

Header Notes:

Class: general analytical classification; BCF: bioconcentration factor (fish); Koc: organic carbon (soils) partition coefficient; Kow: octanol/water partition coefficient; Mol wt: molecular weight; Spec Grav: specific gravity

Miscellaneous Abbreviations:

B: biodegradation; H: hydrolysis; M: metals; O: oxidation; P: photolysis; S: semivolatiles; T1: pesticides; T2: herbicides; T3: polychlorinated biphenyl;
V: volatiles; W: wet chemistry; X: explosives.

Table Notes:

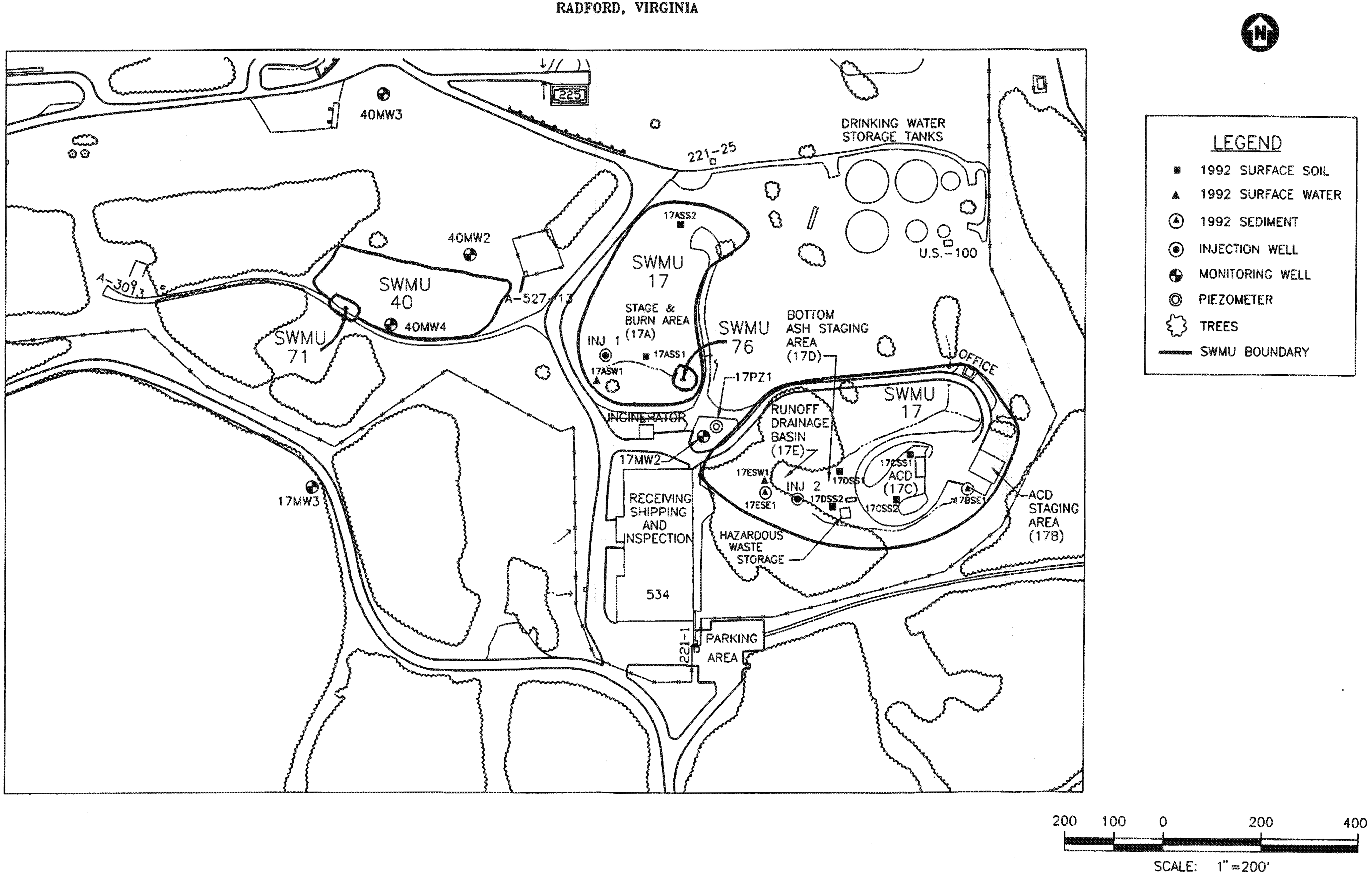
(a) Information gathered from Groundwater Chemicals Desk Reference, Volumes 1 and 2, Montgomery et al. Supplemental information gathered from: The Merck Index, Eleventh Edition; Estimating Toxicity of Industrial Chemicals to Aquatic Organisms Using SARs, Volume I (USEPA 560/688001). Fate and Exposure Data, Volumes 1 - 3 (Howard, et al, Lewis Publishers); Envirofate Database (Chemical Information System). Miscellaneous halflife and/or degradation rates gathered from Envirofate Database (Chemical Information System). Halflife information gathered from Handbook of Environmental Degradation Rates (Philip Howard, et al, Lewis Publishers, 1991).

(b) Gas diffusivity value based upon Graham algorithm as follows: Diffusivity of Gas A = (Diffusivity of Gas B) × (Square root of (Mol Wt of Gas B/Mol Wt of Gas A))
where: Gas B diffusivity value = ethyl ether (0.089 g/cm^2) and Gas B mol wt = ethyl ether (74.14 g/mole)

(c) USEPA, 1992

FIGURE 7.1
SWMU 17/SWMU 40 LOCATION MAP (CONTAMINATED WASTE BURNING AREA)

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



residue and accumulated in piles to be sold for recycling. If ash is characterized as hazardous it is transported off-post for proper disposal. Non-hazardous ash is shipped off-post to an industrial landfill. When the USTs were removed in 1991, lead slag was detected in soils at the SWMU 76 area. This unnumbered SWMU was identified as the Former Lead Furnace Area (FLFA), a facility used at the time of World War II.

7.1.2 SWMU 17B: Air Curtain Destructor (ACD) Staging Area

7.1.2.1. SWMU 17B (as well as 17C, 17D, and 17E), is located within the easternmost sinkhole of SWMU 17. The sinkhole is approximately 40 feet deep by 600 feet long by 350 feet wide. SWMU 17B is a staging area for the ACD. It is divided into two bays; one is covered with a roof and the other is open. Both are constructed with concrete floors and 6-foot high concrete walls on three sides. Materials are accumulated in this staging area prior to burning in the ACD. Adjacent to the uncovered storage bay is a below-grade, concrete-lined settling basin that collects surface water runoff from the staging pads. The pit is equipped with a sump pump that, at one time, peridocially pumped the collected water into an unlined drainage ditch leading to the Runoff Drainage Basin (17E). Currently, runoff is collected in a sump and treated at RAAP's industrial sewage treatment plant.

7.1.3 SWMU 17C: Air Curtain Destructor (ACD)

7.1.3.1. Contaminated wastes small enough to feed into the burn chamber are burned in the ACD (17C), a large concrete pit enclosed within a metal structure. Forced air blowers increase burning efficiency. The system does not qualify as an incinerator under EPA definitions and is considered simply a form of controlled open burning (USAEHA, 1980).

7.1.4 SWMU 17D: Ash Staging Area

7.1.4.1. SWMU 17D is a staging area adjacent to the ACD. It is used for accumulating and storing ACD ash and scrap metal prior to disposal. The staging area is currently composed of a storage shed with a concrete floor. Prior to construction of the shed, the ash and scrap metal were staged on the ground.

7.1.5 SWMU 17E: Runoff Drainage Basin

7.1.5.1. Directly west of the ACD Ash Staging Area (17D) is SWMU 17E. It is an unlined settling basin. This unit appears to be a natural drainage depression rather than a constructed basin. Surface water runoff from the ACD and Ash Staging Area drains into SWMU 17E; water from the settling basin at SWMU 17B also discharges to this drainage basin.

7.1.6 SWMU 40: Sanitary Landfill

7.1.6.1. This SWMU was identified in the RCRA Facility Assessment (USEPA, 1989) as having a potential for releasing contaminants into the environment and was included in the RCRA Permit for Corrective Action and Incinerator Operation (USEPA, 1989) as warranting investigation. SWMU 40 is a Sanitary Landfill (Nitroglycerin Area) located in the south-central section of the RAAP Main Manufacturing Area. It is situated about 200 feet west-northwest of the Contaminated Waste Burning Areas (SWMU 17). This landfill was never permitted, and was reportedly used in the 1970s and early 1980s (following closure of SWMU 43) for the disposal of uncontaminated paper, municipal refuse, cement, and rubber tires (USEPA, 1987; USATHAMA, 1976). No known hazardous wastes or wastes containing hazardous constituents were ever disposed of in the landfill.

7.1.6.2. The landfill is approximately 430 feet by 100 feet in size (about 1 acre). The unit was an area fill; no trenches were excavated. The unit was closed with a soil cap and moderate grass cover. Since closure, excavated "clean" soils have been stockpiled on top of the unit by the USACE as a result of construction activities at RAAP. In 1991 and 1992, a fenced enclosure for asbestos storage and other hazardous materials was constructed near the northeast corner of this SWMU.

7.2 PREVIOUS INVESTIGATIONS

7.2.0.1. Initial RFI activities were conducted at SWMU 17 between Fall 1991 and Spring 1992, and VI activities were performed at SWMU 40 in Fall 1991. The findings of the RFI program for the five different areas in SWMU 17 (Dames & Moore, 1992a) and the VI results for SWMU 40 (Dames & Moore, 1992b) are discussed below. Results of soil, surface water and sediment sampling for the five SWMU 17 areas are summarized in Tables 7.1, 7.2, and 7.3, respectively. Also included in these summary tables for comparison are

TABLE 7.1
RFI DATA 1992
SUMMARY OF ANALYTICAL DATA FOR SOIL SAMPLES COLLECTED AT SWMU 17
RADFORD ARMY AMMUNITION PLANT, VIRGINIA

	PQLs	No. of Samples	Concentration Range 26 Feb 92 - 27 Feb 92 1.0 ft - 2.8 ft	Upland Soil Background Comparison Level*	HBN	RBC Industrial Soil
TAL Inorganics (µg/g)						
Aluminum	14.1	8	7,170 - 37,600	22,921	230,000	1,000,000
Antimony	20	8	LT 7.14 - 22.9	7.14	30	410
Arsenic	30	8	[5.55] - [100]	9	0.5	1.6
Barium	1	8	39.3 - [1,120]	109	1,000	72,000
Beryllium	0.2	8	LT 0.5 - [2.11]	1.10	0.1	0.67
Cadmium	2	8	LT 0.7 - 10.2	0.70	40	510
Calcium	100	8	1,460 B - 130,000	109,994	NSA	NA
Chromium	4	8	25.8 - 210	47.46	400	1,000,000**
Cobalt	3	8	[7.83] - [27.5]	27.90	0.8	NA
Copper	7	8	16.6 - [4,000]	29.69	2,900	38,000
Iron	1,000	8	18,500 - 110,000	39,707	NSA	NA
Lead	2	8	16.2 - [1,990]	282.84	200	NA
Magnesium	50	8	5,270 - 92,000	45,931	NSA	NA
Manganese	0.275	8	200 - 901	978	8,000	5,100
Mercury	0.1	8	LT 0.05 - 0.569	0.05	20	310
Nickel	3	8	9.7 - 120	37.23	1,000	20,000***
Potassium	37.5	8	523 - 8,580	3,864	NSA	NA
Silver	4	8	1.07 - 23	1.75	200	5,100
Sodium	150	8	180 B - 3,240	313.20	NSA	NA
Thallium	20	8	LT 6.62 - [79]	6.62	6	NA
Vanadium	0.775	8	27.9 - 69.1	73.89	560	7,200
Zinc	30.2	8	63.1 - 11,000	373.56	16,000	310,000
Explosives (µg/g)						
24DNT	0.424	8	0.963 - LT 0.424	1	NT	2,000

* Upland soil samples were collected from 5 locations at RAAP. The mean and standard deviations were calculated. Background comparison levels were selected from the upper 95 percent confidence interval of the background data set, which is equal to the mean plus two standard deviations.

** Chromium III and compounds

*** Nickel (soluble salts)

B Analyte was detected in corresponding method blank; values are flagged if the sample concentration is less than 10 times the method blank concentration for common laboratory constituents and 5 times for all other constituents.

HBN Health-based number as defined in the RCRA permit. HBNs not specified in the permit were derived using standard exposure and intake assumptions consistent with EPA guidelines (51 Federal Register 33992, 34006, 34014, and 34028).

LT Concentration is reported as less than the certified reporting limit.

NA Not available; no RBC provided

NSA No standard (HBN) available; health effects data were not available for the calculation of an HBN. HBNs were not derived for TICs.

NT Not tested.

PQL Practical quantitation limit; the lowest concentration that can be reliably detected at a defined level of precision for a given anaytical method.

RBC Risk-based concentration provided by USEPA (USEPA,1994)

TAL Target analyte list.

µg/g Micrograms per gram.

[ ] Brackets indicate that the detected concentration exceeds the HBN.

From Dames & Moore, 1992a

TABLE 7.2
RFI DATA 1992
SUMMARY OF ANALYTICAL DATA FOR SURFACE WATER SAMPLES COLLECTED AT SWMU 17
RADFORD ARMY AMMUNITION PLANT, VIRGINIA

	PQLs	No. of Samples	Concentration Range 27 Feb 92 - 05 Mar 92	HBN	RBC Tap Water
TAL Inorganics (µg/L)					
Aluminum	141	3	4,000 - 21,000	101,500	110,000
Arsenic	10	3	[59.2] - [96.3]	50	0.038
Barium	20	3	86.9 - 175	1,000	2,600
Calcium	500	3	30,200 - 47,400	NSA	NA
Chromium	10	3	[52.9] - [156]	50	180*
Copper	60	3	266 - 682	1,295	1,400
Iron	38.1	3	3,940 - 31,200	NSA	NA
Lead	10	3	[150] - [520]	50	NA
Magnesium	500	3	7,800 - 25,700	NSA	NA
Manganese	2.75	3	67.7 - 339	3,500	180
Mercury	2	3	0.236 - 0.383	2	11
Nickel	50	3	LT 34.3 - 44.5	700	730**
Potassium	375	3	8,330 - 11,400	NSA	NA
Silver	2	3	0.396 - 1.25	50	180
Sodium	500	3	14,400 - 32,000	NSA	NA
Vanadium	40	3	LT 11 - 68.7	245	260
Zinc	50	3	624 - 1,700	7,000	11,000
Explosives (µg/L)					
24DNT	0.064	3	[0.092] - [0.372]	0.05	73
Other (µg/L)					
Total Organic Carbon	1,000	3	9,330 - 12,900	NSA	NA
Total Organic Halogens	1	3	44.9 - 96.5	NSA	NA
pH	NA	3	7.41 L - 7.71	NSA	NA

*	Chromium VI and compounds.
**	Nickel (soluble salts).
HBN	Health-based number as defined in the RCRA permit. HBNs not specified in the permit were derived using standard exposure and intake assumptions consistent with EPA guidelines (51 Federal Register 33992, 34006, 34014, and 34028).
L	Indicates holding time for analysis was missed, but data quality is not believed to be affected.
LT	Concentration is reported as less than the certified reporting limit.
NA	Not available.
NSA	No standard (HBN) available; health effects data were not available for the calculation of an HBN. HBNs were not derived for TICs.
PQL	Practical quantitation limit; the lowest concentration that can be reliably detected at a defined level of precision for a given anaytical method.
RBC	Risk-based conentration provided by USEPA (USEPA, 1994).
TAL	Target analyte list.
µg/L	Micrograms per liter.
[ ]	Brackets indicate that the detected concentration exceeds the HBN and/or RBC.

From Dames & Moore, 1992a

TABLE 7.3
RFI DATA 1992
SUMMARY OF ANALYTICAL DATA FOR SEDIMENT SAMPLES COLLECTED AT SWMU 17
RADFORD ARMY AMMUNITION PLANT, VIRGINIA

	PQLs	No. of Samples	Concentration Range 27 Feb 92 - 05 Mar 92 0.5 ft - 1.0 ft	Upland Soil Background Comparison Level*	HBN	RBC Industrial Soil
TAL Inorganics (µg/g)						
Aluminum	14.1	3	22,700 - 27,200	22,921	230,000	1,000,000
Arsenic	30	3	[33.5] - [200]	9	0.5	0.038
Barium	1	3	243 - 273	109	1,000	72,000
Cadmium	2	3	LT 0.7 - 14.1	0.70	40	510
Calcium	100	3	11,000 - 58,100	109,994	NSA	NA
Chromium	4	3	93.9 - 232	47.46	400	1,000,000**
Cobalt	3	3	[13.5] - [14.6]	27.90	0.8	NA
Copper	7	3	475 - 1,130	29.69	2,900	38,000
Iron	1,000	3	27,600 - 35,900	39,707	NSA	NA
Lead	2	3	[542] - [1,370]	282.84	200	NA
Magnesium	50	3	16,600 - 26,800	45,931	NSA	NA
Manganese	0.275	3	253 - 427	978	8,000	5,100
Mercury	0.1	3	0.206 - 1.69	0.05	20	310
Nickel	3	3	38.2 - 56.1	37.23	1,000	20,000***
Potassium	37.5	3	1,730 - 2,920	3,864	NSA	NA
Silver	4	3	1.92 - 6.31	1.75	200	5,100
Sodium	150	3	704 B - 1,400 B	313.20	NSA	NA
Vanadium	0.775	3	49.1 - 65.2	73.89	560	7,200
Zinc	30.2	3	1,510 - 4,230	373.56	16,000	310,000
Explosives (µg/g)						
24DNT	0.424	3	[1.04] - [56]	NT	1	2,000
TCLP Metals (µg/L)						
Arsenic	10	1	97	NT	5,000	NA
Barium	20	1	1,520	NT	100,000	NA
Chromium	10	1	102	NT	5,000	NA
Silver	2	1	13.2	NT	5,000	NA

* Upland soil samples were collected from 5 locations at RAAP. The mean and standard deviations were calculated. Background comparison levels were selected from the upper 95 percent confidence interval of the background data set, which is equal to the mean plus two standard deviations.

** Chromium III and compounds.

*** Nickel (soluble salts).

B Analyte was detected in corresponding method blank; values are flagged if the sample concentration is less than 10 times the method blank concentration for common laboratory constituents and 5 times for all other constituents.

HBN Health-based number as defined in the RCRA permit. HBNs not specified in the permit were derived using standard exposure and intake assumptions consistent with EPA guidelines (51 Federal Register 33992, 34006, 34014, and 34028).

LT Concentration is reported as less than the certified reporting limit.

NA Not available, no RBC provided.

NSA No standard (HBN) available; health effects data were not available for the calculation of a HBN. HBNs were not derived for TICs.

NT Not tested.

PQL Practical quantitation limit; the lowest concentration that can be reliably detected at a defined level of precision for a given anaytical method.

RBC Risk-based concentration provided by USEPA (USEPA, 1994).

TAL Target analyte list.

TCLP Toxicity Characteristic Leaching Procedure.

µg/g Micrograms per gram.

µg/L Micrograms per liter.

[ ] Brackets indicate that the detected concentration exceeds the HBN and/or RBC.

From Dames & Moore, 1992a

health-based numbers (HBNs) taken from the RCRA permit (USEPA, 1989a). Risk-based concentrations (RBCs) for commercial industrial soils are also presented in Tables 7.1 and 7.3 (soils and sediments, respectively), and RBCs for tapwater are presented in Table 7.2 (USEPA, 1994). Additionally, comparison levels of upland soil background data, as calculated by Dames & Moore (1992a), are included in Table 7.1 (soil) and Table 7.3 (sediment). A total of 10 background soil samples were collected during the RFI from off-post locations in the immediate vicinity of RAAP. Sample locations from the Dames & Moore investigation are shown in Figure 7.1.

7.2.1 SWMU 17A

7.2.1.1. The ash from the Stage and Burn Area was sampled in 1980. The extract procedure (EP) toxicity test determined that the ash was nonhazardous (USAEHA, 1980).

7.2.1.2. Near-surface soil samples (0 to 0.5 feet) were collected from two locations (17ASS1 and 17ASS2) at SWMU 17A to determine if soils had been contaminated by burning activities. No deeper soil samples were collected. All soil samples were analyzed for metals and explosives. Concentrations of arsenic, beryllium, cobalt, copper, lead, and thallium exceeded the HBN or RBC criteria in one or more samples. In sample 17ASS1, concentrations of 15 metals exceeded background comparison criteria for upland soil, but only four of these metals (arsenic, copper, lead, and thallium) also exceeded HBNs, and only arsenic also exceeded the RBC. Cobalt also exceeded the HBN, but did not exceed the background criterion. Four metals exceeded the background comparison criteria in sample 17ASS2, but only arsenic also exceeded the HBN, and only arsenic and beryllium exceeded the RBC. Lead, cobalt, and beryllium also exceeded the HBN, but not background criteria. Based on the data for these two soil samples, arsenic, beryllium, copper, lead, and thallium were identified as potential contaminants of concern in SWMU 17A soils. Concentrations of aluminum, antimony, barium, cadmium, chromium, iron, mercury, nickel, silver, sodium, and zinc in soil sample 17ASS1 exceeded the background criteria but were less than HBNs and RBCs and were not identified as a concern. Samples 17ASS2 also had concentrations of barium, copper, and sodium above background but below HBNs and RBCs. One explosive, 2,4-DNT, was detected in one soil sample (17ASS1). The 2,4-DNT concentration, however, was slightly less than the HBN criterion and much less than the RBC.

7.2.1.3. One sample (17ASW1) also was collected from the surface water ponded in the depression located in the southern end of SWMU 17A to assess the potential for contaminant migration by surface water runoff or infiltration. The surface water sample contained 15 metals at detectable concentrations with three of these exceeding HBN or RBC criteria. Arsenic, chromium and lead exceeded the HBNs by factors ranging from two to three, and arsenic exceeded the RBC by three orders of magnitude. The explosive 2,4-DNT was detected in this surface water sample at a concentration slightly less than 10 times the HBN and three orders of magnitude less than the RBC.

7.2.2 SWMU 17B

7.2.2.1. At the ACD Staging Area (SWMU 17B), one sediment sample (17BSE1) was collected from the concrete-lined settling basin for metals and explosives analysis to determine if runoff from the staging bays could transport contaminants. Arsenic, cobalt and lead concentrations exceeded the HBN criteria, but only arsenic exceeded the RBCs. Concentrations of lead and arsenic were five to 20 times greater than the soil background criteria. Nine other metals (barium, cadmium, chromium, copper, mercury, nickel, silver, sodium, and zinc), although at levels less than the HBNs and RBCs, were detected at concentrations greater than the background soil criteria for upland soils. A relatively high concentration of the explosive 2,4-DNT in this sample exceeded the HBN; however, the concentration was less than the RBC.

7.2.3 SWMU 17C

7.2.3.1. In February 1990, a sample of ash was collected from the ACD (SWMU 17C) and analyzed for EP toxicity (now the toxic characteristic leaching procedure [TCLP]) (USAEHA, 1980). The cadmium concentration (2.42 mg/L) exceeded the Virginia regulatory level of 1.0 mg/L.

7.2.3.2. To address the potential for soil contamination resulting from accumulating burned scrap metal and potentially contaminated ash at SWMU 17C, a total of four soil samples were collected from two locations (17CSS1 and 17CSS2), two surface and two near-surface, and analyzed for metals and explosives. Concentrations of arsenic, beryllium, and cobalt exceeded the HBN criteria in all samples, and arsenic and beryllium exceeded the RBCs. Concentrations of barium in one sample and thallium in three of four samples also

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exceeded the HBN criteria but did not exceed RBCs. Only barium, beryllium and thallium were detected above both HBN and background comparison criteria. Barium was detected above the HBN only in one sample. Beryllium was detected at less than twice the background criteria. Several other metals (aluminum, chromium, copper, iron, magnesium, mercury, nickel, potassium, silver, sodium, and zinc) were reported at concentrations greater than the upland soil background criteria but were less than the HBN or RBC. Most of the elevated metal concentrations were reported for the two samples collected from 17CSS2, which was located at the southern end of the site. One explosive compound was detected in the 1-foot sample collected at 17CSS2. However, the concentration of the explosive 2,4-DNT did not exceed the HBN or RBC criteria.

7.2.4 SWMU 17D

7.2.4.1 Two surface soil samples (17DSS1 and 17DSS2) were collected at the ACD Ash Staging Area (SWMU 17D) and analyzed for metals and explosives to assess potential soil contamination from the storage of ACD ash and from the coal bottom ash pile. The results of the chemical analyses indicated that concentrations of five metals exceeded the HBN criteria and as many as 11 other metal concentrations were elevated above background soil criteria. Only arsenic exceeded the RBC. In both samples collected, arsenic, cobalt, lead and thallium concentrations exceeded the HBN criteria and arsenic exceeded the RBC in both samples. With the exception of cobalt, the concentrations of these metals also exceeded the soil background criteria by factors ranging from 6 to greater than 10. Although elevated in both samples, copper exceeded the HBN criterion in only one sample (17DSS1). Concentrations of antimony, barium, cadmium, calcium, chromium, iron, mercury, nickel, silver, sodium, and zinc, although less than the applicable HBN or RBC, were greater than the soil background criteria. Explosives were not detected in either sample.

7.2.5 SWMU 17E

7.2.5.1. To determine whether contaminants were migrating from SWMUs 17B, 17C, and 17D to the Runoff Drainage Basin (17E) via surface water runoff, one surface water sample (17ESW1) and one sediment sample (17ESE1) were collected from the basin for metals and explosives analysis. Arsenic, chromium, lead, and 2,4-DNT concentrations exceeded HBNs in the surface water sample from SWMU 17E. However, only arsenic exceed the RBC. Concentrations of 10 additional metals in the sediment sample were greater than the soil background criteria but were less than applicable HBNs or RBCs. In the

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SWMU 17E sediment sample, arsenic exceeded the RBC and lead concentrations exceeded the HBN but not the RBC. Cobalt was detected above the HBN criteria but less than the background criterion.

7.2.6 SWMU 40

7.2.6.1. Two wells were installed into the bedrock (40MW2 and 40MW4); however, no water was measured in these wells in October 1991 or March 1992, and they could not be sampled. No soil samples were collected and no soil or aqueous analytical results were obtained during the VI at SWMU 40.

7.3 SUMMARY OF RFI FIELD ACTIVITIES

7.3.0.1. The field activities for SWMU 17/40 were not limited to the investigations performed at the sub-areas discussed above, but included the dye tracing test, the sampling of the discharge point determined by the test, and the sampling of the wells installed for monitoring the test. The dye tracing test was completed prior to the Parsons ES RFI field activities, and has been described in detail in Subsection 4.5. The discussion of the sampling of the discharge point and the dye tracing monitoring wells is presented below in the SWMU 17 (Vicinity) subsection. SWMU 17E was not investigated further since it has been adequately characterized. The analytical parameters for the sampling described below are shown in Tables 4.3 and 4.4; the sample locations are shown in Figure 7.2.

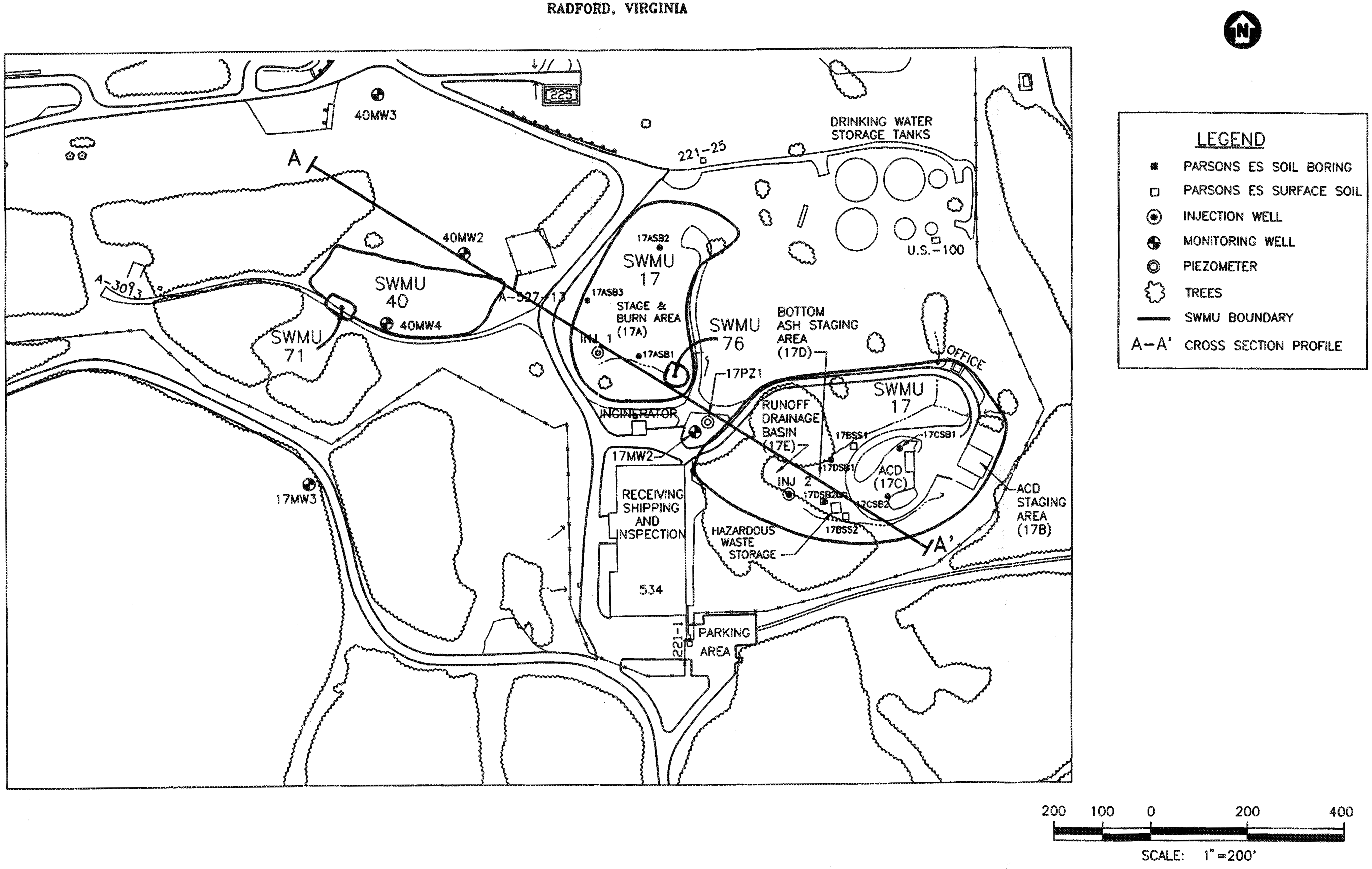
7.3.1 SWMU 17A

7.3.1.1. A total of three soil borings were advanced to the soil-bedrock interface at SWMU 17A to better characterize the extent of contamination in SWMU 17A soils. Two borings (17ASB1, 17ASB2) were located near previous RFI soil sampling locations to define the vertical extent of soil contamination and the third boring (17ASB3) was located in the western portion of SWMU 17A to extend soil data coverage both horizontally and vertically.

7.3.1.2. Soil samples were collected at 5-foot intervals from each boring location and submitted for metals and explosives analysis; samples from 5 feet below ground surface and just above the bedrock surface were also analyzed for volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) to address potential soil contamination

FIGURE 7.2
SWMU 17/SWMU 40 SAMPLE LOCATION MAP (CONTAMINATED WASTE BURNING AREA)

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



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resulting from the use of fuels to ignite the burn piles. A composite sample from each boring was analyzed for TOC (to evaluate sorptive properties of the soil) and BTU and waste characterization (to evaluate disposal properties). A near-surface soil sample (0 to 0.5 feet) was collected at 17ASB3 and analyzed for metals and explosives.

7.3.2 SWMU 17B

7.3.2.1. Two channel soil samples were collected from the unlined drainage ditch located adjacent to SWMU 17B. This ditch was previously used to carry runoff from SWMU 17B to SWMU 17E. These soil samples were analyzed for metals and explosives.

7.3.3 SWMU 17C

7.3.3.1. Two soil borings (17CSB1 and 17CSB2) were advanced to the soil-bedrock interface at SWMU 17C near previous RFI soil sampling locations to better characterize the vertical extent of metals and explosives contamination in the soils. Soil samples were collected at 5-foot intervals in each boring and submitted for metals and explosives analysis. A composite sample from each boring was analyzed for TOC, BTU, and waste characterization to evaluate remedial options for the soils.

7.3.4 SWMU 17D

7.3.4.1. Two soil borings (17DSB1 and 17DSB2) were advanced to the soil-bedrock interface in the ACD Ash Staging Area near previous RFI soil sampling locations to better characterize the vertical extent of metals and explosives contamination in the soils. Soil samples were collected at 5-foot intervals in each boring and submitted for metals and explosives analysis. A composite sample was collected from each boring and analyzed for TOC, BTU, and waste characterization to help evaluate remedial options for the soils.

7.3.5 SWMU 17 (Vicinity)

7.3.5.1. Groundwater samples were collected from four of the six monitoring wells in the vicinity of SWMU 17/40. Wells 40MW2 and 40MW4, which were installed around the SWMU 40 landfill during the VI, were dry and could not be sampled. Wells 17PZ1, 17MW2, 17MW3, and 40MW3 were sampled for metals (total and dissolved), explosives, TOC, and TOX. These wells had not previously been sampled (17PZ1 had previously been dry, and the other three were installed to monitor the dye tracing test). Field measurements of the groundwater from these wells were also obtained.

7.3.5.2. The results of the dye tracing test revealed that a spring near the New River was hydraulically connected to SWMU 17. Dye introduced into injection well 1 (located in the 17A sinkhole. The spring, which discharges directly to the New River, is approximately 4,800 feet west of the SWMU 17A sinkhole. Figure 3.10 shows the orientation of the spring, river, and SWMU, as well as fracture traces and other sinkholes in the vicinity. The spring surface water and sediment was sampled (SPG3SW1 and SPG3SE1, respectively) for total metals, explosives, TOC, and TOX. Field measurements were also taken.

7.3.5.3. Table 7.4 summarizes the field activities conducted at SWMU 17/40 for this investigation.

7.4 ENVIRONMENTAL SETTING

7.4.1 Topography and Site Layout

7.4.1.1. SWMU 17 comprises two large sinkholes which dominate the area, and the surrounding buildings which support the burning operations. The westernmost sinkhole is approximately 30 feet deep by 200 feet wide by 400 feet long. SWMU 17A is situated on the level floor of this sinkhole. SWMU 76 is located on the eastern embankment of the sinkhole. A single dirt road leads down to the burning area. The southern part of the sinkhole collects surface runoff water and is often ponded.

7.4.1.2. The other major sinkhole is to the east and south of the 17A sinkhole. The two sinkholes are separated by approximately 100 feet of level ground 30-40 feet above the sinkhole floors. Wells 17PZ1 and 17MW2 are located on this high ground. This sinkhole is approximately 40 feet deep by 600 feet long by 350 feet wide. It also has a single dirt road leading to the level floor.

7.4.1.3. SWMUs 17B, 17C, 17D, and 17E are located in this eastern sinkhole. 17B and 17C are constructed on a level grade slightly above the sinkhole floor. The western section of the sinkhole collects surface water runoff and is often ponded.

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SMP

TABLE 7.4
SUMMARY OF SWMU 17/40 RFI FIELD ACTIVITIES
RADFORD ARMY AMMUNITION PLANT

Monitoring Wells Sampled*	Surface Water* and Sediment Samples	Soil Boring Samples			Surface Soil Samples
		SWMU Location	Name	Depth (Feet Below Ground Surface)	
17PZ1	SPG3SW1	17A	17ASB105	3-5	17BSS1
17MW2	SPG3SE1		17ASB110	8-10	17BSS2
17MW3			17ASB115	13-15	
40MW3			17ASB120	18-20	
			17ASB122	20-22	
			17ASB1	Composite	
			17ASB205	3-5	
			17ASB210	8-10	
			17ASB215	13-15	
			17ASB220	18-20	
			17ASB225	23-25	
			17ASB2	Composite	
			17ASS3	0-0.5	
			17ASB305	3-5	
			17ASB310	8-10	
			17ASB315	13-15	
			17ASB320	18-20	
			17ASB325	23-25	
			17ASB3	Composite	
		17C	17CSB105	3-5	
			17CSB110	8-10	
			17CSB114	12-14	
			17CSB1	Composite	
			17CSB205	3-5	
			17CSB210	8-10	
			17CSB215	13-15	
			17CSB2	Composite	
		17D	17DSB105	3-5	
			17DSB110	8-10	
			17DSB115	13-15	
			17DSB120	18-20	
			17DSB125	23-25	
			17DSB127	25-27	
			17DSB1	Composite	
			17DSB205	3-5	
			17DSB210	8-10	
			17DSB215	13-15	
			17DSB220	18-20	
			17DSB225	23-25	
			17DSB2	Composite	

* Field measurements of pH, temperature, and conductivity were also collected.

7.4.1.4. The SWMU 40 landfill is approximately 150 feet west of the 17A sinkhole. The highest point of the landfill is approximately equivalent to the divide between the two large sinkholes. SWMU 40 is an area of gently to steeply sloping ridges. To the north, the elevation decreases by approximately 20 feet at the lower boundary of SWMU 40. The SWMU is bordered by trees to the west and south. Numerous paved roads and man-made structures are in the general vicinity of the SWMU 17/40 area.

7.4.2 Geology

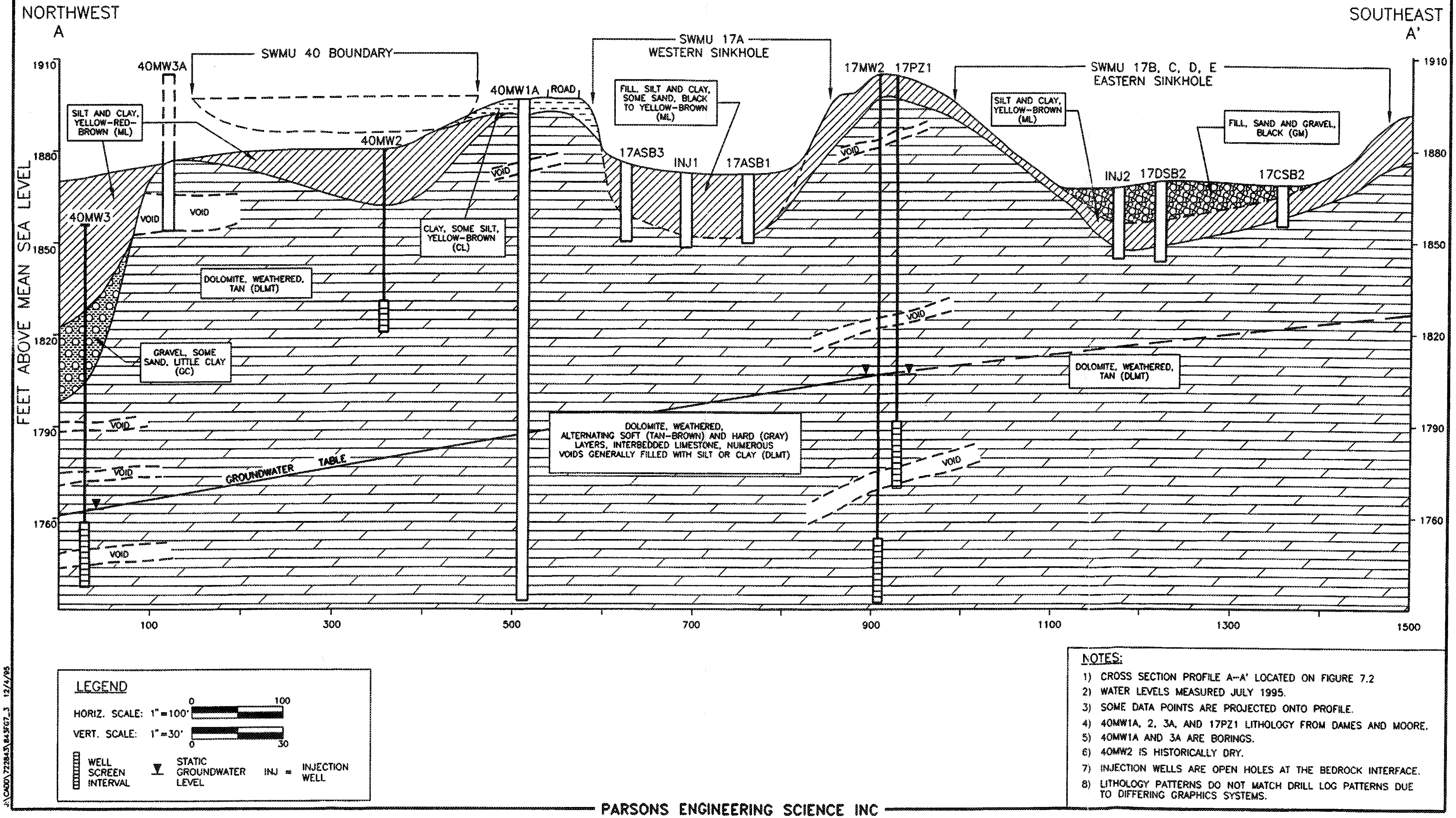
7.4.2.1. The geology of the SWMU 17 and SWMU 40 area was mostly characterized through previous investigations. Dames & Moore RFI (SWMU 17) and VI (SWMU 40) activities included the installation of three monitoring wells and two soil borings. The Parsons ES dye tracing study investigatory activities included the installation of three monitoring wells and two dye injection wells. Seven additional soil borings were installed for this RFI in the two SWMU 17 sinkholes. The vertical extent of all drilling activities was approximately 190 feet ranging from 1905 feet above mean sea level (amsl) to 1715 feet amsl.

7.4.2.2. All geological samples were categorized under the Unified Soil Classification System (USCS) in accordance with the work plan. The USCS designation was determined in the field by the project geologist. The information from all the investigations was compiled to prepare the geologic cross section presented as Figure 7.3. The profile line, A-A' (Figure 7.2), is a northwest to southeast oriented section which spans both SWMUs and generally parallels the groundwater flow direction as determined by the dye tracing study.

7.4.2.3. As seen in the cross section, very little overburden is present mantling the bedrock in this part of the facility. A thin yellow-brown silt and clay (ML) layer or clay with less silt (CL) layer was generally encountered overlying a weathered dolomite. The overburden thickened in the vicinity of 40MW3 and included a gravel and sand sequence (GC) above the bedrock. It is possible the a filled-in sinkhole is present in this area. The western sinkhole of SWMU 17 contained approximately 20 feet of fill overlying the bedrock. The fill is the probable result of overburden slumping into the sinkhole caused by the collapsed bedrock. The fill was predominantly black to yellow-brown silt and clay, with some sand and gravel; it was penetrated by three soil borings and one injection well. The

FIGURE 7.3
SWMU 17/SWMU 40 GEOLOGIC CROSS SECTION (A–A')

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



NOTES:

1) CROSS SECTION PROFILE A–A' LOCATED ON FIGURE 7.2
2) WATER LEVELS MEASURED JULY 1995.
3) SOME DATA POINTS ARE PROJECTED ONTO PROFILE.
4) 40MW1A, 2, 3A, AND 17PZ1 LITHOLOGY FROM DAMES AND MOORE.
5) 40MW1A AND 3A ARE BORINGS.
6) 40MW2 IS HISTORICALLY DRY.
7) INJECTION WELLS ARE OPEN HOLES AT THE BEDROCK INTERFACE.
8) LITHOLOGY PATTERNS DO NOT MATCH DRILL LOG PATTERNS DUE TO DIFFERING GRAPHICS SYSTEMS.

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eastern sinkhole of SWMU 17 contained less fill. Approximately 5-10 feet of black sand and gravel was present above a yellow-brown silt and clay (ML) layer. The ML layer did not appear to be fill; it overlaid the weathered dolomite from 10-20 feet below ground surface (bgs).

7.4.2.4. The Elbrook Formation bedrock underlying the entire SWMU vicinity was predominantly an argillaceous dolomite interbedded with limestone and siltstone. It was very weathered with alternating hard and soft layers; the softer layers were typically tan-brown and the harder layers were gray. Numerous fractures were observed in the cored samples (Dames & Moore); the fractures were usually clay-filled. A substantial number of voids, a typical solution feature, was encountered resulting in losses of drilling fluids and air circulation. In some cases, the voids were partially filled with sand, silt, or clay. The cross section indicates voids where fluid circulation was lost or where coring revealed large filled-in fractures. Some calcite mineralization of the fractures was observed in the core samples. A field test of hydrochloric acid effervescence was conducted to differentiate between limestone and dolomite.

7.4.3 Hydrogeology

7.4.3.1. Currently, there are five monitoring wells, one piezometer and two injection wells within, or in the vicinity of, SWMU 17/SWMU 40 (Figure 7.1). 40MW2 and 40MW4 were installed during VI activities at SWMU 40 (Dames & Moore, 1992a). Both wells were set at approximately 60 feet below ground surface (bgs) and both have been dry since installation. The piezometer at SWMU 17 (17PZ1) was installed during previous RFI activities (Dames & Moore, 1992b) at a depth of 132.5 feet bgs. A 20 foot screen was set at the bottom of 17PZ1, from 112.5 feet to 132.5 feet bgs. In May 1993, three bedrock monitoring wells and two dye-injection wells were installed in the vicinity of SWMU 17 and 40 as part of the dye tracing study conducted at the site (Engineering Science, 1994b). The monitoring wells were designed to intercept the regional water table associated with the New River. Monitoring well 17MW2 is located adjacent to 17PZ1 and is screened between 150 feet and 170 feet bgs. Monitoring well 40MW3 is located in an apparent downgradient flow direction from SWMU 17 and SWMU 40 and is screened at depth between 97 feet and 117 feet bgs. Well 17MW3 was installed along an axis of sinkhole alignment in the area to evaluate the influence of structural features and/or solution features on groundwater flow. The well was completed to a depth of 179 feet and is constructed with 20 feet of screen. The two dye-injection wells (INJ1 and INJ2) are located in the sinkholes comprising SWMUs 17A through 17E. These wells were installed to a maximum depth of 23.5 feet through the fill-overburden to the bedrock interface. Well construction details for the SWMU 17 and SWMU 40 monitoring wells are given in Table 4.1.

7.4.3.2. Groundwater occurrence and movement in the vicinity of these SWMUs is complex. Observations and measurements of the groundwater are consistent with karst subsurface features. As indicated in Section 3.6, although the concept of a groundwater table in karst geology may be misleading, the following discussion is presented to support observations of flow direction and flow rates. The concept of a regional groundwater table in karst geology is applicable when considering the area involved in the direct discharge of SWMU 17 groundwater to the New River (approximately 4,800 feet away) as shown in the dye tracing study.

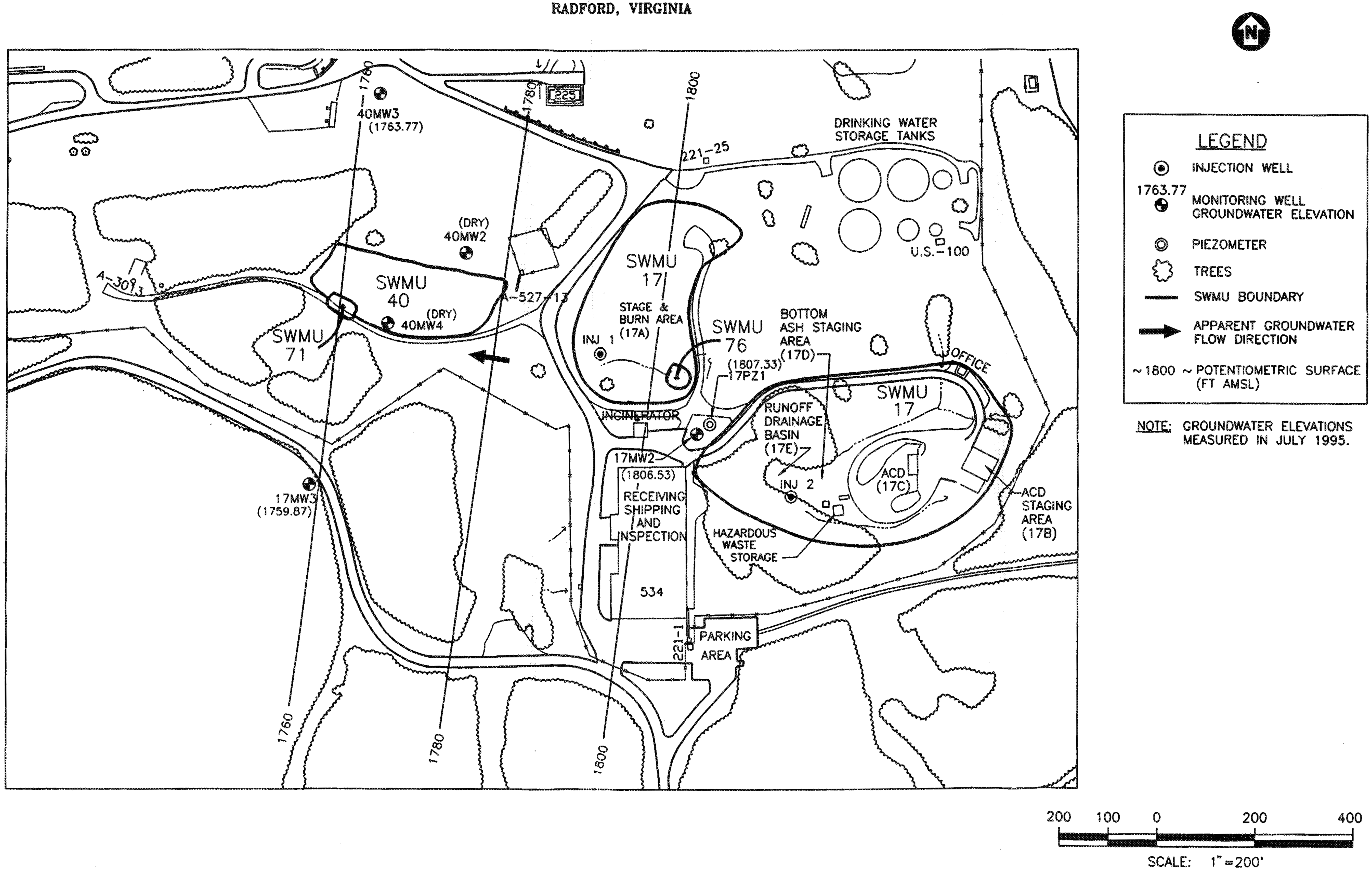
7.4.3.3. The potentiometric surface (groundwater table) at SWMU 17/SWMU 40 is shown in cross section in Figure 7.3 and in plan view in Figure 7.4. Field data used to prepare Figure 7.4, photoionization detector (PID) readings of the well headspace in parts per million (ppm), pH, temperature, and conductivity of the groundwater, are summarized in Table 7.5.

7.4.3.4. The groundwater table in the vicinity of SWMU 17/SWMU 40 is relatively deep (typically greater than 100 feet bgs) and contained within the bedrock of the Elbrook Formation. Groundwater level measurements taken at SWMU 17/SWMU 40 periodically between 1992 and 1995 have demonstrated that the groundwater elevations in this area fluctuate over a wide range. This is especially apparent in 17PZ1 and 17MW2, which has been observed to display 20 to 30 feet of seasonal variation of groundwater levels (approximately five feet of variation was seen in the January and July, 1995 investigations). The observed groundwater fluctuations are typical of groundwater flow through fractures, bedding planes, and karst solution features. The voids encountered in the bedrock during drilling activities of SWMU 17/SWMU 40 (Figure 7.3) have the potential to control or affect groundwater flow rate and direction.

7.4.3.5. The presence of the large sinkholes indicates that SWMU 17 is within a groundwater recharge zone. Figure 7.4 depicts the direction of groundwater flow at

FIGURE 7.4
SWMU 17/SWMU 40 GROUNDWATER POTENTIOMETRIC SURFACE MAP

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



NOTE: GROUNDWATER ELEVATIONS MEASURED IN JULY 1995.

TABLE 7.5
SWMU 17: GROUNDWATER FIELD DATA
RADFORD ARMY AMMUNITION PLANT

Well Name	Date	Depth to Bottom (ft)	Depth to Water (ft)	Groundwater Elevation*(ft)	PID (ppm)	pH	Temperature (degrees F)	Conductivity (us/cm)
17MW2	1-17-95	173.0	106.94	1799.35	6.4	7.19	48.4	0.92
17PZ1	1-17-95	132.5	106.88	1800.14	9.2	7.23	50.2	0.94
17MW3	1-17-95	190.0	146.19	1760.59	3.5	7.08	58.1	0.97
40MW3	1-17-95	120.0	94.38	1763.83	2.9	7.51	58.5	0.94
40MW2	1-17-95	60.0	DRY	NA	NA	NA	NA	NA
40MW4	1-17-95	62.8	DRY	NA	NA	NA	NA	NA
17MW2	7-19-95	173.0	99.76	1806.53	0.0	6.96	76.5	615
17PZ1	7-19-95	132.5	99.69	1807.33	0.0	7.06	78.5	682
17MW3	7-22-95	190.0	146.91	1759.87	0.0	7.12	69.2	298
40MW3	7-21-95	120.0	94.44	1763.77	0.0	7.59	73.6	374
40MW2	7-19-95	60.0	DRY	NA	NA	NA	NA	NA
40MW4	7-19-95	62.8	DRY	NA	NA	NA	NA	NA

* Feet above mean sea level

SWMU17/SWMU 40 toward the west-northwest at a hydraulic gradient of 0.05 feet/foot (ft/ft). The dye tracing study also indicated that groundwater flow in the vicinity of SWMU 17 is toward the west-northwest (Parsons Engineering Science, 1994). The dye tracing study further indicated that a spring (SPG 3) which discharges directly to the New River is hydraulically connected to the sinkhole which SWMU 17A occupies. Dye placed into INJ1 traveled 4,800 feet to the spring in approximately 24 hours. The flow path identified by the dye trace closely parallels a west-northwest to east-southeast trending fracture trace which can be extended to connect both the dye injection point and the dye resurgence point (Figure 3.10). This condition suggests that a direct conduit exists between SWMU 17A and SPG 3 which was likely created by solution opening along a subsurface fracture. The travel time for groundwater flow through this conduit, under low flow conditions, is calculated to range between 2,095 feet/day and 3,716 feet/day and under high flow conditions is calculated to average about 4,800 feet/day. Because dye was not found in any of the monitoring wells, the flow path is interpreted to be narrow and laterally limited.

7.4.3.6 Dye placement into the eastern sinkhole (INJ2) did not infiltrate the subsurface. This may be explained by the presence of the clay rich, non-fill ML layer encountered above the bedrock. It may also indicate a less fractured section of bedrock below the sinkhole.

7.4.4 Surface Water

SWMU 17/SWMU 40 is located in the south-central section of the Main Manufacturing Area in a region of gently to steeply sloping ridges and scattered sinkholes. Based on topography, surface water runoff in this vicinity generally flows northwest approximately 4,800 feet to the New River. However, the sinkholes which comprise SWMU 17A and SWMUs 17B through 17E capture a significant quantity of surface water runoff. Both of these sinkholes contain minor intermittent ponded surface water bodies which act as local recharge areas. The SWMU 17A sinkhole contains a surface water drainage ditch and a small water-filled depression approximately 20 feet across. The SWMU 17B through 17E sinkhole contains two surface water drainage ditches and a swampy runoff drainage basin.

7.5 NATURE AND EXTENT OF CONTAMINATION

7.5.0.1. For the purposes of the nature and extent discussions which follow, the SWMU areas have been grouped by their locations; SWMU 17A is assessed separately from the other SWMU areas, which are grouped together (SWMU 17B,C,D). The SWMU vicinity discussion addresses the monitoring wells. The spring location (SPG3) which has been shown to be hydraulically connected to the SWMU 17A sinkhole had been part of the SWMU vicinity discussions. However, for a more detailed contamination evaluation, that sample has been included with the New River section (Section 12), since the results are likely to reflect the river environment as well as the SWMU 17A environment.

7.5.0.2. All positive results (detected compounds) for soil samples for SWMU 17A and SWMU 17B,C,D are presented in Tables 7.6 and 7.7, respectively. The positive results for the aqueous samples for SWMU 17/40 (vicinity) are presented in Table 7.8. The chemicals of concern (COCs) were identified by the methods described in Section 6. The focus of this section is on the COCs determined to be potential human health threats as discussed in the subsequent Risk Assessment subsections.

7.5.1 Nature of Contamination (SWMU 17A)

7.5.1.1 Surface Soils

7.5.1.1.1 Only one surface soil sample was collected at 17A. This sample, 17ASS3, was the surface portion of the 17SB3 boring. However, other data from the previous Dames & Moore investigation were also considered for 17A surface soils. Metals detected at COC levels included: arsenic, lead, silver, barium, beryllium, cadmium, chromium, nickel, and mercury. Of these, arsenic and beryllium were found at levels considered to pose a potential threat to human health. Therefore, arsenic and beryllium were determined to be the risk drivers. The concentrations of all of the metals with positive results, except beryllium, exceeded Dames & Moores's background levels for upland soils.

7.5.1.1.2 The arsenic concentration was 101.70 ug/g. Lead was found at 4721.55 ug/g. Cadmium and nickel were detected at 4.29 ug/g and 69.13 ug/g, respectively. Beryllium, at a concentration of 0.98 ug/g, was less than background in this sample.

TABLE 7.6
POSITIVE RESULTS TABLE OF SWMU 17 - Solid Samples (SWMU 17a)
RADFORD ARMY AMMUNITION PLANT

HBN (ug/g)	Field Sample Number	17ASB105	17ASB110	17ASB115	17ASB120	17ASB122	17ASB205
	METALS (ug/g)						
0.5	Arsenic	94.87 J4	9.30 J4	13.50 J4	16.69 J4		7.33 J4
200	Lead	5256.41 J6	101.39 J6	56.44 J6	273.97 J6	11.79 J6	26.28 J6
200	Silver	42.31 J4	0.39 J4		2.12 J4		
1000	Barium	5128.21 J1	63.12 J1	69.20 J1	69.36 J1	71.50 J1	64.38 J1
0.1	Beryllium	1.65 J4	2.22 J4	2.11 J4	1.77 J4	2.13 J4	2.23 J4
40	Cadmium	13.72					
400	Chromium	2051.28 J6	55.51 J6	54.72 J6	54.92 J6	68.50 J6	46.82 J6
1000	Nickel	902.56 J4	24.84 J4	29.20 J4	24.28 J4	28.37 J4	26.15 J4
30	Antimony	77.95					
20	Mercury	0.29 J4	0.14 J4	0.16 J4	0.11 J4	0.09 J4	0.18 J4
	SEMIVOLATILES (ug/g)						
50	Bis(2-ethylhexyl) phthalate	10.13				2.48	5.85
0.2	Benzo[a]anthracene	0.99					
0.4	Benzo[b]fluoranthene	1.92					
	Benzo[ghi]perylene	1.23				0.24	0.22
80	Benzo[k]fluoranthene	0.56					
4	Chrysene	1.04					
1000	Diethyl phthalate						
500	Fluoranthene	0.81					
40	Phenanthrene	1.67					
1000	Pyrene	1.54					
	OTHER (ug/g)						
	Total Organic Carbon						

TABLE 7.6
POSITIVE RESULTS TABLE OF SWMU 17 - Solid Samples (SWMU 17a)
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	17ASB210	17ASB215	17ASB220	17ASB225	17ASB305	17ASB310
METALS (ug/g)						
Arsenic		8.98 J4			6.70 J4	7.51 J4
Lead	14.13 J6	69.06 J6	41.78 J6	77.36 J6	27.08 J6	23.02 J6
Silver						
Barium	75.69 J1	86.91 J1	134.26 J1	9.56 J1	71.26 J1	126.39 J1
Beryllium	2.06 J4	4.52 J4	6.82 J4		3.40 J4	7.39 J4
Cadmium						
Chromium	49.70 J6	86.04 J6	122.27 J6	7.56 J6	53.71 J6	79.33 J6
Nickel	27.78 J4	56.83 J4	78.96 J4	6.12 J4	34.64 J4	71.26 J4
Antimony						
Mercury		0.12 J4			0.18 J4	0.13 J4
SEMIVOLATILES (ug/g)						
Bis(2-ethylhexyl) phthalate					3.48	
Benzo[a]anthracene						
Benzo[b]fluoranthene						
Benzo[ghi]perylene				0.26	0.27	
Benzo[k]fluoranthene						
Chrysene						
Diethyl phthalate						
Fluoranthene						
Phenanthrene						
Pyrene						
OTHER (ug/g)						
Total Organic Carbon						

TABLE 7.6
POSITIVE RESULTS TABLE OF SWMU 17 - Solid Samples (SWMU 17a)
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	17ASB315	17ASB320	17ASB325	17ASB340*	17ASS3
METALS (ug/g)					
Arsenic	4.64 J4	3.75 J4		3.30 J4	101.70 J4
Lead	21.83 J6	30.77 J6	9.23 J6	15.70 J6	4721.55 J6
Silver					2.18 J4
Barium	45.16 J1	52.97 J1	54.71 J1	34.58 J1	577.48 J1
Beryllium	2.20 J4	0.57 J4	0.77 J4	1.55 J4	0.98 J4
Cadmium					4.29
Chromium	75.99 J6	17.25 J6	22.59 J6	45.44 J6	222.76 J6
Nickel	36.43 J4	6.30 J4	10.90 J4	23.71 J4	69.13 J4
Antimony					
Mercury					0.33 J4
SEMIVOLATILES (ug/g)					
Bis(2-ethylhexyl) phthalate			2.30		
Benzo[a]anthracene			0.29		
Benzo[b]fluoranthene					
Benzo[ghi]perylene			0.20	0.20	
Benzo[k]fluoranthene					
Chrysene			0.25		
Diethyl phthalate			9.87		
Fluoranthene			0.38		
Phenanthrene			0.65		
Pyrene			0.50		
OTHER (ug/g)					
Total Organic Carbon				10406.10	

* 17ASB340 is a duplicate sample of 17ASB315

TABLE 7.7
POSITIVE RESULTS TABLE SWMU 17 - Solid samples (SWMUs 17b,17c, 17d)
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	17BSS1	17BSS2	17CSB105	17CSB110	17CSB114	17CSB205	17CSB210
METALS (ug/g)							
Arsenic	127.72 J4	18.18 J4	11.98 J4				
Lead	653.12 J1	128.43 J1	41.82 J1	18.44 J1	18.73 J1	12.20 J1	13.68 J1
Silver	1.89 J4	0.13 J4					
Barium	261.25 J1	99.42 J1	29.40 J1	78.55 J1	84.33 J1	36.74 J1	70.12 J1
Beryllium	1.41 J4	5.61 J4	3.23 J4	5.19 J4	3.61 J4	1.56 J4	5.77 J4
Cadmium	3.12 J4						
Chromium	144.41	76.05	61.87	72.81	59.89	33.62	54.29
Nickel	40.49 J4	51.80 J4	25.95 J4	46.17 J4	35.33 J4	18.68 J4	46.60 J4
Mercury	0.25 J4			0.10 J4			
OTHER (ug/g)							
Total Organic Carbon							

TABLE 7.7
POSITIVE RESULTS TABLE SWMU 17 - Solid samples (SWMUs 17b,17c, 17d)
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	17CSB215	17CSB240*	17DSB105	17DSB110	17DSB115	17DSB120	17DSB125
METALS (ug/g)							
Arsenic	4.59 J4						
Lead	190.60 J1	17.24 J1	20.08 J1	17.95 J1	26.54 J1	12.36 J1	28.23 J1
Silver	0.04 J4		0.03 J4				
Barium	104.70 J1	86.49 J1	68.93 J1	60.40 J1	67.05 J1	69.69 J1	72.73 J1
Beryllium	2.52 J4	6.21 J4	1.83 J4	2.02 J4	3.21 J4	3.04 J4	4.77 J4
Cadmium	4.73 J4						
Chromium	71.92	74.38	29.92	43.94	67.82	56.07	86.92
Nickel	45.62 J4	56.83 J4	14.58 J4	16.21 J4	28.97 J4	45.53 J4	50.40 J4
Mercury							
OTHER (ug/g)							
Total Organic Carbon		1552.79					

* 17CSB240 is a duplicate of 17CSB215

TABLE 7.7
POSITIVE RESULTS TABLE SWMU 17 - Solid samples (SWMUs 17b,17c, 17d)
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	17DSB127	17DSB205	17DSB210	17DSB215	17DSB220	17DSB225	17DSB240*
METALS (ug/g)							
Arsenic			6.32 J4	11.32 J4			8.03 J4
Lead	23.46 J1	20.81 J1	17.87 J1	23.10 J1	11.31 J1	8.43 J1	14.63 J1
Silver	0.07 J4						
Barium	111.48 J1	65.89 J1	80.98 J1	142.65 J1	111.91 J1	55.95 J1	68.85 J1
Beryllium	5.89 J4	1.42 J4	2.48 J4	7.88 J4	5.48 J4	11.84 J4	2.23 J4
Cadmium							
Chromium	77.87	31.28	56.30	97.09	63.30	77.76	49.18
Nickel	66.39 J4	11.18 J4	28.79 J4	72.05 J4	57.42 J4	87.82 J4	23.33 J4
Mercury	0.15 J4			0.24 J4			
OTHER (ug/g)							
Total Organic Carbon							2723.83

* 17DSB240 is a duplicate of 17DSB215

TABLE 7.8
POSITIVE RESULTS TABLE OF SWMU 17 - Aqueous Samples (SWMU 17 Vicinity)
RADFORD ARMY AMMUNITION PLANT

	Field Sample Number	17MW3	17MW3 Dissolved	17MW2	17MW2 Dissolved	17PZ1	17PZ1 Dissolved	40MW3	40MW3 Dissolved
	METALS (ug/l)								
20	Lead	6.3							
10	Selenium			3.63					
1000	Barium	174	164	63.6	63.2	106	110	54.5	31
.007	Beryllium			4.03	4.26	4.55	4.28		
10	Antimony			60.2*					
	OTHER (ug/l)								
	Total Organic Carbon	1240							
	Total Organic Halogens	107		27.5		15.7			

* The positive result for antimony was detected during the January 1995 sampling event.
All other results from July 1995.

7.5.1.2 Subsurface Soils

7.5.1.2.1 Positive results for ten metals and ten SVOCs were detected in the SWMU 17A subsurface samples. Of these, the following were considered to be COCs: antimony, arsenic, barium, cadmium, chromium (as chromium III), lead, nickel, silver, benzo(a)anthracene, benzo(b)fluoranthene, bis(2-ethyl hexyl)phthalate, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, fluoranthene, and phenanthrene. The risk drivers were antimony and arsenic.

7.5.1.2.2 Eight metals concentrations were found at levels greater than the established background for soil horizon B (less than five feet bgs). Those metals were: antimony, arsenic, barium, cadmium, chromium, lead, nickel, and silver. Arsenic, lead, and silver exceeded the soil horizon C background levels.

7.5.1.2.3 In general, the arsenic, barium, cadmium, nickel, and lead levels in the 3-5 foot interval from 17ASB1 (B horizon) were significantly higher than in any other samples. The only antimony (risk driver) detection was from this boring (77.95 ug/g). The arsenic level in this sample was 94.87 ug/g; no other arsenic level exceeded 17 ug/g. The lead concentration in 17ASB105 was 5256.41 ug/g; the next highest level was 273.97 ug/g in 17ASB120, which is the same boring (18-20 foot bgs interval). The barium level was 5128.21 ug/g in 17ASB105. The next highest level was 134.26 ug/g in 17ASB220.

7.5.1.2.4. The significant SVOC detections were mostly in the 17ASB105 sample. All of the SVOC COCs were found in this sample. Few SVOCs were found at depth in this boring. Some SVOCs were found in the 17ASB2 boring, but none at depths greater than five feet. The other significant SVOC detections were in the 17ASB3 boring, from the 23-25 foot bgs interval. The SVOCs were mainly polynuclear aromatic hydrocarbon (PAH) compounds.

7.5.2 Nature of Contamination (SWMU 17B,C,D)

7.5.2.1 Surface Soils

7.5.2.1.1. Two surface soil samples were collected at SWMU 17B,C,D. Positive results for nine metals were found in these surface samples. The nine metals, which were all

COCs, were: arsenic, lead, silver, barium, beryllium, cadmium, chromium nickel, and mercury. Arsenic and beryllium were found at concentrations considered to be a potential human health threat. Therefore, these metals were categorized as risk drivers for SWMU 17B,C,D surface soils.

7.5.2.1.2. The concentrations of the risk drivers exceeded the Dames & Moore background levels established for upland soils for these metals. Both 17BSS1 and 17BSS2 contained arsenic and beryllium detections. The maximum level of arsenic (127.72 ug/g) was from the 17BSS1 sample. 17BSS2 contained the highest beryllium concentration (5.61 ug/g).

7.5.2.1.3. Cadmium was only found in 17BSS1 (3.12 ug/g). The rest of the positive metals detections were evenly distributed between the two surface samples, although the COC mercury was not found in 17BSS2.

7.5.2.2 Subsurface Soils

7.5.2.2.1. Nine metals had positive results in the subsurface samples taken at SWMU 17B,C,D. They were: arsenic, lead, silver, barium, beryllium, cadmium, chromium, nickel, and mercury. Arsenic and lead were COCs. Only arsenic was found at levels considered to be a human health threat and therefore was categorized as the risk driver for subsurface soils at SWMU 17B,C,D.

7.5.2.2.2. Arsenic was detected in four subsurface soil samples, ranging from 4.59 ug/g in 17CSB215 to 11.98 ug/g in 17CSB105. These concentrations exceeded the background level established for B horizon subsurface soils. The B horizon (less than five feet bgs) background for arsenic, 5.5 ug/g, was exceeded in the 17CSB105 sample. The C horizon background for arsenic (11.5 ug/g) was not exceeded. The other COC, lead, was detected in 17 subsurface samples, ranging from 190.60 ug/g in 17CSB215 to 8.43 ug/g in 17DSB225. However, no B horizon samples exceeded the background lead level of 190.56 ug/g, and only the 17CSB215 sample exceeded the C horizon background lead level of 112.16 ug/g.

7.5.2.2.3. Of the other positive metals results, only cadmium exceeded the background level (3.5 ug/g) for the C horizon. This occurred in the 17CSB215 sample. The other detected metals were distributed evenly throughout the samples taken in the 17B,C,D sinkhole.

7.5.3 Nature of Contamination (Vicinity)

7.5.3.1 Groundwater

7.5.3.1.1. Positive results for five metals (lead, antimony, selenium, barium, and beryllium) were found in the samples from the SWMU 17/40 groundwater. Three of these metals, antimony, barium and beryllium, were identified as COCs. Beryllium and antimony were categorized as the risk drivers for groundwater for SWMU 17/40. Dissolved barium was detected in the samples from all four monitoring wells. Dissolved barium concentrations ranged from 31 ug/l in the sample from 40MW3 to 164 ug/l in the sample from 17MW3. Dissolved beryllium was only found in the 17MW2 (4.26 ug/l) and 17PZ1 (4.28 ug/l) samples. Dissolved antimony was only detected in 17MW2 during the January 1995 sampling event at 60.2 ug/l.

7.5.3.1.2. Lead and selenium were detected as total concentrations and were not found in the dissolved state. Selenium was only detected in one sample (from 17MW2 at 3.63 ug/l). Lead was only detected in one sample (6.3 ug/l in 17MW3).

7.5.4 Extent of Contamination (17A)

7.5.4.1 Surface Soils

7.5.4.1.1. Only one surface soil was collected at SWMU 17A. The location was along the western edge of the sinkhole floor. Concentrations of arsenic, beryllium, and lead, the COCs identified by Dames & Moore for surface soil samples along the northern and southern sinkhole floor edge, were similar to the 17ASS3 results.

7.5.4.2 Subsurface Soils

7.5.4.2.1. The maximum concentrations of the COCs were found in the near surface sample of 17ASB1. This sample is located nearest the active burning operations in the

SWMU 17A sinkhole; the other two borings were installed along the edges of the sinkhole floor. Metals were generally evenly distributed throughout, with the exception of the above sample. 17ASB3 is located west of 17ASB1, in the apparent downgradient groundwater direction. Contaminants at depth found in 17ASB3 may be the result of shallow groundwater movement in the fill above the bedrock.

7.5.4.2.2. Some of the metals found in these subsurface samples were also detected in the groundwater samples. Barium, beryllium, and lead were also found in the surface water and sediment samples from SPG3, the spring which has been shown to be directly connected to SWMU 17A by a subsurface groundwater conduit.

7.5.5 Extent of Contamination (17B,C,D)

7.5.5.1 Surface Soils

7.5.5.1.1. There were only two surface soil samples collected at SWMU 17B,C,D. Both were taken to characterize SWMU 17B, the drainage ditches associated with the ACD Staging Area. 17BSS1 contained all the risk driver metals at levels above the Dames & Moore background concentrations for upland sediments. 17BSS2 contained arsenic at concentrations greater than background. That sample contained no detectable amounts of cadmium.

7.5.5.1.2. The 17BSS1 sample generally exceeded the concentrations found in the 17BSS2 sample for all the COCs except beryllium and nickel. 17BSS1 was collected on the north side of the sinkhole floor area, and 17BSS2 was taken from the south side. The locations are approximately 100 feet apart. Each sample is from a separate surface water drainage ditch; both ditches drain into the SWMU 17E Drainage Basin.

7.5.5.2 Subsurface Soils

7.5.5.2.1. Arsenic only exceeded the established background level for the B horizon in one sample, 17CSB105. This maximum subsurface arsenic concentration (11.98 ug/g) was found at the 3-5 foot bgs interval in the boring, which was located on the north side of SWMU 17C. This sample also contained the second highest lead concentration (41.82 ug/g) and a relatively high chromium concentration (61.87 ug/g), although not above the background level. The southern SWMU 17C boring sample, collected from the 13-15 feet bgs interval, exceeded the background levels of lead and cadmium. This sample also contained the maximum barium concentration, 104.70 ug/g, for subsurface soils.

7.5.5.2.2. No other metals exceeded the established background levels for subsurface soils at SWMU 17B,C,D. Of the other detected metals, concentrations appeared to be relatively evenly distributed. Mercury was found in each of the 17D borings; the maximum barium concentration (142.65 ug/g) was found in the 17DSB215 sample, collected from 13-15 feet bgs.

7.5.6 Extent of Contamination (Vicinity)

7.5.6.1 Groundwater

7.5.6.1.1. Barium and the risk driver beryllium were found at similar levels in the samples from 17MW2 and 17PZ1. These wells are adjacent to one another (between the two sinkholes) and the groundwater would be expected to be of similar quality. Antimony was present, at a level just above the detection limit, in 17MW2 during the January 1995 sampling event. Because of the unpredictable components of groundwater flow through the karst subsurface, these wells could be impacted by contaminants present in either sinkhole.

7.5.6.1.2. 17MW3 can be considered to be hydraulically downgradient of both sinkholes based on the observed dye tracing study flow direction. However, this well is also completed in the karst subsurface and could be impacted by flow from other directions. The sample from this well contained the highest dissolved barium concentration, and the only lead detection. Monitoring well 40MW3, which is located in the downgradient groundwater flow direction as determined by the dye tracing study, only had a positive detection for barium. Although in the general downgradient direction, this well did not have dye detections during the tracing study. This may indicate that a narrow conduit exists between the 17A sinkhole and the New River. It is possible that 40MW3 does not fully intercept the preferential pathway to the river, resulting in little migration of contaminants to this well.

7.5.6.1.3 The 17A sinkhole is directly linked to a spring (SPG3) which discharges to the New River. The SPG3 surface water and sediment sample results, which are discussed in more detail in the New River section of this report, indicate positive results for barium, beryllium, and lead.

7.6 CONTAMINANT FATE AND TRANSPORT

7.6.0.1. The environmental fate and transport of chemicals is dependent on the physical and chemical properties of the compounds, the environmental transformation processes affecting them, and the media through which they migrate. At SWMU 17/40, groundwater is the primary migration pathway.

7.6.0.2. The sinkholes for both SWMU 17 areas consist of fill overlying bedrock. The bedrock contains karst features which make groundwater movement and occurrence unpredictable. The dye tracing study demonstrated a direct connection between the SWMU 17A sinkhole and the New River through a spring on the bank of the river approximately 4,800 feet from the SWMU. The travel time calculated for groundwater flow through this conduit ranged between 2,095 feet/day and 4,800 feet/day.

7.6.0.3. Contaminants found in the surface and subsurface soils have been found in the groundwater in the SWMU 17/40 vicinity, and also in the sediment and surface water of the spring (SPG3). The demonstrated connection between these points may represent a preferential migration pathway through a relatively narrow conduit since a minimum of contaminants were detected in the groundwater sample from 40MW3 (located directly in the downgradient groundwater flow direction). Well 17MW3 did contain detectable contaminants although it appears to be side gradient to groundwater flow. This may indicate other migration pathways which were not necessarily detected in the dye tracing study.

7.6.0.4. Although the majority of the metals should be relatively immobile in the undisturbed soil matrix, the contaminants found in the deeper 17A boring samples may be the result of downward leaching from the fill at shallow depths. Groundwater or surface water infiltration in the 17A fill may have allowed for the migration of shallow contamination at 17SB1 to the deeper intervals of boring 17ASB3.

7.6.0.5. SVOCs were identified in the subsurface soils. SVOCs have a high affinity for organic matter and low water solubility. These compounds tend to remain bound to soil particles and dissolve slowly into groundwater. Therefore, the movement of SVOCs is usually controlled by the transport of particulates. SVOCs are readily bioaccumulated by living organisms. The SPG3 sample was not analyzed for VOCs or SVOCs, so it is not known if these contaminants (some of which were detected in SWMU 17 subsurface soils) migrated through the karst conduit to the river. SVOCs were found in various sediment samples collected from the New River downstream of the discharge point, but these may have other sources. Those samples are discussed in Section 12.

7.7 RISK ASSESSMENT

7.7.0.1. SWMU 17 has been divided into five components, four of which are being analyzed for this risk assessment. For risk assessment purposes, SWMU 17A, the Stage and Burn Area, is being evaluated separately from SWMUs 17B, 17C and 17D, which are being grouped and evaluated together. This is due to the close proximity of SWMUs 17B, 17C and 17D (which are physically separated from SWMU 17A) and the potential contaminant migration pathways involved. SWMU 17A is a below-grade (sinkhole) burning pit that is unlined and open to the atmosphere, which does not limit contaminants migrating from explosives-contaminated ash and fuels to the atmosphere, soils and groundwater.

7.7.0.2. SWMUs 17B, 17C and 17D are located in another sinkhole adjacent to SWMU 17A. SWMU 17B is partially covered and contains a concrete staging pad which collects surface water runoff. Contaminants would be limited migrating to soils and groundwater, but contaminant migration to the atmosphere may still occur from contaminated ash. SWMU 17C is an open, concrete-lined controlled burning area. Again, the only potential contaminant migration pathway is to the atmosphere. SWMU 17D is a metal shed with a concrete floor which is used for ash staging. The migration pathways for this SWMU are effectively limited.

7.7.0.3. SWMU 17 is currently in use and this function is expected to continue while the plant exists. It is unlikely that this plant will close as it is the only remaining propellant and explosive manufacturing facility in the country. Therefore, future land use is assumed to remain industrial.

Active, military.

7.7.1 Summary of Chemicals of Potential Concern

7.7.1.0.1. The chemicals considered in the risk evaluation for groundwater at SWMU 17 include antimony, barium and beryllium. The chemicals of concern for surface soils at SWMU 17A are 8 metals (arsenic, barium, cadmium, chromium III, lead, mercury, nickel and silver). The chemicals of concern for subsurface soils at SWMU 17A include 9 metals (antimony, arsenic, barium, beryllium, cadmium, chromium III, lead, nickel and silver) and 9 semivolatiles (benzo(a)anthracene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, bis(2ethylhexyl)phthalate, chrysene, fluoranthene pyrene, and phenanthrene).

7.7.1.0.2. The chemicals of concern for surface soils at SWMU 17 B,C,D are 9 metals (arsenic, barium, beryllium, cadmium, chromium III, lead, mercury, nickel and silver). The chemicals of concern for subsurface soils at SWMU 17B,C,D are arsenic and lead.

7.7.1.0.3. SWMU 17E functions as a surface water runoff drainage basin which appears to be a natural drainage ditch rather than a constructed system. The sampling protocol did not include sampling the surface waters or sediments associated with this area. In addition, during the July sample event, there was no standing surface water in this drainage system. Therefore, surface water is not included in this evaluation of risk for SWMU 17.

7.7.1.1 Comparison to ARARs and TBCs for Groundwater and Soils

7.7.1.1.1. Groundwater in the vicinity of RAAP is not used for drinking water serving more than 25 people and therefore MCLs and MCLGs are not considered as ARARs for SWMU 17. In addition, there are no Federal or Commonwealth of Virginia standards relating chemical concentrations in soils to toxic effects on vegetation or wildlife. TBC criteria considered for human health risk evaluation included reference doses (RfDs) and slope factors (SFs) from USEPA's Integrated Risk Information System and Health Effects Assessment Summary Table (USEPA, 1995).

7.7.2 Exposure Assessment

7.7.2.1 Potential Pathways and Receptors

7.7.2.1.1. The current exposure pathway at SWMUs 17A and 17 B,C,D which is considered to have a high probability of completion is site worker exposure to surface soils. The current construction worker exposure to surface and subsurface soil scenarios also have a high probability of completion should construction activities occur at this SWMU. Other current exposure pathways are considered to have a low probability of completion and therefore, these scenarios were not quantified for current receptors (area residents and fishermen). This SWMU is still active and site workers have access to potentially contaminated surface soils. SWMUs 17A and 17 B,C,D are completely contained within RAAP property which effectively limits public access (residents and fishermen) to potential contaminants. The current groundwater pathway is not complete as groundwater is not used for drinking purposes.

7.7.2.1.2. The potential future exposure scenario quantified for SWMU 17 was future site worker exposure to groundwater through ingestion and dermal contact. This exposure scenario has a low probability of completion since drinking water at RAAP is obtained from the New River However, evaluation of this exposure scenario allows for quantification of the risks due to groundwater exposure. Evaluation of other future exposure scenarios would not be approporiate based on future land use assumptions.

7.7.2.1.3. The conceptual site model summary for SWMU 17 is presented in Figure 7.5 and includes exposure routes, potential receptors and the medium containing the potential contaminants of concern. All chemicals not eliminated by data validation were considered in the risk assessment for this SWMU.

7.7.2.2 Exposure Point Concentrations and Chronic Daily Intakes

7.7.2.2.1. Exposure point concentrations for the metals detected in SWMU 17 groundwater (see Section 7.7.1) are listed in the tables in Appendix I. These concentrations range from 0.00155 mg/L (beryllium) to 0.0771 mg/L (barium). Exposure point concentrations for the contaminants of concern in surface soils at SWMU 17A (also see Section 7.7.1) range from 0.329 ppm (mercury) to 4,720 ppm (lead). Exposure point

Table 7.10
Summary of Human Health Risk
SWMU 17BCD
Radford Army Ammunition Plant

Receptor	Pathways	HI		Cancer Risk	
		CT	RME	CT	RME
Site Worker	Ingestion of Groundwater	0.26	1.02	1.16E-06	2.32E-05
	Dermal Contact with Groundwater	0.12	0.46	5.27E-07	1.06E-05
	Ingestion of Surface Soil	0.04	0.17	1.47E-06	2.95E-05
	Dermal Contact with Surface Soil	0.09	0.23	1.45E-05	1.89E-04
	Inhalation of Surface Soil Particulates	0	0	3.21E-14	4.83E-13
Total for Site Worker		0.51	1.88	1.77E-05	2.52E-04
Hunter	Ingestion of Surface Soil	0.01	0.03	5.31E-07	9.20E-06
	Dermal Contact with Surface Soil	0.01	0.02	3.28E-06	3.57E-05
Total for Hunter		0.02	0.05	3.81E-06	4.49E-05
Construction Worker	Ingestion of Surface Soil	0.17	0.80	5.90E-07	1.13E-05
	Dermal Contact with Surface Soil	0.17	0.23	2.91E-06	1.51E-05
	Inhalation of Surface Soil Particulates	0	0	1.55E-14	1.08E-13
	Ingestion of Subsurface Soil	0.03	0.13	8.52E-08	1.64E-06
	Dermal Contact with Subsurface Soil	0.01	0.01	3.93E-08	2.04E-07
	Inhalation of Subsurface Soil Particulates	0	0	2.49E-15	1.74E-14
Total for Construction Workers		0.38	1.17	3.62E-06	2.82E-05

Figure 7.5
Conceptual Site Model for Current and Future Exposure Pathways
SWMU 17 ABCD
Radford Army Ammunition Plant
Radford, Virginia

Primary Source	Release Mechanism	Receiving Medium	Exposure Route	Current Receptors				Future Receptor
				Site Workers	Rec. Users	Hunters, Fisherman	Const. Workers	Site Workers
RAAP Activities	Surface Runoff/ Groundwater Discharge	Surface Water and Sediment	Ingestion					
			Inhalation					
			Dermal					
	Tracking Deposition	Surficial Soils	Ingestion	X		X(H)	X	
			Inhalation	X			X	
			Dermal	X		X(H)	X	
	Leaching/ Deposition	Subsurface Soils	Ingestion				X	
			Inhalation				X	
			Dermal				X	
	Uptake	Biota	Ingestion					
	Leaching	Groundwater	Ingestion					X
			Inhalation					
			Dermal					X

X = Pathways of potential concern
H = Hunter scenario

concentrations for contaminants of concern at SMWU 17A subsurface soils range from 0.073 ppm (fluoranthene) to 5,260 ppm (lead).

7.7.2.2.2. Exposure point concentrations for the nine metals evaluated in SWMU 17 B,C,D surface soil range from 0.0941 ppm (mercury) to 290 ppm (lead). Exposure point concentrations for the chemicals of concern in subsurface soils range from 8.13 ppm (arsenic) to 27.4 ppm (lead).

7.7.3 Risk Characterization

7.7.3.0.1. The carcinogenic risk and hazard index were calculated for the groundwater ingestion and dermal contact pathways (future site worker receptor) and surface and subsurface soil ingestion, dermal contact, and inhalation of volatiles and particulates (construction worker, site worker and hunters). These calculations are presented in Appendix I. A discussion of the results of each pathway for non-carcinogenic and carcinogenic effects is presented below.

7.7.3.1 Non-carcinogenic Effects

7.7.3.1.1. The calculated hazard index for the hypothetical future site worker groundwater ingestion exposure scenario exceeds acceptable levels due to the presence of antimony. The RME receptor hazard index is 1.01. The dermal contact exposure scenario hazard indices are within acceptable levels. The calculated hazard indices for current site worker surface soil exposure scenarios at SWMUs 17A and 17B,C,D do not exceed acceptable levels.

7.7.3.1.2. The calculated hazard indices for the construction worker surface soil ingestion exposure scenario exceeds acceptable levels for RME receptors at SWMU 17A. At SWMU 17A, the surface soil ingestion hazard index for RME receptors exceeds one primarily due to arsenic (1.59).

7.7.3.1.3. The calculated hazard indices for the construction worker subsurface soil ingestion and dermal contact scenarios exceed acceptable levels for CT and RME receptors at SWMU 17A, with the exception of the CT ingestion scenario. The subsurface soil ingestion hazard index for RME receptors exceeds one primarily due to arsenic (1.49) and antimony

(0.84). The dermal contact exposure scenario primary risk driver and hazard index at SWMU 17A for CT and RME receptors is antimony (2.77 and 7.18, respectively). Arsenic, barium, cadmium and nickel hazard indices also contribute to the hazard index.

7.7.3.2 Carcinogenic Effects

7.7.3.2.1. The calculated cancer risks for the hypothetical future site worker groundwater ingestion and dermal contact scenario are within the USEPA target risk range primarily due to beryllium, for RME receptors. Beryllium was calculated to have ingestion exposure scenario cancer risks for the RME receptors of 2.32 x 10^{-5}. Dermal contact exposure scenario cancer risks for RME receptors are 1.06 x 10^{-5}.

7.7.3.2.2. The calculated cancer risks for the current site worker surface soil ingestion and dermal contact exposure scenarios are within the USEPA target risk range at SWMUs 17A and 17 B,C,D. The primary ingestion risk drivers and cancer risks for CT and RME receptors at SWMU 17A are arsenic (2.67 x 10^{-6} and 5.33 x 10^{-5}) and beryllium (7.40 x 10^{-8} and 1.48 x 10^{-6}). These chemicals also have cancer risks within the target risk range for dermal contact with surface soils at SWMU 17A. The primary dermal contact risk drivers and cancer risks for CT and RME receptors at SWMU 17 B,C,D are also arsenic (1.16 x 10^{-6} and 1.51 x 10^{-5}) and beryllium (1.34 x 10^{-5} and 1.74 x 10^{-4}). Calculated cancer risks for site worker ingestion of surface soil at SWMU 17 B,C,D are also within the USEPA target risk range of 1 x 10^{-4} to 1 x 10^{-6}, primarily due to arsenic and beryllium.

7.7.3.2.3. Cancer risks for the hunter surface soil exposure scenarios are within the target risk range for ingestion of surface soils at SWMUs 17A and 17 B,C,D. The primary risk driver and calculated cancer risk for the RME at SWMU 17A is arsenic (1.66 x 10^{-5}). At SWMU 17 B,C,D, the primary risk drivers and calculated cancer risks for RME receptors are also arsenic (7.88 x 10^{-6}) and beryllium (1.32 x 10^{-6}). The dermal contact exposure scenario also shows cancer risks within the target risk range for CT and RME receptors at SWMU 17A, primarily due to beryllium (1.05 x 10^{-6} and 1.15 x 10^{-5}). Beryllium is also contributing to the risk for this exposure scenario at SWMU 17 B,C,D. The calculated cancer risks for CT and RME receptors are 3.02 x 10^{-6} and 3.29 x 10^{-5}, respectively.

7.7.3.2.4. Construction worker cancer risks are within the target risk range for the dermal contact with surface soil exposure scenario at SWMUs 17A and 17 B,C,D. Primary risk drivers and cancer risks for CT and RME receptors at SWMU 17A are arsenic (4.91×10^{-7} and 2.55×10^{-6}) and beryllium (9.35×10^{-7} and 4.85×10^{-6}). The risk drivers and cancer risks for CT and RME receptors at SWMU 17 B,C,D are also arsenic (2.33×10^{-7} and 1.21×10^{-6}) and beryllium (2.68×10^{-6} and 1.39×10^{-5}). The ingestion of surface soil exposure scenario also exhibits cancer risks within the target risk range at these SWMUs for RME receptors. At SWMU 17A, the risk driver is arsenic, and at SWMU 17 B,C,D, the risk drivers are arsenic and beryllium. Calculated cancer risks for the construction worker ingestion of subsurface soil exposure scenario are also within the target risk range for SWMU 17A. The primary risk driver is arsenic, with CT and RME receptor cancer risks being 9.95×10^{-7} and 1.91×10^{-5}, respectively. At SWMU 17A, the dermal contact with subsurface soil is also within the target risk range with the primary risk driver being beryllium. CT and RME receptor cancer risks are 7.02×10^{-6} and 3.64×10^{-5}. The RME receptor cancer risk for the subsurface soil ingestion exposure scenario at SWMU 17 B,C,D is also within the target risk range, due to arsenic.

7.7.4 Uncertainty Analysis

7.7.4.0.1. Data collection/evaluation uncertainty may be relevant at SWMU 17 due to the types and numbers of samples collected and evaluated. As a conservative measure, all anthropogenic chemicals detected in surface soils at SWMU 17A were included in the risk evaluation, regardless of whether RBCs were exceeded. This was performed to allow the final risk calculations to determine the risk drivers for the site. In addition, data from the January groundwater sampling event was included that was not detected during the July sampling event (e.g., antimony). These determinations concerning the inclusion of data to be evaluated may overestimate the risk for this site.

7.7.4.0.2. Many metals detected at this site in groundwater, surface and subsurface soils are naturally occurring and in some cases (i.e., subsurface soil), statistical methods were used to distinguish site-related from non-site-related metals. All metals detected in groundwater and surface soil were included for evaluation in the final risk calculations, due to the absence of background data in these media. This may overestimate the risk for this site.

7.7.4.0.3. The hunter scenario was included for evaluation in the risk evaluation as a potentially complete exposure pathway. SWMU 17 is an active area of the plant, and is located inside the RAAP boundaries; therefore, it is presently not accessible by recreational hunters. The dermal contact and ingestion of surface soils exposure scenarios exhibit risk for this receptor. As with all modeled concentrations and exposure scenarios, there are assumptions based on best professional judgement and this may over- or underestimate risk.

7.7.4.0.4. Another area of uncertainty in evaluating human health risk from SWMU 17 is toxicity assessment. Oral and dermal slope factors are not available for some of the metals (i.e., lead) and semivolatiles which were detected in groundwater and subsurface soils. However, lead generally exists in a state that is relatively immobile unless site soil conditions approach very high or low pH. Most studies are based on animal data and extrapolated to humans and also subchronic studies may be used assess chronic effects. In addition, extrapolations are characterized by uncertainty factors which can be as large as four orders of magnitude. This may tend to over- or underestimate risk.

7.8 RISK SUMMARY

7.8.0.1. Carcinogenic risks and non-carcinogenic hazard indices were calculated for various receptors potentially exposed to multiple chemicals in groundwater, surface and subsurface soils. These calculations are summarized and presented in Tables 7.9 and 7.10. Under the NCP, the probability of excess cancers over a lifetime of exposure within or below USEPA's target risk range of 1×10^{-4} to 1×10^{-6} are considered to pose a low threat while a probability of excess cancers over a lifetime of exposures greater than 1×10^{-4} may pose an unacceptable threat of adverse health effects. For noncarcinogens, a hazard index below one is considered to pose a low threat of adverse health effects, while a hazard index greater than one may pose an unacceptable threat of adverse health effects.

7.8.0.2. At SWMUs 17A and 17 B,C,D, the site worker CT and RME receptors' total hazard index is greater than one for RME receptors and the cancer risk is within the target risk range. The RME receptor exposure scenario exceeds the target cancer risk range for both SWMUs. These values indicate a potential for carcinogenic adverse human health effects for this receptor.

7.8.0.3. The hunter CT and RME receptors' total hazard index is less than one at SWMUs 17A and 17 B,C,D. The cancer risk for these receptors is within the target risk

Table 7.9
Summary of Human Health Risk
SWMU 17A
Radford Army Ammunition Plant

Receptor	Pathways	HI		Cancer Risk	
		CT	RME	CT	RME
Site Worker	Ingestion of Groundwater	0.26	1.02	1.16E-06	2.32E-05
	Dermal Contact with Groundwater	0.12	0.46	5.27E-07	1.06E-05
	Ingestion of Surface Soil	0.09	0.35	2.74E-06	5.48E-05
	Dermal Contact with Surface Soil	0.19	0.5	7.13E-06	9.25E-05
	Inhalation of Surface Soil Particulates	0	0	6.61E-14	9.96E-13
Total for Site Worker		0.66	2.33	1.16E-05	1.81E-04
Hunter	Ingestion of Surface Soil	0.02	0.06	9.86E-07	1.71E-05
	Dermal Contact with Surface Soil	0.02	0.05	1.61E-06	1.75E-05
Total for Hunter		0.04	0.11	2.60E-06	3.46E-05
Construction Worker	Ingestion of Surface Soil	0.35	1.70	1.10E-06	2.10E-05
	Dermal Contact with Surface Soil	0.39	0.50	1.43E-06	7.40E-06
	Inhalation of Surface Soil Particulates	0	0	3.19E-14	2.23E-13
	Ingestion of Subsurface Soil	0.64	3.06	4.99E-07	1.92E-05
	Dermal Contact with Subsurface Soil	3.47	8.99	2.89E-07	3.00E-06
	Inhalation of Subsurface Soil Volatiles	0	0	8.85E-09	1.07E-07
	Inhalation of Subsurface Soil Particulates	0	0	6.40E-15	7.70E-14
Total for Construction Workers		4.85	14.25	3.33E-06	5.07E-05

range for CT and RME receptors at these SWMUs. These values indicate a potential for carcinogenic adverse human health effects for this receptor.

7.8.0.4. The construction worker CT and RME receptors' total hazard index is greater than one at SWMU 17A. The RME receptor hazard index is greater than one at SWMU 17B,C,D. The CT and RME receptors' cancer risk is within the target risk range at both SWMUs. These values indicate a potential for noncarcinogenic and carcinogenic adverse human health effects at SWMUs 17A, and 17B,D,D.

7.9 SWMU 17/40 SUMMARY

7.9.0.1. SWMU 17 is subdivided into five separate areas based on history, operations, and topography. SWMU 17A located in the western-most of two significant sinkholes was considered separately, while SWMUs 17B,C,D,E located in the eastern sinkhole, were considered together. SWMU 40 was grouped with SWMU 17 because of their proximity and similar subsurface conditions. Only groundwater was characterized for SWMU 40.

7.9.0.2. The groundwater associated with SWMU 17/40 is contained within the fractured dolomite of the karst aquifer underlying the SWMU. Although the groundwater flow direction appears to be west-northwest toward the New River, groundwater movement and occurrence in this area can be unpredictable because of the karst features. A dye tracing study demonstrated a connection between groundwater at the western sinkhole (SWMU 17A) and a spring located on the bank of the New River.

7.9.0.3. Groundwater, surface soil, and subsurface soil samples were collected to characterize SWMU 17/40. The sampling of the spring was included with the New River discussion in Section 12. Barium, antimony, and beryllium were identified as the COC compounds for groundwater at SWMU 17/40. Barium was found in the samples from all four wells; beryllium, which was a risk driver, was detected in the samples from two of the four wells. Antimony, a risk driver, was only detected in one well during the January 1995 sampling event; this metal was not detected during the July 1995 sampling event. Only a minimal barium detection was found in the sample from the well directly downgradient of the SWMUs (as determined by the results of the dye tracing study). This may indicate a narrow, laterally limited, groundwater preferential migration pathway. Contaminants detected in the soils and groundwater at SWMU 17 (particularly the risk driver compound beryllium) were also found in the spring surface water and sediment samples, demonstrating a migration of contaminants from the SWMU to the New River.

7.9.0.4. Arsenic and beryllium were identified as the risk driver compounds for surface soils at SWMU 17A; arsenic and antimony were risk driver compounds for subsurface soils. The highest metals concentrations were found in the near surface sample from the boring nearest the active burning operations. Arsenic and beryllium were also determined to be the risk driver compounds for surface soils at SWMU 17B,C,D. Most of the surface soil high metals concentrations in this SWMU were from one sample (17BSS1). Arsenic was the risk driver compound for subsurface soils at SWMU 17B,C,D. The maximum concentration was in the near surface sample from boring 17CSB1.

7.9.0.5. The human health risk assessment indicated a potential for noncarcinogenic or carcinogenic adverse human health effects for ingestion or dermal contact of groundwater, surface soil, or subsurface soil by site workers, construction workers, or hunters.

SECTION 8

SITE CHARACTERIZATION OF SWMU 31 (COAL ASH SETTLING LAGOONS)

8.1 HISTORY AND OPERATIONS

8.1.0.1. The Coal Ash Settling Lagoons (SWMU 31) are located in the northwest section of the Horseshoe Area. Plate 1 shows SWMU 31 in relation to the rest of the facility. A detailed location map of SWMU 31 is presented as Figure 8.1. The unit has previously been referred to as both the "fly ash settling lagoon" and the "bottom ash settling lagoon." The SWMU has been referred to as the Coal Ash Settling Lagoons throughout this investigation, reflecting the probability that both fly ash and bottom ash have been discharged into it. In addition, the flocculating basin underdrainage and filter backwash water from Water Plant 4330 reportedly flowed to this unit (USATHAMA, 1976).

8.1.0.2. SWMU 31 is associated with Power House No. 2, which burned low sulfur coal to supply steam at 150 pounds per square inch (psi) to the buildings in the Horseshoe Area. Power House No. 2 has not been active for approximately two years. Prior to 1971, when electrostatic precipitators were installed at the power house, fly ash contaminated wastewater was discharged directly to the New River (USATHAMA, 1984).

8.1.0.3. SWMU 31 consists of three unlined settling lagoons. During active use of Power House No. 2, water carrying fly ash from the power house flowed down a below-grade, concrete-lined sluice waterway to the small primary settling lagoon (approximately 100 feet long by 50 feet wide), which was constructed in 1962. At one time, the supernatant from the primary settling lagoon was emptied directly into the New River via Outfall 024 (Permit No. VA 0000248). In 1978 or 1979, additional components were added to the unit; wastewater now flows from the primary settling lagoon through a below-ground pipe to a concrete sump. The sump is 18 to 20 feet deep, 2 feet of which is above grade. From the concrete sump, water is discharged to the secondary settling lagoon, which is approximately 150 feet wide by 200 feet long. From the secondary settling lagoon, water is discharged to the tertiary settling lagoon (approximately 150 feet wide by 250 feet long).

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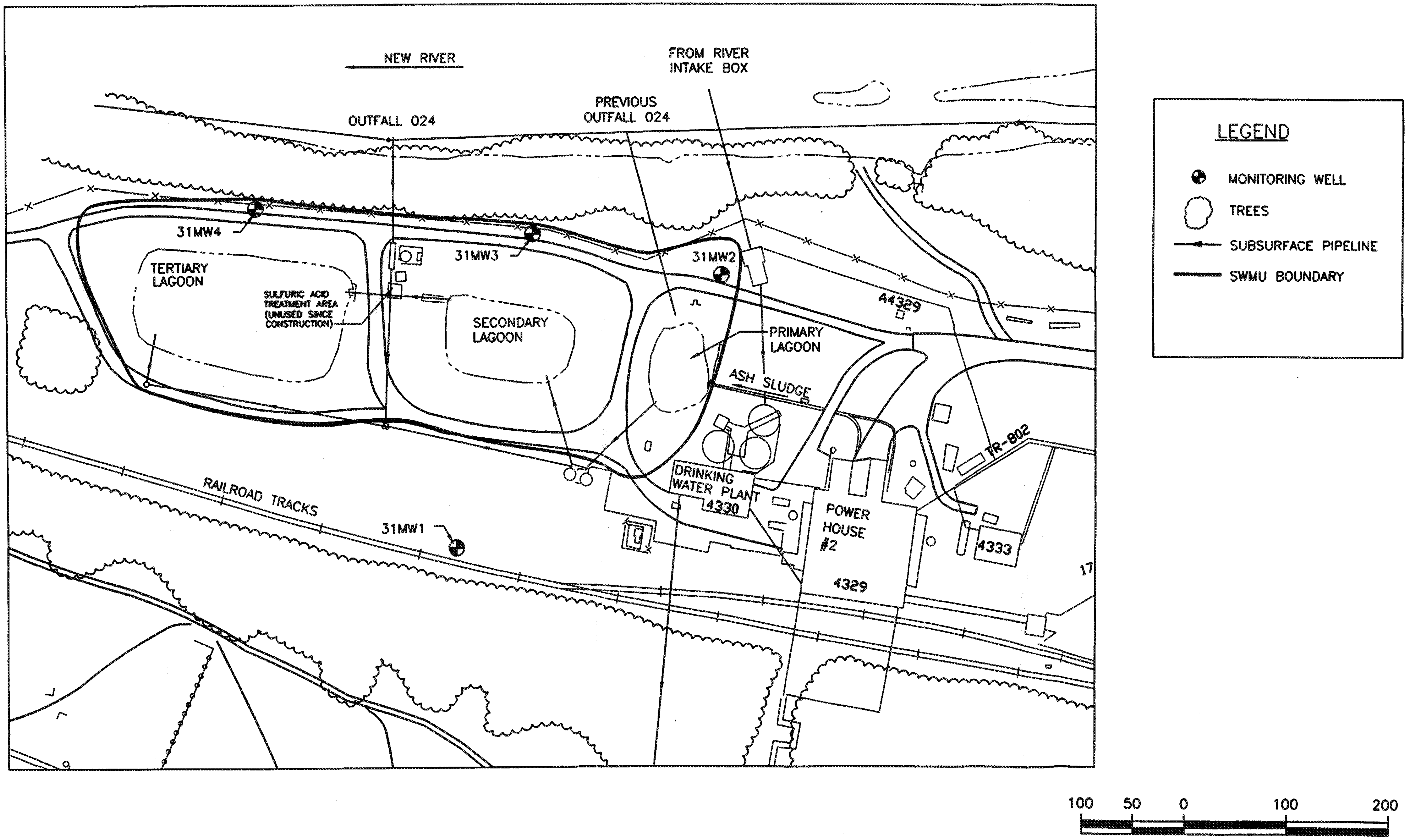
FIGURE 8.1
SWMU 31 LOCATION MAP (COAL ASH SETTLING LAGOONS)

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



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8.1.0.4. Facility representatives indicate that the water currently flowing into the primary settling lagoon consists of either overflow from the drinking water settling tanks or backwash from the cleaning of the filters at the drinking water settling tanks. On average, 20,000 gallons of overflow water per day is released to the primary lagoon at a relatively constant flow rate. At a minimum, the filters require cleaning once every three days. This process involves passing 2800 gallons of water per minute through the filters for 20 minutes to remove accumulated river sediment. The 56,000 gallons of turbid sediment-rich water yielded by this process is discharged to the primary settling lagoon. The yield is then split so that equal volumes of this water are discharged to the secondary and tertiary settling lagoons.

8.1.0.5. The effluent from the tertiary settling lagoon is designed to discharge to the New River through the new location of Outfall 024 following pH adjustment with sulfuric acid. However, facility representatives indicate that there has never been a discharge. All water discharged to the basin apparently percolates through the basin into the surrounding soils or evaporates.

8.1.0.6. Coal ash that settled out in the three lagoons was periodically dredged and disposed in Fly Ash Landfill (FAL) No. 2 (SWMU 29). Previously, coal ash was disposed in FAL No. 1 (SWMU 26).

8.2 PREVIOUS INVESTIGATIONS

8.2.0.1. A waste characterization study was conducted at SWMU 31 by Dames & Moore in February 1992. During this study, three composite sediment samples were collected, one from each of the three lagoons (Figure 8.2). Samples were collected from the top one foot of sludge beneath the water/sludge interface along the edges of the lagoons. Two of the samples (31SL2 and 31SL3) were composited from three subsample locations in the secondary and tertiary lagoons respectively, and the third sample (31SL1) was composited from two subsample locations in the primary lagoon. These samples plus one duplicate were analyzed for metals and semivolatile organic compounds (SVOCs). No other types of samples were collected at this SWMU. The results of the 1992 sediment sampling are summarized in Table 8.1. Also included in the summary table are the HBNs from the RCRA permit (USEPA, 1989a), comparison levels of soil background data calculated by Dames & Moore (1992a), and RBCs for commercial and industrial soils (USEPA, 1994).

FIGURE 8.2
SWMU 31 SAMPLE LOCATION MAP (COAL ASH SETTLING LAGOONS)
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

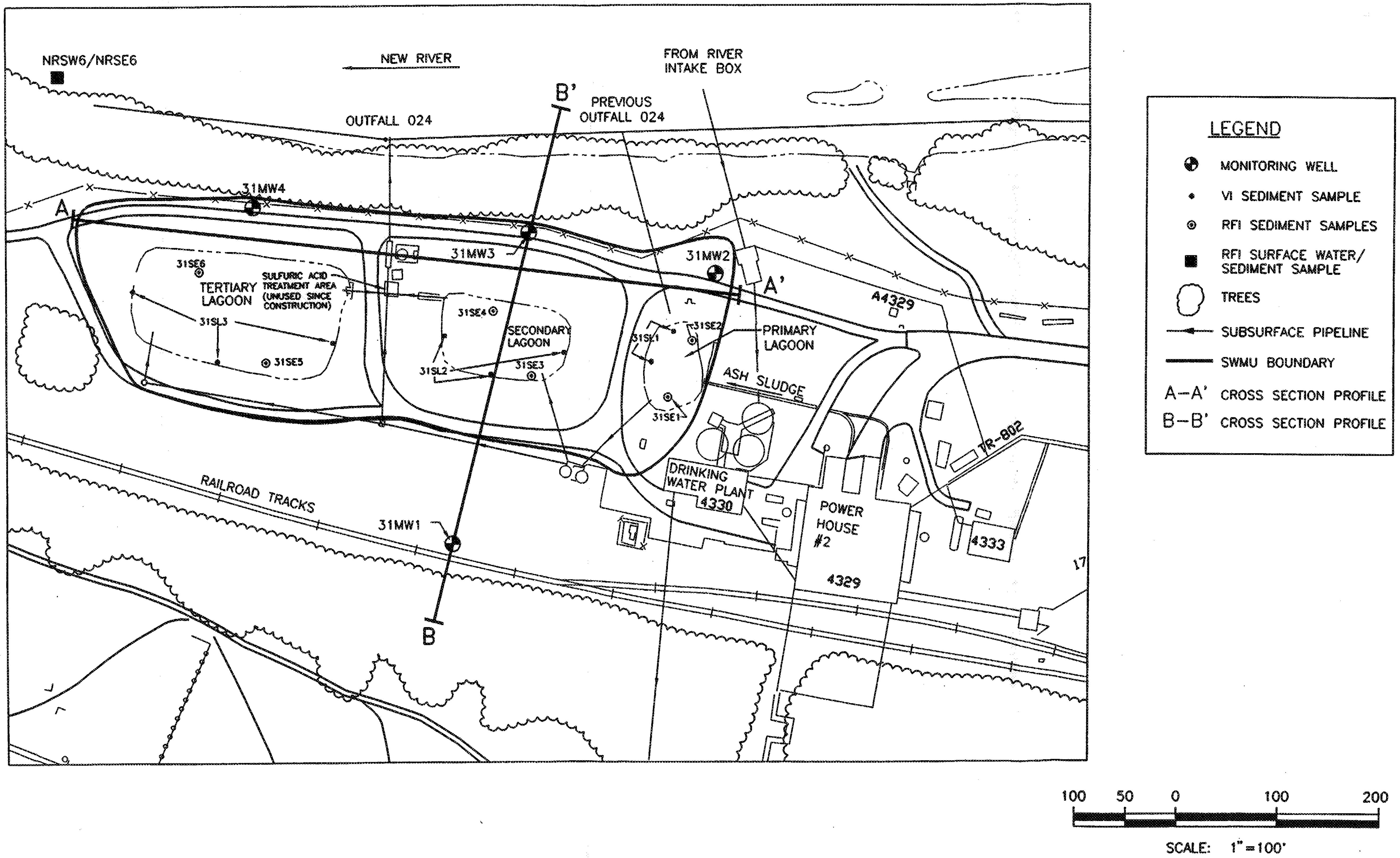

TABLE 8.1
VI DATA 1992
SUMMARY OF ANALYTICAL DATA
FOR SEDIMENT SAMPLES COLLECTED AT SWMU 31
RADFORD ARMY AMMUNITION PLANT, VIRGINIA

	PQLs	No. of Samples	Concentration Range 25 Feb 92 - 10 Mar 92 1.0 ft	Alluvial Soil Background Comparison Level*	HBN	RBC Industrial Soil
TAL Inorganics (µg/g)						
Aluminum	14.1	4	8,770 - 18,900	18,275	230,000	1,000,000
Arsenic	30	4	[4.59] - [9.78]	9.01	0.5	1.6
Barium	1	4	80.8 - 149	209	1,000	72,000
Beryllium	0.2	4	[1.41] - [2.33]	0.90	0.1	0.67
Calcium	100	4	1,790 B - 3,980 B	89,890	NSA	NA
Chromium	4	4	11.1 - 34.2	25.67	400	1,000,000
Cobalt	3	4	[8.16] - [16.1]	18.21	0.8	NA
Copper	7	4	26.4 - 32.9	45.65	2,900	38,000
Iron	1,000	4	7,380 - 33,300	47,506	NSA	NA
Lead	2	4	LT 10.5 - 19.7	292.14	200	NA
Magnesium	50	4	951 - 6,620	38,682	NSA	NA
Manganese	0.275	4	134 - 664	2,236	8,000	5,100
Mercury	0.1	4	LT 0.05 - 0.142	0.05	20	310
Nickel	3	4	18.7 - 22.5	29.68	1,000	20,000
Potassium	37.5	4	576 - 2,650	4,532	NSA	NA
Selenium	40	4	LT 0.25 - 0.882	0.57	200	5,100
Silver	4	4	LT 0.589 - 1.23	1.88	200	5,100
Sodium	150	4	328 B - 541 B	399	NSA	NA
Thallium	20	4	LT 6.62 - [14.5]	6.62	6	NA
Vanadium	0.775	4	21.2 - 64.5	41.49	560	7,200
Zinc	30.2	4	38.6 - 95.8	942	16,000	310,000
Semivolatiles (µg/g)						
1,2-Dichlorobenzene	0.01	4	LT 0.11 - 3.46	NT	1,000	92,000
2-Methylnaphthalene	0.3	4	1.15 - 1.53	NT	NSA	NA
Dibenzofuran	0.3	4	LT 0.035 - 0.285	NT	NSA	NA
Fluoranthene	0.3	4	LT 0.068 - 0.157	NT	500	41,000
Fluorene	0.3	4	LT 0.033 - 0.09	NT	3,200	41,000
Naphthalene	0.3	4	0.092 - 1.42	NT	1,000	41,000
Phenanthrene	0.5	4	0.078 - 1.26	NT	40	NA

TABLE 8.1 (CONTINUED)
VI DATA 1992
SUMMARY OF ANALYTICAL DATA
FOR SEDIMENT SAMPLES COLLECTED AT SWMU 31
RADFORD ARMY AMMUNITION PLANT, VIRGINIA

	PQLs	No. of Samples	Concentration Range 25 Feb 92 - 10 Mar 92 1.0 ft	Alluvial Soil Background Comparison Level*	HBN	RBC Industrial Soil
Semivolatile TICs (µg/g)						
1-Methylnaphthalene	NA	4	ND - 0.917 S	NT	NSA	NA
2,6,10,14-Tetramethylpentadecane	NA	4	ND - 4.88 S	NT	NSA	NA
Cyclohexene Oxide	NA	4	ND - 0.296 SB	NT	NSA	NA
Decane	NA	4	ND - 0.55 S	NT	NSA	NA
Heneicosane	NA	4	ND - 0.55 S	NT	NSA	NA
Heptadecane	NA	4	ND - 0.917 S	NT	NSA	NA
Hexadecanoic Acid, Butyl Ester	NA	4	ND - 7.61 S	NT	NSA	NA
Octadecanoic Acid, Butyl Ester	NA	4	ND - 5.08 S	NT	NSA	NA
Pentacosane	NA	4	ND - 2.44 S	NT	NSA	NA
Tridecane	NA	4	ND - 0.734 S	NT	NSA	NA
Total Unknown TICs	NA	4	ND - (5)383	NT	NSA	

* Alluvial soil samples were collected from 5 locations at RAAP. The mean and standard deviations were calculated. Background comparison levels were selected from the upper 95 percent confidence interval of the background data set, which is equal to the mean plus two standard deviations.

** Chromium II and compounds.

B Analyte was detected in corresponding method blank; values are flagged if the sample concentration is less than 10 times the method blank concentration for common laboratory constituents and 5 times for all other constituents.

HBN Health-based number as defined in the RCRA permit. HBNs not specified in the permit were derived using standard exposure and intake assumptions consistent with EPA guidelines (51 Federal Register 33992, 34006, 34014, and 34028).

LT Concentration is reported as less than the certified reporting limit.

NA Not available; PQLs are not available for TICs detected in the library scans.

ND Analyte was not detected.

NT Not tested.

NSA No standard (HBN) available; health effects data were not available for the calculation of a HBN. HBNs were not derived for TICs.

PQL Practical quantitation limit; the lowest concentration that can be reliably detected at a defined level of precision for a given anaytical method.

S Results are based on an internal standard; flag is used for TICs detected in library scans.

TAL Target analyte list.

TICs Tentatively identified compounds that were detected in the GC/MS libarary scans.

µg/g Micrograms per gram.

( ) Parentheses indicate the number of unknown TICs that were detected in either the volatile or semivolatile GC/MS library scans. The number beside the parentheses is the total concentration of all TICs detected in each respective scan.

[ ] Brackets indicate that the detected concentration exceeds the HBN.

From Dames & Moore, 1992b

8.2.0.2. The results of the chemical analyses for metals and SVOCs indicated that concentrations of arsenic and beryllium exceeding HBN and RBC criteria, and cobalt exceeding HBN criteria were found in all three samples. Thallium was also detected at a concentration above the HBN in sample 31SL2. The arsenic and cobalt levels were less than or slightly greater than the background soil criteria. Several other metals such as aluminum, chromium mercury, selenium, and vanadium were detected at concentrations above background levels but below HBNs and RBCs. Several SVOCs and SVOC tentatively identified compounds (TICs) were detected but not at levels above HBNs or RBCs.

8.3 SUMMARY OF RFI FIELD ACTIVITIES

8.3.0.1. To determine the migration of any metals from the lagoons, three downgradient and one upgradient groundwater monitoring well was installed at SWMU 31. Two soil samples were collected from each well boring. During the drilling of the 31MW1 boring, one sample was collected in a Shelby tube for geotechnical testing.

8.3.0.2. Groundwater samples were collected from each well. Field measurements of the groundwater were taken. To determine potential disposal characteristics of the lagoon sediments, two composite sediment samples representing the total sediment column were collected from each lagoon. The analytical parameters for these samples are shown in Tables 4.3 and 4.4. The sample locations are shown in Figure 8.2. A summary of the field activities for SWMU 31 is presented in Table 8.2.

8.3.0.4. After installation of the wells, an aquifer slug test (insertion and removal) was conducted on the newly-installed wells to evaluate potential migration rates and other hydrogeologic characteristics. In addition, each well was surveyed to determine elevation and location coordinates. Staff gauges were placed in each of the lagoons. These gauges were surveyed to facilitate the study of groundwater flow from the lagoons to the river. All of these field activities were completed in January 1995.

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TABLE 8.2

SUMMARY OF SWMU 31 RFI FIELD ACTIVITIES
RADFORD ARMY AMMUNITION PLANT

SWMU	Monitoring Wells Installed and Sampled*	Well Boring Samples	Depth (Feet Below Ground Surface)	Sediment Samples	Geotechnical Samples/ Depth	Slug Tests	Staff Gauges Installed
31	31MW1	31MW1A25	23-25	31SE1	31MW1(10-12)	31MW1	Primary Lagoon
	31MW2	31MW1B35	33-35	31SE2		31MW2	Secondary Lagoon
	31MW3	31MW2A12	10-12	31SE3		31MW3	Tertiary Lagoon
	31MW4	31MW2B22	20-22	31SE4		31MW4	
	31MW5 (Dup. of 31MW3)	31MW3A10	5-10	31SE5			
		31MW3B20	15-20	31SE6			
		31MW4A12	10-12				
		31MW4B22	20-22				
		31MW4C40 (Dup. Of 31MW4A12)					

* Field measurements of pH, temperature, and conductivity were also recorded.

8.4 ENVIRONMENTAL SETTING

8.4.1 Topography and Site Layout

8.4.1.1. SWMU 31 is located on a nearly level terrace adjacent to the New River at an approximate elevation of 1,700 feet above mean sea level. The New River flows from northeast to southwest along the northern boundary of the SWMU. The river is approximately 100 feet from the lagoons. The facility's New River water intake (No. 2) is approximately 300 feet upstream of Outfall 024.

8.4.1.2. Railroad tracks (inactive) run along the southern boundary of SWMU 31; the tracks are elevated approximately 15 feet above the level terrace. South of the tracks, the elevation increases further, so that the SWMU vicinity is a "stepped" terrace leading down to the New River.

8.4.2 Geology

8.4.2.1. The geology of SWMU 31 was characterized by drilling four groundwater monitoring wells for the RFI. Samples were either collected continuously or at five foot intervals in each boring as described in section 4. The vertical extent of all investigatory drilling activities was approximately 53 feet, ranging from 1715 feet above mean sea level (amsl) to 1662 feet amsl.

8.4.2.2. All geological samples were categorized under the Unified Soil Classification System (USCS) in accordance with the work plan. One geotechnical sample was taken from monitoring well boring 31MW1 at 10-12 feet below ground surface (bgs) and submitted for laboratory analysis to determine USCS designation. All other samples, including those collected for chemical analysis or general site characterization, were given a USCS designation in the field by the project geologist. The compiled information was used to prepare the geologic cross sections presented as Figures 8.3 and 8.4. The cross section profile lines are shown on Figure 8.2.

8.4.2.3. The geology of SWMU 31 was consistent across the study area; the subsurface generally comprised unconsolidated alluvial sediments overlying the weathered limestone of the Elbrook Formation. The SWMU 31 vicinity displays the characteristic terraces of the unconsolidated sediments at RAAP. Cross section B-B' (Figure 8.4) reveals

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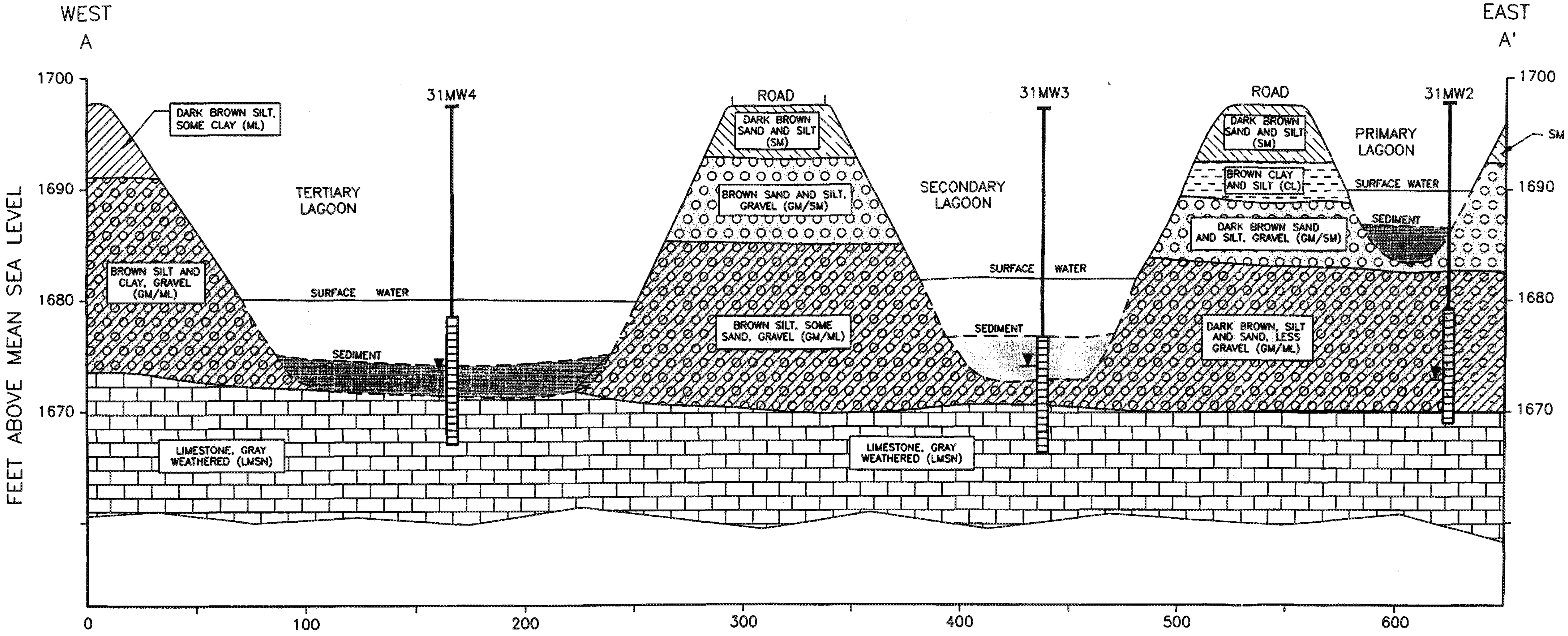
FIGURE 8.3
SWMU 31 GEOLOGIC CROSS SECTION (A–A')

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



LEGEND

HORIZ. SCALE: 1" = 50' (0–50)

VERT. SCALE: 1" = 10' (0–10)

▤ WELL SCREEN INTERVAL

▼ STATIC GROUNDWATER LEVEL

NOTES:

1) CROSS SECTION PROFILE A–A' LOCATED ON FIGURE 8.2.
2) WATER LEVELS MEASURED JULY 1995.
3) MONITORING WELLS PROJECTED THROUGH LAGOONS.
4) LITHOLOGY PATTERNS DO NOT MATCH DRILL LOG PATTERNS DUE TO DIFFERING GRAPHICS SYSTEMS.

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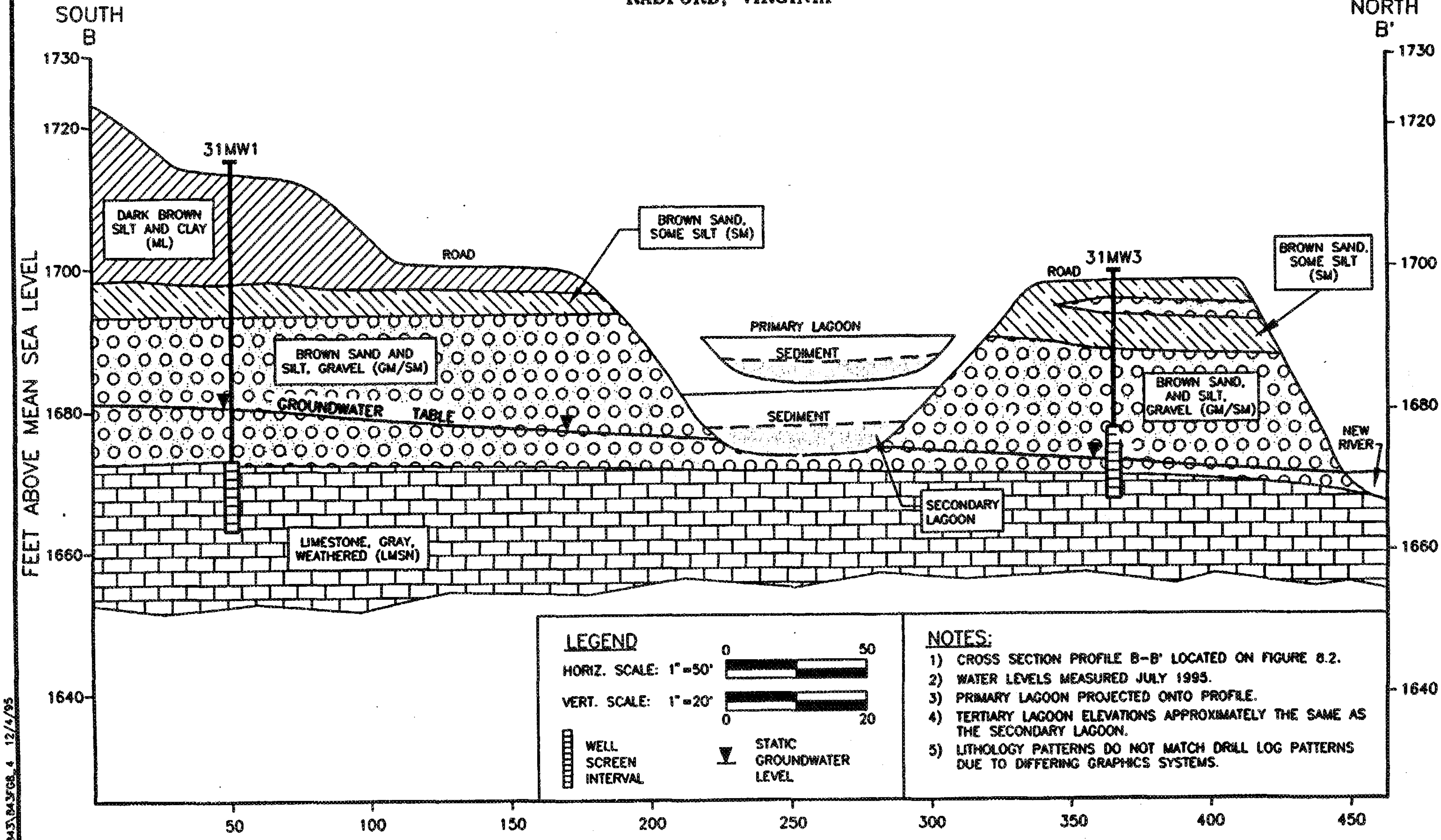
FIGURE 8.4
SWMU 31 GEOLOGIC CROSS SECTION (B–B')

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



NOTES:
1) CROSS SECTION PROFILE B–B' LOCATED ON FIGURE 8.2.
2) WATER LEVELS MEASURED JULY 1995.
3) PRIMARY LAGOON PROJECTED ONTO PROFILE.
4) TERTIARY LAGOON ELEVATIONS APPROXIMATELY THE SAME AS THE SECONDARY LAGOON.
5) LITHOLOGY PATTERNS DO NOT MATCH DRILL LOG PATTERNS DUE TO DIFFERING GRAPHICS SYSTEMS.

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the terraced morphology and the sediments gently dipping to the New River (south to north). There is a general fining upwards textural sequence as silts and clays overlie gravels and silty sands. Below the gravels and sands, the bedrock interface was encountered. The unconsolidated sediments were 25-28 feet thick along the New River as shown in the west to east cross section A-A' (Figure 8.3).

8.4.2.4. A dark brown silt layer containing varying amounts of clay (ML) was typically encountered overlying a silty sand (SM). At approximately 6-8 feet bgs, a dark brown sand, silt, and gravel layer (GM/SM) was present. It was 5-7 feet thick. Below this layer was a brown silt, clay, and gravel (GM/ML) section, which extended to the bedrock interface. To the west, the GM/SM interval was absent. To the east, a brown clay layer (CL) was observed at 5-8 feet bgs between well borings 31MW3 and 31MW2. The GM layers often contained the cobbles or boulders (river jack) that occur throughout the alluvial strata along the river. The bedrock was a gray weathered limestone which was partially penetrated by hollow stem augers in some borings, but which required air drilling methods to complete the wells in other borings. The rock samples at the bedrock interface were determined to be limestone by hydrochloric acid effervescence testing.

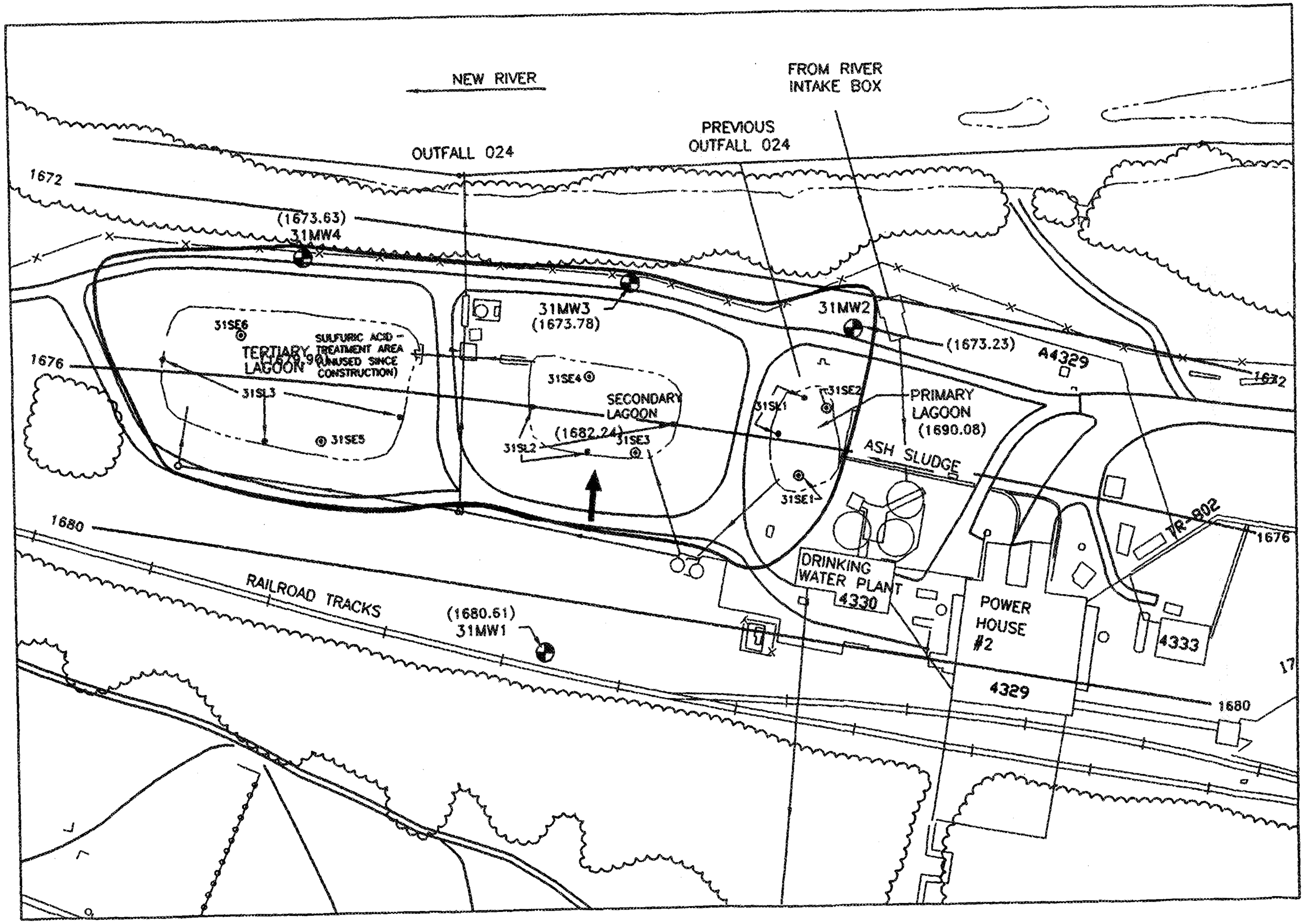
8.4.3. Hydrogeology

8.4.3.0.1. Three of the four wells installed at SWMU 31 (31MW2, 32MW3, and 31MW4) were screened in the alluvial sediments overlying the Elbrook Formation bedrock. The fourth well (31MW1) was screened at the bedrock interface. Groundwater was encountered approximately 23 feet bgs at wells 31MW2, 31MW3 and 31MW4, which are located along the New River. 31MW1 was installed on the terrace approximately 15 feet higher in elevation than the other three wells at this site; groundwater was encountered at approximately 32 feet bgs in this well.

8.4.3.0.2. Groundwater occurrence and movement does not appear to be complex at this SWMU. Groundwater is present within a relatively shallow unconfined aquifer consisting of unconsolidated alluvial sediments overlying the Elbrook limestone. The potentiometric surface of the groundwater at SWMU 31 is shown in cross section in Figures 8.3 (perpendicular to flow direction) and 8.4 and in plan view in Figure 8.5. Groundwater elevations have been observed to fluctuate seasonally from 2-7 feet at this SWMU (January

FIGURE 8.5
SWMU 31 GROUNDWATER POTENTIOMETRIC SURFACE MAP

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



LEGEND

1673.78 ●	MONITORING WELL GROUNDWATER ELEVATION
○	TREES
—◄—	SUBSURFACE PIPELINE
——	SWMU BOUNDARY
~1676 ~	POTENTIOMETRIC SURFACE (FT AMSL)
➡	APPARENT GROUNDWATER FLOW DIRECTION

NOTES: 1. GROUNDWATER ELEVATIONS FOR ALL WELLS MEASURED ON 7/13/95.

LAGOON SURFACE WATER ELEVATIONS MEASURED ON 7/15/95

100 50 0 100 200

SCALE: 1" = 100'

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and July measurements). The groundwater elevations presented in the figures are from the July 1995 sampling event.

8.4.3.0.3. Subsurface conditions in the vicinity of 31MW1 were slightly different than for the wells along the river. Although the same layers were encountered at similar elevations, the GM/SM layer was considerably drier in this area than near the river. The well boring was advanced into a wet zone of the bedrock to ensure that the well would not be dry. The result was a screened interval lower than the other wells. After approximately 24-36 hours, the groundwater stabilized above the screen as shown in Figure 8.4. The groundwater potentiometric level in this area is consistent with flow toward the river, but the overburden may contain more clay, or the bedrock may have fewer fractures, resulting in slower recharge of groundwater in 31MW1. Since light non-aqueous phase liquid compounds (floaters) are not a contaminant of concern at this SWMU, the stabilized groundwater level relative to the top of the screen is not significant in this well.

8.4.3.0.4. The direction of groundwater flow at SWMU 31 is north to northwest, toward the New River. The hydraulic gradient is approximately 0.01 ft/ft. The potentiometric surface of the groundwater is approximately the same elevation as the secondary and tertiary lagoon sediment levels. Since these lagoons were excavated to the bedrock surface, the bottoms of the lagoons are essentially at the groundwater table; the surface water elevations of these two lagoons are consistently above the groundwater table, although the discharge of water into the lagoons from the drinking water settling tanks (Subsection 8.4.4) contributes to this condition. The primary lagoon was constructed at a higher elevation. The relationships between groundwater and sediment and surface water levels in the lagoons can be seen in the cross sections.

8.4.3.0.5. Well construction details for the SWMU 31 monitoring wells are shown in Table 4.1. Field data collected during the January and July 1995 sampling events is summarized in Table 8.3. Field data included the groundwater elevations used to prepare Figure 8.5, photoionization detector (PID) readings of the well headspace in parts per million (ppm), pH, temperature, and conductivity of the groundwater.

TABLE 8.3
SWMU 31: GROUNDWATER FIELD DATA
RADFORD ARMY AMMUNITION PLANT

Well Name	Date	Depth to Bottom (ft)	Depth to Water (ft)	Groundwater Elevation*(ft)	PID (ppm)	pH	Temperature (degrees F)	Conductivity (us/cm)
31MW1	1-17-95	52.40	32.36	1682.68	0.3	7.21	65.5	660
31MW2	1-17-95	28.50	19.62	1679.43	3.2	7.95	65.1	560
31MW3	1-17-95	32.43	18.76	1680.82	2.2	7.25	60.7	570
31MW4	1-17-95	30.45	20.15	1678.40	30.1	7.52	64.2	580
31MW1	7-15-95	52.40	34.43	1680.61	0.0	7.10	73.3	725
31MW2	7-15-95	28.50	25.82	1673.23	0.0	7.17	91.2	2.2
31MW3	7-15-95	32.43	25.04	1673.78	0.0	7.29	NA	1.02
31MW4	7-15-95	30.45	24.92	1673.63	0.0	7.94	80.0	347

* Feet above mean sea level

NA: No data due to instrument malfunction.

8.4.3.1 Aquifer Testing Results

8.4.3.1.1. In order to further investigate the groundwater characteristics at SWMU 31, four falling-head (injection) and two rising-head (withdrawal) slug tests were conducted on wells 31MW1 through 31MW4 in January 1995 as discussed in section 4.7. Data are included for falling-head slug tests 31MW3 and 31MW4, however the results were deemed invalid due to quick recharge resulting from a heavy rainstorm.

8.4.3.1.2. All four wells intercept groundwater flow from a shallow, unconfined zone of unconsolidated alluvial sediments. The bottom of the screened interval is positioned in the bedrock for all wells; the screen of 31MW1 is almost entirely in the bedrock. The hydraulic conductivity and transmissivity data for these wells are summarized in Table 8.4; calculations and type curves from the slug test data are located in Appendix E.

8.4.3.1.3. The highest hydraulic conductivity value calculated at SWMU 31 was at well 31MW2 (2.11×10^{-4} cm/sec or 0.6 ft/day). The lowest hydraulic conductivity value at SWMU 31 was at 31MW4 (9.18×10^{-6} cm/sec or 0.026 ft/day). The average hydraulic conductivity calculated at SWMU 31 (7.80×10^{-5} cm/sec) falls into the range of silt, loess, or silty sand for unconsolidated deposits or alluvium (Freeze and Cherry, 1979). The hydraulic conductivity value of 8.15×10^{-5} cm/sec for 31MW1, which more fully penetrates the bedrock, falls into the silt and loess range (unconsolidated) and into the limestone and dolomite range (bedrock).

8.4.3.1.4. Transmissivity, the rate at which water moves through a unit width of aquifer material under a unit hydraulic gradient, is the product of hydraulic conductivity and aquifer thickness. The highest transmissivity value calculated at SWMU 31 was in well 31MW2 (11.98 ft^2/day), and the lowest was in well 31MW4 (0.52 ft^2/day). The average calculated transmissivity value for SWMU 31 is 4.65 ft^2/day.

8.4.3.1.5. The horizontal groundwater flow velocity can be calculated by using the average hydraulic conductivity (7.80×10^{-5} cm/sec), the hydraulic gradient (1 percent) as measured from Figure 8.5, and an estimated effective porosity of 35 percent. The estimated porosity of 35 percent for the unconsolidated layer is based on a range of porosities typical for unconsolidated sand and silt mixtures (Freeze and Cherry, 1979). By using the Darcy

TABLE 8.4

SUMMARY OF SLUG TESTING DATA
SWMU 31 (COAL ASH SETTLING LAGOONS)

RADFORD ARMY AMMUNITION PLANT

WELL	TEST DATE	SLUG TEST TYPE	HYDRAULIC CONDUCTIVITY (K) IN:		TRANSMISSIVITY (t) FT^2/DAY
			FT/MIN	CM/SEC	
31MW1	1-12-95	Injection/falling-head	1.61×10^{-4}	8.15×10^{-5}	4.62
31MW2	1-12-95	Injection/falling-head	4.16×10^{-4}	2.11×10^{-4}	11.98
31MW3	1-11-95	Injection/falling-head	1.02×10^{-5}	5.30×10^{-6}	0.30
31MW3	1-12-95	Withdrawal/rising-head	2.03×10^{-5}	1.03×10^{-5}	1.47
31MW4	1-11-95	Injection/falling-head	1.16×10^{-3}	5.90×10^{-4}	33.4
31MW4	1-12-95	Withdrawal/rising	$1.82 \text{ X } 10^{-5}$	$9.18 \text{ X } 10^{-6}$	0.52
		Average for SWMU 31*:	1.54×10^{-4}	7.80×10^{-5}	4.65

* The averages do not include 31MW3 and 31MW4 injection/falling-head tests, as a heavy rainstorm significantly affected those test results.

8.9.0.3. In general, the highest subsurface soil metals concentrations appeared to be from the downgradient well borings. Although most of the metals detected in the groundwater were from the downgradient well samples, the maximum concentrations of two of the groundwater COC metals and the only sample with a positive detection for antimony were found in the sample from the upgradient well. However, the well is close enough to the lagoons to suggest the possibilty that seasonal groundwater level fluctuations can allow the lagoon sediments to impact the quality of the groundwater in the vicinity of this well. Additionally, the infiltration of the lagoon surface water may be adversely impacting the upgradient well.

8.9.0.4. The human health risk assessment indicated a potential for carcinogenic and noncarcinogenic adverse human health effects for SWMU 31 groundwater ingestion or dermal contact for site worker receptors.

Equation and standard equation of hydraulics (V=Ki/n) where V is velocity, K is hydraulic conductivity, i is the hydraulic gradient, and n is effective porosity, the estimated groundwater flow velocity was calculated to be 2.23 x 10^{-6} cm/sec or 2.31 ft/yr.

8.4.4 Surface Water

8.4.4.1. The New River is approximately 70 feet northwest of the boundary of SWMU 31, and about 30 feet lower in elevation. The New River in this vicinity flows parallel to SWMU 31 from northeast to southwest. Flow in this section of the river is generally calm with relatively deep pooled areas. This is one of the widest parts of the river (approximately 600 feet) in the vicinity of RAAP.

8.4.4.2. Three settling lagoons are present at the SWMU as shown in Figure 8.1. The surface water elevation in the settling lagoons decreases from east to west during both high and low flow conditions, as indicated by the data summarized below:

	Lagoon Surface Water Elevation (feet AMSL)		
Date	Primary Lagoon	Secondary Lagoon	Tertiary Lagoon
1/19/95	1690.3	1685.9	1683.7
7/15/95	1690.1	1682.2	1679.9

The settling lagoons may act as groundwater recharge areas, however, the daily discharge of water from the drinking water settling tanks into the lagoons makes it difficult to determine this based upon relative water levels. Surface topography in the vicinity of SWMU 31 indicates a surface water flow northwestward, toward the New River. However, within the boundaries of SWMU 31, the settling lagoons capture a significant quantity of surface water runoff. As indicated in Figure 8.1 and as discussed in Section 8.1, there are numerous subsurface pipelines throughout SWMU 31.

8.4.4.3. As discussed in Section 8.1.0.4., approximately 38,670 gallons of water is discharged to the lagoons each day from the drinking water treatment plant. Average daily net precipitation results in an additional 1,800 gallons of water per day to the three lagoons. Thus, on average 40,470 gallons of water per day are added to the lagoons. Because the lagoons are at a relative steady state (i.e. neither going dry nor requiring water release through an outfall), the quantity of water input to the lagoons is equivalent to the output. Output of water is either in the form of evaporation or infiltration. The quantity of water lost to evaporation has been accounted for in the net precipitation value given above. Therefore, if these conditions are true, an average of 40,470 gallons of water per day infiltrate the substrate of the three lagoons. The groundwater table has been observed to consistently lie below the surface water elevation of the lagoons (Figure 8.4), demonstrating that infiltration of water from the lagoons is feasible. The infiltration rate has been calculated to be in the range of 1.9 inches per day. Under these conditions, the water released by the lagoons recharges the underlying aquifer and is discharged to the New River. No direct mechanical discharge of the lagoon contents to the river occurs according to facility personnel.

8.5 NATURE AND EXTENT OF CONTAMINATION

8.5.0.1. All positive results (detected compounds) for soil and aqueous samples for SWMU 31 are presented in Tables 8.5 and 8.6, respectively. The positive results and the chemicals of concern (COCs) as identified by the methods described in Section 6 are discussed below. However, the focus of the section is on the COCs identified as potential human health threats as detailed in the subsequent Risk Assessment subsections.

8.5.1 Nature of Contamination

8.5.1.1 Subsurface Soils

8.5.1.1.1. No COCs were identified in the subsurface soils at SWMU 31. Positive results were detected for eight metals in these soils, but none exceeded the established background levels for these soil types. The metals were arsenic, lead, silver, barium, beryllium, chromium, nickel, and mercury. All of these metals except mercury, silver, and arsenic, were found in every subsurface soil sample. Arsenic was found in two samples, silver was found in two samples, and mercury was found in two samples; however, not the same samples.

8.5.1.2 Groundwater

8.5.1.2.1. Positive results for nine metals were detected in the SWMU groundwater samples. Of these, selenium, barium, antimony, and beryllium were identified as COCs. Beryllium and antimony were found at concentrations considered to be a potential human

TABLE 8.5
POSITIVE RESULTS TABLE OF SWMU 31 - Solid Samples
RADFORD ARMY AMMUNITION PLANT

HBNS	Field Sample Number	31MW1A25	31MW1B35	31MW2A12	31MW2B22	31MW3A10	31MW3B20	31MW4A12	31MW4B22
	METALS (ug/g)								
0.5	Arsenic				4.40 J4				
200	Lead	0.63 J6	7.32 J6	21.16 J1	20.86 J1	31.54 J1	40.00 J1	17.70 J1	13.96 J1
200	Silver		0.02 J4				0.11 J4		
1000	Barium	28.11 J1	58.39 J1	134.90 J1	97.33 J1	134.00 J1	75.10 J1	136.78 J1	82.68 J1
0.1	Beryllium	0.94 J4	1.18 J4	1.00 J4	1.06 J4	0.95 J4	0.75 J4	1.18 J4	0.83 J4
400	Chromium	18.50 J6	24.10 J6	43.94	34.00	26.80	19.50	43.91	32.03
1000	Nickel	23.62 J4	30.89 J4	13.37 J4	22.78 J4	12.60 J4	13.30 J4	20.23 J4	18.18 J4
20	Mercury				0.07 J4	0.18 J4			
	OTHER (ug/g)								
	Total Organic Carbon								

TABLE 8.5
POSITIVE RESULTS TABLE OF SWMU 31 - Solid Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	31MW4C40*	31SE1	31SE3	31SE5
METALS (ug/g)				
Arsenic				
Lead	19.98 J1			
Silver				
Barium	140.53 J1			
Beryllium	1.22 J4			
Chromium	44.13			
Nickel	21.49 J4			
Mercury				
OTHER (ug/g)				
Total Organic Carbon		58557.00	77281.60	62372.90

* 31MW4C40 is a duplicate sample of 31MW4A12

TABLE 8.6
POSITIVE RESULTS TABLE OF SWMU 31 - Aqueous Samples
RADFORD ARMY AMMUNITION PLANT

HBN	Field Sample Number	31MW1	31MW1 Dissolved	31MW2	31MW2 Dissolved	31MW3	31MW3 Dissolved	31MW4	31MW4 Dissolved	31MW5*
	METALS (ug/l)									
50	Arsenic			7.44						
2	Mercury					0.138		0.142		
50	Lead	7.58		41.8		36.2		11.3		
10	Selenium				5.4					
1000	Barium	300	264	183	27	257	24.7	137	19.7	
0.007	Beryllium	5.16	3.98	6	1.63	5.24	1.86	5.26		
50	Chromium			97.3		89.1		31.6		
70	Nickel			49.9		58.4				
10	Antimony		65.2**							
	OTHER (ug/l)									
	Total Organic Carbon	2040		1320		1160				1350
	Total Organic Halogens	15.4		15		25.3		15.6		33.4

* 31MW5 is a duplicate sample of 31MW3.

** The positive result for antimony was detected during the January 1995 sampling event.

All other results from July 1995.

health risk. Therefore, these metals were categorized as the risk drivers for SWMU 31 groundwater. Dissolved selenium was only found in the sample from 31MW2 at a concentration of (5.4 ug/l). Dissolved barium was detected in all four monitoring well samples, ranging from 19.7 ug/l (31MW4) to 264 ug/l (31MW1). Total beryllium was found in the samples from all wells, but dissolved beryllium concentrations were only detected in the samples from three of the wells; 31MW4 did not contain dissolved beryllium. The maximum dissolved beryllium concentration (3.98 ug/l) was in the 31MW1 sample. Dissolved antimony was only detected in 31MW1 during the January 1995 sampling event at 65.2 ug/l.

8.5.1.2.2. The other metals detected in the groundwater, but not considered to be COCs, were arsenic, mercury, lead, chromium, and nickel. However, none of these metals were found in the dissolved fraction of the metals analysis for the samples. Arsenic was only found in the 31MW2 sample. Nickel was only detected in the samples from 31MW2 and 31MW3. Mercury was only detected in the 31MW3 and 31MW4 samples. Chromium was detected in three samples, with a maximum concentration of 97.3 ug/l (31MW2).

8.5.2 Extent of Contamination

8.5.2.1 Subsurface Soils

8.5.2.1.1. Positive results for metals were found in the well borings as described above. Two soil samples were collected from each boring, one shallow and one deep. In general, no obvious pattern of metals occurrence in the samples could be observed when comparing shallow to deep samples. In four instances, metals were detected in the deep sample which were not present in the shallow sample. In one case, a metal was detected in the shallow sample which was not found in the deep sample from that boring. Overall, the metals concentrations in the three well borings along the river (in the apparent downgradient groundwater flow direction from the settling lagoons) were higher than those found in the 31MW1 well boring samples (upgradient of the lagoons). However, this was not true for all metals. The deepest samples taken which had positive detections for metals were from the same approximate elevation as the bottoms of the secondary and tertiary lagoons.

8.5.2.2 Groundwater

8.5.2.2.1. The maximum concentration of dissolved beryllium, the risk driver metal, was found in the sample from 31MW1. The maximum concentration of dissolved barium was also in the sample from 31MW1. The only detection of antimony, a risk driver metal, was also from 31MW1, in the sample collected during the January 1995 sampling event. Selenium was not detected in this well sample. This well has been shown to be hydraulically upgradient of the lagoons, which are the likely source of metals contamination at SWMU 31. The three wells along the New River, 31MW2, 31MW3, and 31MW4, are downgradient of the lagoons. The only selenium detection was in the sample from 31MW2; all three of the downgradient wells contained detectable amounts of beryllium, an identified risk driver metal. With the exception of lead, which was also detected in the upgradient well sample, all of the other detected metals were from these downgradient well samples.

8.6 CONTAMINANT FATE AND TRANSPORT

8.6.0.1. The environmental fate and transport of chemicals is dependent on the physical and chemical properties of the compounds, the environmental transformation processes affecting them, and the media through which they migrate. At SWMU 31, both the surface water and groundwater are potential migration pathways to the New River. Flooding of this area by the river is possible. Groundwater in the vicinity of SWMU 31 appears to be discharging directly to the river. Contaminants discharging to the New River would likely be significantly diluted before reaching distant downgradient receptors. The river is approximately 100 feet from the lagoon area and the groundwater velocity is estimated to be 2.31 feet/year.

8.6.0.2. The source of the relatively high metals contamination in the upgradient well (31MW1) is not clear, however, the groundwater gradient at SWMU 31 is low. The sediments in the secondary and tertiary lagoons are approximately five feet below the potentiometric surface in 31MW1. The well is approximately 140 feet from the nearest lagoon. It is possible that seasonal groundwater fluctuations allow for impact of the slightly upgradient groundwater in 31MW1. It is also possible that infiltration of the lagoon surface water is impacting the groundwater quality in the upgradient well vicinity.

8.6.0.3. Beryllium and antimony, the risk driver metals for SWMU 31 groundwater, were not detected in the surface water sample collected from the New River at the likely discharge point of SWMU 31 groundwater. Metals were found in the subsurface soils, but at levels below established background concentrations. The lagoon sediments were within TCLP regulatory limits for all parameters. Migration of metals to the river by the groundwater pathway would likely occur as dissolved ions. Movement would be at a lower rate due to dispersion and adsorption to the aquifer matrix. Metals are generally immobile in the clayey soils which are interbedded throughout the unconsolidated alluvium.

8.6.0.4. Nickel, which was one of the New River sediment COC compounds, was found in the sediment sample (NRSE6) collected just downstream of the lagoon area. However, although nickel was found at detectable levels in the SWMU 31 groundwater and soil samples, it was not found at COC levels. Chromium, barium, silver, and lead were found in both the SWMU 31 soils and the NRSE6 sediment sample. Lead, chromium, and nickel were found in the SWMU 31 groundwater and also in the NRSE6 sediment sample.

8.7 RISK ASSESSMENT

8.7.0.1. The coal ash settling lagoons are unlined and uncovered which does not limit the potential for emissions to the atmosphere and contaminants migrating from settled ash to subsurface soils and groundwater. In the future, these settling lagoons may be removed from operation and completely dismantled.

8.7.0.2. At present, future land use at this SWMU is uncertain; Power House No. 2 has been inactive since January 1993 and is currently scheduled for layaway. A potential scenario would consist of the decommissioning of the settling lagoons along with this power house. Future uses of the land in this area are expected to remain industrial.

8.7.1 Summary of Chemicals of Potential Concern

8.7.1.0.1. The chemicals considered in the risk evaluation for SWMU 31 include 4 metals, antimony, barium, beryllium and selenium in groundwater. Volatiles, semivolatiles, and explosive constituents were not included in the analytical program for groundwater at this SWMU.

8.7.1.0.2. Subsurface soil samples were collected during well drilling activities; however, the metals detected in these samples were either not detected or were below 10 feet in depth. Sediment samples were also collected from the settling lagoons, but these were collected for disposal classification purposes and the results are not quantifiable for risk assessment purposes.

8.7.1.1 Comparison to ARARs and TBCs for Groundwater

8.7.1.1.1. Groundwater in the vicinity of RAAP is not used for drinking water serving more than 25 people and therefore MCLs and MCLGs are not considered as ARARs for SWMU 31. TBC criteria considered for human health risk evaluation included reference doses (RfDs) and slope factors (SFs) from USEPA's Integrated Risk Information System and Health Effects Assessment Summary Table (USEPA, 1995a).

8.7.2 Exposure Assessment

8.7.2.1 Potential Pathways and Receptors

8.7.2.1.1. Current exposure pathways at SWMU 31 are considered to have a low probability of completion and therefore, these scenarios were not quantified for current receptors (site workers, recreational surface water users, hunters and fishermen). Although current site workers have access to potentially contaminated sediments and surface waters from the settling lagoons, contaminant concentrations are unknown and therefore human health risk is not quantifiable. SWMU 31 is completely contained within RAAP property which effectively limits public access (recreational surface water users and fishermen) to potential contaminants. Surface soil samples were not appropriate at this SWMU because the potential contamination results from chemicals migrating from the lagoons to subsurface soils and groundwater. In addition, the current groundwater pathway is not complete as this water is not used for drinking purposes. Potential future routes of human exposure which were considered for SWMU 31 include site worker ingestion and dermal exposure to potentially contaminated groundwater. However, this exposure scenario is expected to have a low probability of completion due to present drinking water use. Future pathways for subsurface soil have a high probability of completion if this area were to undergo future development; however, contaminants detected in this medium were below the upper 95% tolerance limits established through background sampling and therefore were not included for evaluation.

8.7.2.1.2. The conceptual site model summary for SWMU 31 is presented in Figure 8.6 and includes exposure routes, potential receptors and the medium containing the potential contaminants of concern. All chemicals not eliminated by data validation and background screening were considered in the risk assessment for this SWMU.

8.7.2.2 Exposure Point Concentrations and Chronic Daily Intakes

8.7.2.2.1. Exposure point concentrations for the three metals evaluated at SWMU 31 are listed in the tables in Appendix I. These concentrations range from 0.00161 mg/L (beryllium) to 0.0432 mg/L (barium).

8.7.3 Risk Characterization

8.7.3.0.1. The carcinogenic risk and hazard index were calculated for the groundwater ingestion and dermal contact pathways. These calculations are presented in Appendix I. A discussion of the results of each pathway for non-carcinogenic and carcinogenic effects is presented below.

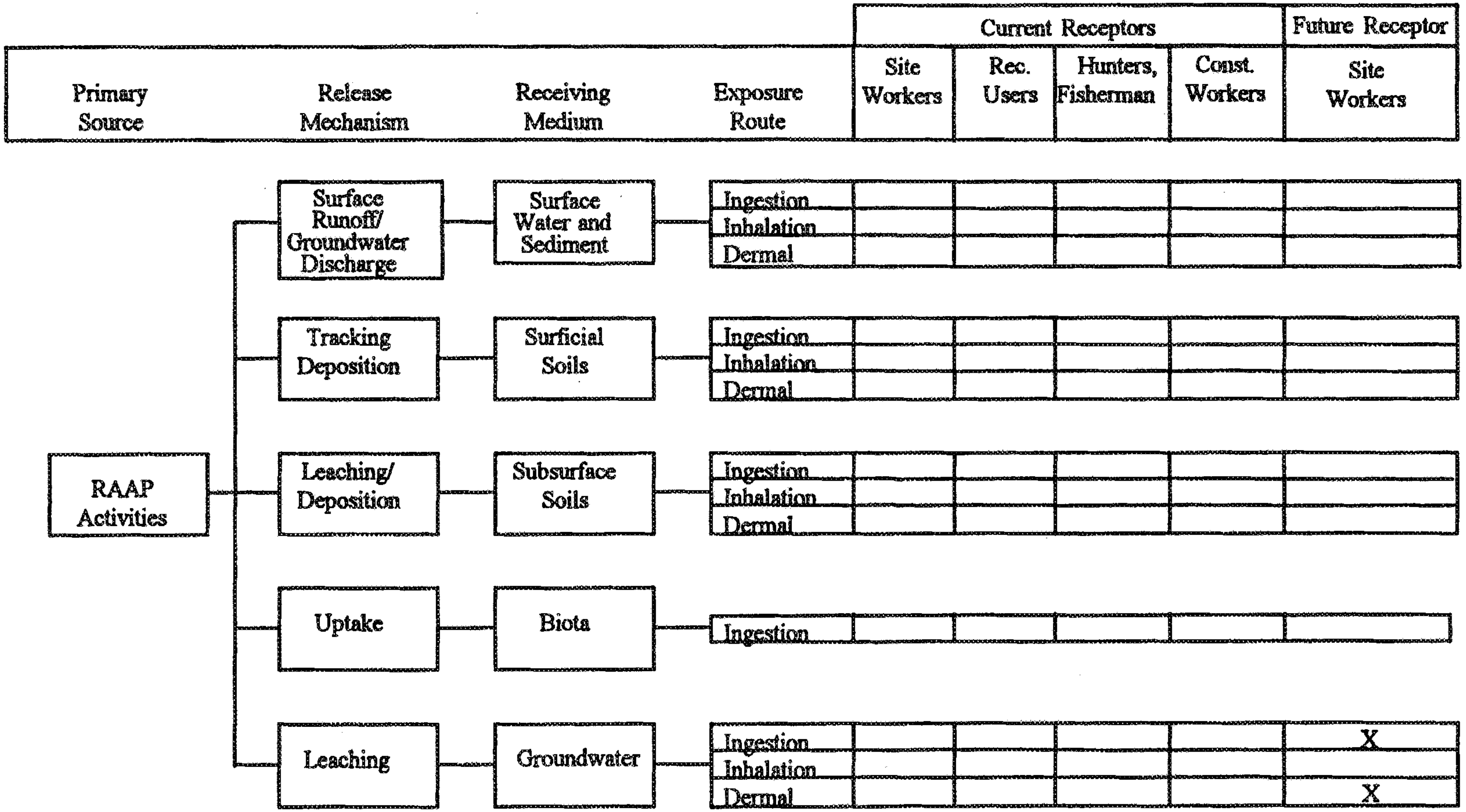
8.7.3.1 Non-carcinogenic Effects

8.7.3.1.1. Hazard indices for the hypothetical future site worker ingestion scenario exceed acceptable levels primarily due to antimony for RME receptors. The calculated hazard index is 1.03. Barium, beryllium and selenium hazard indices are at least two orders of magnitude below acceptable levels.

8.7.3.2 Carcinogenic Effects

8.7.3.2.1. The calculated cancer risks for the hypothetical future site worker ingestion and dermal contact scenario are within the USEPA target risk range primarily due to beryllium, for CT and RME receptors. The other metals evaluated do not show a cancer risk which is due to a lack of toxicity information. The CT and RME ingestion cancer risks for beryllium are 1.21×10^{-6} and 2.42×10^{-5}, respectively. Calculated dermal cancer risks for beryllium for CT and RME receptors are 5.50×10^{-7} and 1.10×10^{-5}, respectively.

Figure 8.6
Conceptual Site Model for Current and Future Exposure Pathways
SWMU 31
Radford Army Ammunition Plant
Radford, Virginia



				Current Receptors				Future Receptor
Primary Source	Release Mechanism	Receiving Medium	Exposure Route	Site Workers	Rec. Users	Hunters, Fisherman	Const. Workers	Site Workers
RAAP Activities	Surface Runoff/ Groundwater Discharge	Surface Water and Sediment	Ingestion					
			Inhalation					
			Dermal					
	Tracking Deposition	Surficial Soils	Ingestion					
			Inhalation					
			Dermal					
	Leaching/ Deposition	Subsurface Soils	Ingestion					
			Inhalation					
			Dermal					
	Uptake	Biota	Ingestion					
	Leaching	Groundwater	Ingestion					X
			Inhalation					
			Dermal					X

X = Pathways of potential concern
H = Hunter scenario

8.7.4 Uncertainty Analysis

8.7.4.0.1. Data collection/evaluation uncertainty may be relevant at SWMU 31 due to the types and numbers of samples collected. Analyses performed on the surface water and sediment samples from the settling lagoons only included total organic carbon and waste characterization. These analyses do not yield results that are usable for risk assessment purposes. Therefore, current site worker risks from potential contamination through exposure to lagoon surface water and sediments are not quantifiable and unknown.

8.7.4.0.2. Some of the metals detected at this site in groundwater are naturally occurring and in some cases, statistical methods were used to distinguish site-related from non-site-related metals. In this case, all metals detected in groundwater were retained as if they were site-related. The calculations have shown to present unacceptable risks due to these metals and this could be an overestimate due to natural metals concentration in groundwater.

8.7.4.0.3. One of the main areas of uncertainty is in exposure assessment as relates to determining future land uses at a contaminated site. The majority of the land at RAAP is commercial or industrial and used for support of the explosives manufacturing process, with few scattered residential communities located in Montgomery and Pulaski counties. Access to the SWMU 31 is restricted and therefore the use of a current residential exposure scenario is unlikely.

8.7.4.0.4. Another area of uncertainty in evaluating human health risk from SWMU 31 is toxicity assessment. Oral and dermal slope factors are not available for three of the four metals which were detected in groundwater. Most studies are based on animal data and extrapolated to humans and also subchronic studies may be used assess chronic effects. In addition, extrapolations are characterized by uncertainty factors which can be as large as four orders of magnitude. This may tend to over- or underestimate risk.

8.8 RISK SUMMARY

8.8.0.1. Carcinogenic risks and non-carcinogenic hazard indices were calculated for site worker receptors potentially exposed to multiple chemicals in groundwater during domestic use. The groundwater pathway calculations were summarized and are presented in

Table 8.7. Under the NCP, the probability of excess cancers over a lifetime of exposure within or below USEPA's target risk range of 1×10^{-4} to 1×10^{-6} are considered to pose a low threat while a probability of excess cancers over a lifetime of exposures greater than 1×10^{-4} may pose an unacceptable threat of adverse health effects. For noncarcinogens, a hazard index below one is considered to pose a low threat of adverse health effects, while a hazard index greater than one may pose an unacceptable threat of adverse health effects.

8.8.0.2. At SWMU 31, the site worker RME receptors' total hazard index is greater than one for ingestion of groundwater. The total cancer risk value for these scenarios is within the target risk range. These values indicate a potential for noncarcinogenic and carcinogenic adverse human health effects.

8.9 SWMU 31 SUMMARY

8.9.0.1. The groundwater associated with SWMU 31 resides in the alluvial sediments overlying the limestone bedrock. The groundwater is approximately at the same elevation as the bottoms of the coal ash settling lagoons; flow direction is toward the New River. Groundwater, subsurface soils, and lagoon sediment samples were collected to characterize SWMU 31. Additionally, a surface water and sediment sample was taken from the New River at the likely discharge point of groundwater from beneath the SWMU.

8.9.0.2. Eight metals were detected in the subsurface soil samples, but concentrations were less than the established background levels for B and C horizon soils in this area. Beryllium and antimony were identified as the risk driver compounds for SWMU 31 groundwater. The lagoon sediments were only sampled for TCLP parameters. However, the previous Dames & Moore characterization sampling found beryllium at significant levels (groundwater risk driver). The lagoon sediments were within regulatory limits for all TCLP parameters. Metals found in the SWMU 31 subsurface soils and groundwater were also detected in the surface water and sediment sample collected downstream of the SWMU in the New River.

Table 8.7
Summary of Human Health Risk
SWMU 31
Radford Army Ammunition Plant

Receptor	Pathways	HI		Cancer Risk	
		CT	RME	CT	RME
Site Worker	Ingestion of Groundwater	0.26	1.05	1.21E-06	2.42E-05
	Dermal Contact with Groundwater	0.12	0.47	5.50E-07	1.10E-05
Total for Site Workers		0.38	1.52	1.76E-06	3.52E-05

SECTION 9

SITE CHARACTERIZATION OF SWMU 48 (OILY WASTEWATER DISPOSAL AREA)

9.1 HISTORY AND OPERATIONS

9.1.0.1. The Oily Wastewater Disposal Area (SWMU 48) is located in the RAAP Horseshoe Area, approximately 3,600 feet east of the main bridge over the New River. Plate 1 shows SWMU 48 in relation to the rest of the facility. A detailed location map of SWMU 48 is presented as Figure 9.1. The USEPA reported this unit as contiguous to SWMU 59 (Bottom Ash Pile) and SWMU 50 (Calcium Sulfate Disposal Area), with no distinction possible by visual observation (USEPA, 1987). However, based on a review of historical aerial photographs and discussions with plant personnel, it has been determined that the unit consists of two separate disposal areas. The northern (upper) disposal area is a long, narrow raised mound approximately 30 feet north of SWMU 50 and 75 feet west of SWMU 59. The southern (lower) disposal area is substantially smaller and is located approximately 30 feet south of SWMU 59 and 75 feet east of SWMU 50.

9.1.0.2. Between approximately 1975 and 1985, prior to off-post waste oil reclamation procedures, oily wastewaters removed from oil/water separators throughout RAAP were disposed at SWMU 48. Trenches the width of a bulldozer were excavated. The oily wastewater was disposed in these trenches and then the trenches were backfilled with soil and revegetated. Each new trench was dug adjacent to the previously backfilled trench. Backfill soils consisted of sandy silt or clayey silt soils obtained from either the SWMU 48 area or an onsite borrow site. It is estimated that 200,000 gallons or more of oil-contaminated wastewater was disposed of in unlined trenches at this unit.

9.2 PREVIOUS INVESTIGATIONS

9.2.0.1. This SWMU was identified in the RCRA Facility Assessment (USEPA, 1987) as having a potential for releasing contaminants into the environment and was included in the RCRA Permit for Corrective Action and Incinerator Operation (USEPA, 1989a) as

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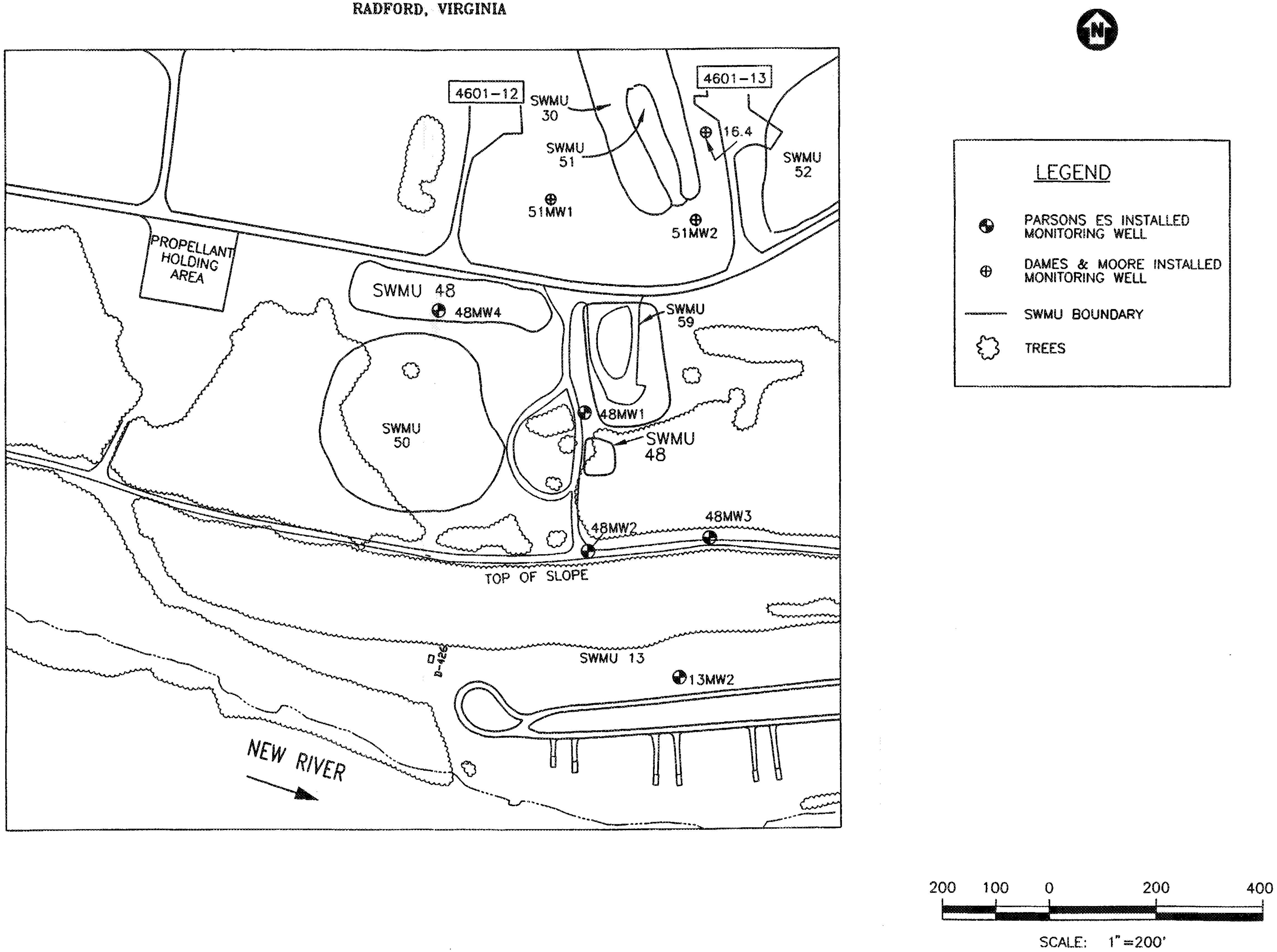
FIGURE 9.1
SWMU 48 LOCATION MAP (OILY WASTEWATER DISPOSAL AREA)

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



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warranting investigation. Subsequently, Dames & Moore conducted a VI in August 1991. No other investigations have been undertaken at this SWMU.

9.2.0.2. During the VI, three soil borings (48SB1, 48SB2, and 48SB3) were installed in the two disposal areas, as shown in Figure 9.2. Samples from borings 48SB1 and 48SB2 were collected at depths of 9.5 and 12 feet, respectively, in soil suspected to be contaminated at the upper disposal area. At both locations, samples were also obtained from soil below the suspected contamination at depths of 14 and 22 feet in 48SB1 and 48SB2, respectively. Only one sample was collected (from 13 feet in depth) from boring 48SB3, which was located in the smaller lower disposal area. This soil sample exhibited a fuel-like odor. The five soil samples collected were analyzed for target analyte list (TAL) metals, toxicity characteristic leaching procedure (TCLP) metals, volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOCs). The results of the 1992 soil sampling are summarized in Table 9.1. Also included in the summary table are HBNs from the RCRA permit (USEPA, 1989a), comparison levels of soil background data calculated by Dames & Moore (1992a), and RBCs for commercial and industrial soils (USEPA, 1994).

9.2.0.3. The results of these chemical analyses indicated the presence of 19 metals. Soil sample concentrations of arsenic, beryllium and cobalt exceeded the HBN criteria, and arsenic and beryllium exceeded the RBC. The concentrations of beryllium, calcium, copper, magnesium, mercury, and sodium exceeded background uplands soil concentrations in at least one sample. Beryllium and sodium were the only inorganics to exceed background concentrations in the underlying soil in 48SB1 and 48SB2. Sodium was found in the method blanks, and beryllium was higher in the lower samples than the upper oily samples. TCLP metal concentrations did not exceed RCRA waste characterization regulatory levels. Explosives were detected in 48SB2 and were the only contaminants of concern, based on HBN criteria; they did not exceed the RBC.

9.2.0.4. VOCs were detected in soil samples collected in boring 48SB2, located in the eastern portion of the upper disposal area, and boring 48SB3, located in the lower disposal area. Ethylbenzene, toluene, and xylenes were detected in sample 48SB3 but toluene was detected at a concentration below the PQL, and the other two compounds were detected at three to five orders of magnitude below the HBN or RBC. Toluene, the only known VOC found in 48SB2, was detected at a concentration equal to the detection limit and below the PQL and was not identified as a concern. Nine VOC tentatively identified

FIGURE 9.2
SWMU 48 SAMPLE LOCATION MAP (OILY WASTEWATER DISPOSAL AREA)

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

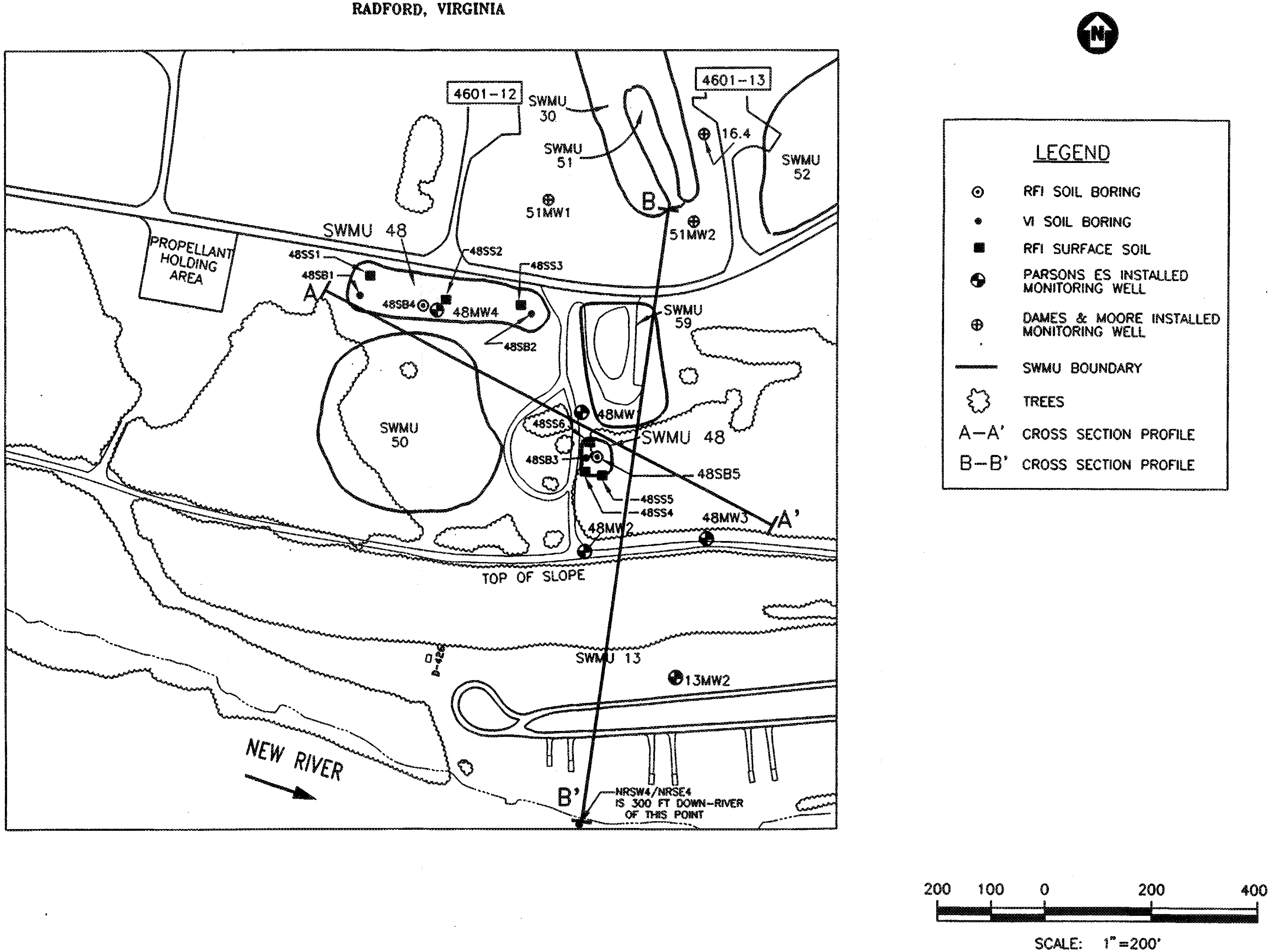

TABLE 9.1
VI DATA 1991
SUMMARY OF ANALYTICAL DATA FOR SOIL SAMPLES COLLECTED AT SWMU 48 RADFORD ARMY AMMUNITION PLANT, VIRGINIA

	PQLs	No. of Samples	Concentration Range 25 Feb 92 - 10 Mar 92 1.0 ft	Upland Soil Background Comparison Level*	HBN	RBC Industrial Soil
TAL Inorganics (µg/g)						
Aluminum	14.1	5	2,940 B - 16,400	22,921	230,000	1,000,000
Arsenic	30	5	LT 0.5 B - [8.19]	9	0.5	1.6
Barium	1	5	32.5 - 70.8	109	1,000	72,000
Beryllium	0.2	5	[0.767] - [4.98]	1.10	0.1	0.67
Calcium	100	5	LT 100 - 240,000	109,994	NSA	NA
Chromium	4	5	7.78 - 31.9	47.46	400	1,000,000**
Cobalt	3	5	[3.01] - [25.7]	27.90	0.8	NA
Copper	7	5	3 B - 135	29.69	2,900	35,000
Iron	1,000	5	8,550 B - 41,600	39,707	NSA	NA
Lead	2	5	LT 10.5 - 154	282.84	200	NA
Magnesium	50	5	751 B - 130,000	45,931	NSA	NA
Manganese	0.275	5	168 B - 547	978	8,000	5,100
Mercury	0.1	5	LT 0.05 - 2.6	0.05	20	310
Nickel	3	5	4.91 - 30.8	37.23	1,000	20,000***
Potassium	37.5	5	327 B - 1,890	3,864	NSA	NA
Silver	4	5	LT 0.589 - 1.03	1.75	200	5,100
Sodium	150	5	315 B - 2,880	313.20	NSA	NA
Vanadium	0.775	5	8.97 - 34.3	73.89	560	7,200
Zinc	30.2	5	23.1 - 71.3	373.56	16,000	310,000
Volatiles (µg/g)						
Ethylbenzene	0.005	5	LT 0.002 - 0.047	NT	1,000	100,000
Toluene	0.005	5	LT 0.001 - 0.003	NT	1,000	200,000
Xylenes	0.005	5	LT 0.002 - 0.252 X	NT	1,000	1,000,000
Volatile TICs (µg/g)						
1,1,3-Trimethylcyclohexane	NA	5	ND - 0.06 S	NT	NSA	NA
Total Unknown TICs	NA	5	ND - (8)0.167	NT	NSA	NA
Semivolatiles (µg/g)						
2-Methylnaphthalene	0.3	5	LT 0.049 - 29.2	NT	NSA	NA
24DNT	0.3	5	LT 0.14 - [3.22]	NT	1	2,000
26DNT	0.3	5	LT 0.085 - [1.22]	NT	1.03	1,000
bis(2-Ethylhexyl)phthalate	0.3	5	LT 0.62 - 1.02	NT	50	200
di-n-Butylphthalate	0.3	5	LT 0.061 - 2.94	NT	1,000	100,000
Fluorene	0.3	5	LT 0.033 - 8.49	NT	3,200	41,000
Naphthalene	0.3	5	LT 0.037 - 5.64	NT	1,000	41,000
Phenanthrene	0.5	5	LT 0.033 - 10	NT	40	NA
Pyrene	0.3	5	LT 0.033 - 0.318	NT	1,000	31,000

TABLE 9.1 (CONTINUED)
VI DATA 1991
SUMMARY OF ANALYTICAL DATA
FOR SOIL SAMPLES COLLECTED AT SWMU 48
RADFORD ARMY AMMUNITION PLANT, VIRGINIA

	PQLs	No. of Samples	Concentration Range 25 Feb 92 - 10 Mar 92 1.0 ft	Upland Soil Background Comparison Level*	HBN	RBC Industrial Soil
Semivolatile TICs (µg/g)						
2,6,10,14-Tetramethylpentadecane	NA	5	ND - 169 S	NT	NSA	NA
Eicosane	NA	5	ND - 96.9 S	NT	NSA	NA
Heptadecane	NA	5	ND - 218 S	NT	NSA	NA
Hexadecane	NA	5	ND - 218 S	NT	NSA	NA
Nonadecane	NA	5	ND - 145 S	NT	NSA	NA
Octadecane	NA	5	ND - 169 S	NT	NSA	NA
Tetradecane	NA	5	ND - 242 S	NT	NSA	NA
Tridecane	NA	5	ND - 218 S	NT	NSA	NA
Total Unknown TICs	NA	5	ND - (15)1,137	NT	NSA	
TCLP Metals (µg/L)						
Barium	20	5	131 - 485	NT	100,000	
Lead	10	5	LT 18.6 - 149	NT	5,000	

*	Upland soil samples were collected from 5 locations at RAAP. The mean and standard deviations were calculated. Background comparison levels were selected from the upper 95 percent confidence interval of the background data set, which is equal to the mean plus two standard deviations.
**	Chromium II and compounds.
***	Nickel (soluble salts).
B	Analyte was detected in corresponding method blank; values are flagged if the sample concentration is less than 10 times the method blank concentration for common laboratory constituents and 5 times for all other constituents.
HBN	Health-based number as defined in the RCRA permit. HBNs not specified in the permit were derived using standard exposure and intake assumptions consistent with EPA guidelines (51 Federal Register 33992, 34006, 34014, and 34028).
LT	Concentration is reported as less than the certified reporting limit.
NA	Not available; PQLs are not available for TICs detected in the library scans.
ND	Analyte was not detected.
NSA	No standard (HBN) available; health effects data were not available for the calculation of a HBN. HBNs were not derived for TICs.
NT	Not tested.
PQL	Practical quantitation limit; the lowest concentration that can be reliably detected at a defined level of precision for a given analytical method.
S	Results are based on an internal standard; flag is used for TICs detected in library scans.
TAL	Target analyte list.
TICs	Tentatively identified compounds that were detected in the GC/MS library scans.
TCLP	Toxicity Characteristic Leaching Procedure
µg/g	Micrograms per gram.
µg/L	Micrograms per liter.
X	Analyte recovery is outside of the certified range, but within acceptable limits such that a dilution is not warranted.
( )	Parentheses are used to indicate the number of unknown TICs that were detected in either the volatile or semivolatile GC/MS library scans. The number beside the parentheses is the total concentration of all TICs detected in each respective scan.
[ ]	Brackets indicate that the detected concentration exceeds the HBN or RBC.

From Dames & Moore, 1992b

compounds (TICs) were detected in sample 48SB3, but with a total concentration less than 0.23 μg/g. Two VOC TICs at a concentration less than 0.04μg/g and one VOC TIC detected at 0.009 μg/g also was found in the deeper 48SB1 sample and the shallow 48SB2 sample, respectively.

9.2.0.5. Trace concentrations of petroleum-related SVOCs were detected at the upper disposal area, but were below HBN or RBC criteria and limited to 48SB2 at a depth of 12 feet. The SVOCs and explosives were present only in the shallower of the two samples collected from each boring in the upper disposal area. Moderate levels of petroleum-related SVOC TICs were found in the soil sample 48SB3 at a depth of 13 feet.

9.2.0.6. A subsurface soil gas survey was performed on a 100-foot by 100-foot grid (50-foot intervals) around the lower disposal area. A total of eight samples, from a depth of 4 feet, were all below detection limits for pentane, methyl tertiary butyl ether (MTBE), benzene, toluene, ethylbenzene, and xylenes, except for one sample. This sample had a concentration of total volatile compounds slightly above the detection limit of 1.1 μg/L.

9.3 SUMMARY OF RFI FIELD ACTIVITIES

9.3.0.1. The RFI was undertaken at SWMU 48 to determine the source and extent of the contamination beneath the lower disposal area and to address any impact on groundwater quality, and to further assess the possible presence of oily waste and explosive contamination in the upper disposal area. To support the RFI objectives, two soil borings and four monitoring wells were installed, and six surface soil samples were collected. Locations are shown in Figure 9.2.

9.3.0.2. One soil boring was placed in the center of each of the disposal areas. Two soil samples from each boring were collected (deep and shallow). A composite soil sample from each boring was collected for disposal characterization. Three groundwater monitoring wells were placed around the lower disposal area; one was installed in the center of the upper disposal area (next to the boring). Two soil samples were collected from each of the well borings associated with the lower disposal area wells. A total of three geotechnical samples were collected from the soil or well borings, as shown in Table 4.5. Six surface soil samples were taken, three from each disposal area.

9.3.0.3. Groundwater samples were collected from all four monitoring wells. Field measurements of the groundwater were also recorded. Slug insertion and removal aquifier tests were performed on the three lower disposal area monitoring wells. All wells were surveyed for elevation and location coordinates. Additionally, the two soil borings were surveyed for elevations. All field activities were completed in January 1995, with the exception of 48MW4 (the upper disposal area well) which was installed and sampled in July 1995. The analytical parameters for all of these samples are indicated in Tables 4.3 and 4.4. A summary of these field activities is presented in Table 9.2.

9.4 ENVIRONMENTAL SETTING

9.4.1 Topography and Site Layout

9.4.1.1. SWMU 48 is situated in a cluster of SWMUs in the eastern Horseshoe Area of the facility. SWMUs in this general vicinity include SWMUs 50, 59, 51, 30, 16, 52, 27, 28, 29, and 53. SWMU 50, which is contiguous to both SWMU 48 disposal areas, is located to the south and west of the upper and lower disposal areas, respectively. Similarly, SWMU 59 is located contiguously to the east and north of the upper and lower disposal areas, respectively.

9.4.1.2. The SWMU 48 area is generally flat, sitting on a high bluff overlooking SWMU 13 and the New River. The approximate elevation of the SWMU is 1,820 feet above mean sea level. The New River is approximately 120 feet below this level. There are few buildings in the vicinity; the surroundings are undeveloped grasslands or woodlands. An asphalt road runs east-west to the north of the SWMU. A dirt road leading south from this road runs between the upper and lower disposal areas.

9.4.1.3. The upper disposal area is approximately 350 feet long by 100 feet wide. It is mounded so that it is 10-15 feet higher than the lower mound. The lower mound is approximately 75 feet long by 50 feet wide, although the exact dimensions are not known.

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TABLE 9.2

SUMMARY OF SWMU 48 RFI FIELD ACTIVITIES
RADFORD ARMY AMMUNITION PLANT

SWMU	Monitoring Wells Installed and Sampled*	Soil Boring Samples	Depth (Feet Below Ground Surface)	Well-Boring Samples	Depth (Feet Below Ground Surface)	Geotechnical Samples/Depth	Surface Soil Samples	Slug Tests
48	48MW1	48SB4A11	10-11	48MW1A22	20-22	48MW2 (40-42)	48SS1	48MW1
	48MW2	48SB4B21	20-21	48MW1B54	52-54	48MW3 (10-12)	48SS2	48MW2
	48MW3	48SB4	Composite	48MW2A42	40-42	48SB5 (10-11)	48SS3	48MW3
	48MW4	48SB5A19	17-19	48MW2B46	44-46		48SS4	
		48SB5B37	35-37	48MW3A22	20-22		48SS5	
		48SB5	Composite	48MW3B32	30-32		48SS6	
							48SS8 (Dup. Of 48SS2)	

* Field measurements of pH, temperature, and conductivity were also recorded.

9.4.2 Geology

9.4.2.1. The geology of SWMU 48 was characterized by drilling four monitoring wells and two soil borings for the RFI. Additionally, data collected by Dames & Moore from three soil borings installed for the verification investigation (VI) supplemented the geological characterization. Samples were either collected continuously or at five foot intervals in each boring as described in section 4. The vertical extent of all investigatory drilling activities for the RFI was approximately 152 feet, ranging from 1830 feet above mean sea level (amsl) to 1678 feet amsl.

9.4.2.2. All geological samples were categorized under the Unified Soil Classification System (USCS) in accordance with the work plan. One sample was taken from each of three borings (48MW2, 48MW3, and 48SB5) and submitted for laboratory analysis to determine USCS designation. All other samples, including those collected for chemical analysis or general site characterization were given a USCS designation by the project geologist. This information, supplemented by the lithologic logs from the VI, as well as data from various investigations at SWMUs in the vicinity (SWMU 51, SWMU 13), was used to prepare the geologic cross sections presented as Figures 9.3 and 9.4. The cross section profile lines are shown on Figure 9.2. A west to east profile (A-A') was constructed to show the relative locations of the two disposal areas (upper and lower) of SWMU 48, while a north to south profile (B-B') shows SWMU 48 relative to the New River.

9.4.2.3. The geology of the SWMU 48 area was more complex than that of the SWMUs along the New River. The subsurface consisted of unconsolidated alluvium and residual deposits (physically and chemically weathered bedrock) overlying interbedded siltstones, limestones, and dolomites of the Elbrook Formation. The Max Meadows Breccia was evident in outcroppings along the slope leading to the river, however, it was difficult to distinguish during the drilling activities. The tectonic breccia was generally brown-red and highly weathered with many solution cavities (see Table 3.5, reference locality 1, and also Figure 3.6 which is a photograph of the breccia).

9.4.2.4. Geologic cross section A-A' (Figure 9.3) shows the shallow fill of the upper disposal area overlying a red-brown clay and silt layer (CL). Below the fill of the lower disposal area, less clay and more silt and sand was encountered in an orange-brown ML layer. The CL layer coarsened into a red-orange silt and clay (ML) at approximately 1800

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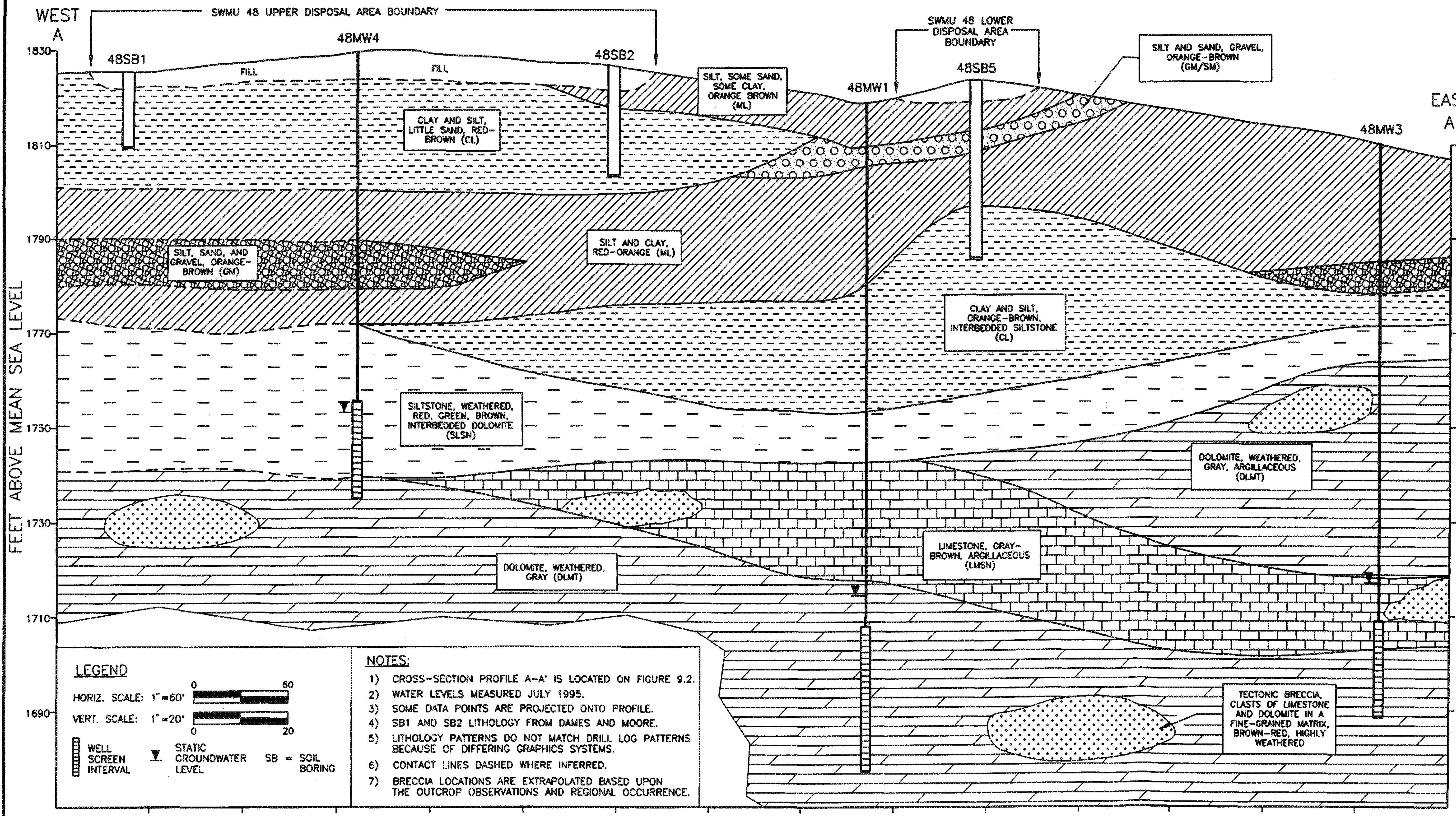
FIGURE 9.3
SWMU 48 CROSS SECTION (A–A')
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



NOTES:

1) CROSS-SECTION PROFILE A-A' IS LOCATED ON FIGURE 9.2.
2) WATER LEVELS MEASURED JULY 1995.
3) SOME DATA POINTS ARE PROJECTED ONTO PROFILE.
4) SB1 AND SB2 LITHOLOGY FROM DAMES AND MOORE.
5) LITHOLOGY PATTERNS DO NOT MATCH DRILL LOG PATTERNS BECAUSE OF DIFFERING GRAPHICS SYSTEMS.
6) CONTACT LINES DASHED WHERE INFERRED.
7) BRECCIA LOCATIONS ARE EXTRAPOLATED BASED UPON THE OUTCROP OBSERVATIONS AND REGIONAL OCCURRENCE.

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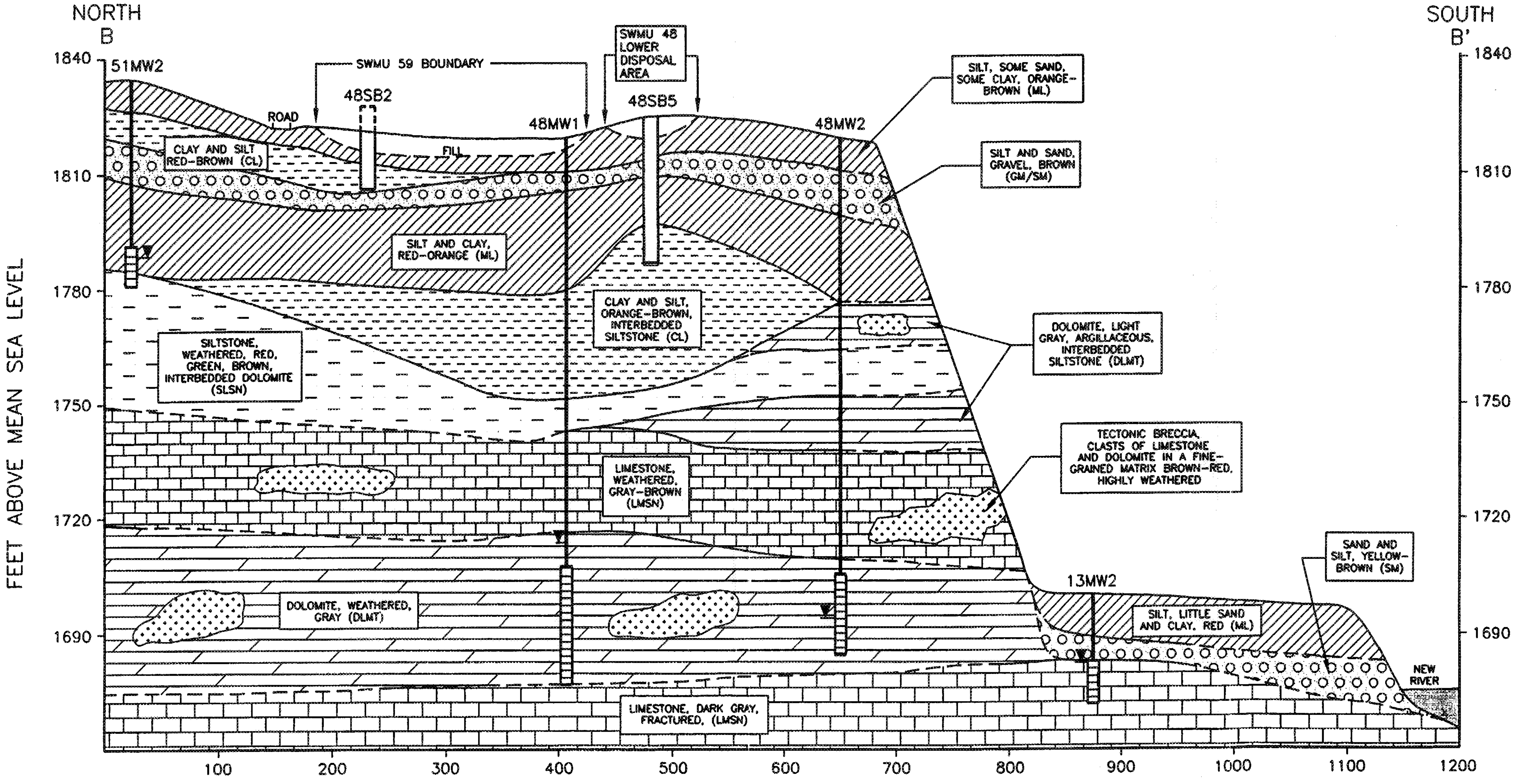
FIGURE 9.4
SWMU 48 CROSS SECTION (B–B')
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



NOTES:

1) CROSS SECTION PROFILE B–B' LOCATED ON FIGURE 9.2.
2) WATER LEVELS MEASURED JULY 1995, EXCEPT FOR 13MW2 (MARCH 1992) WHICH IS PRESENTED FOR RELATIVE COMPARISON ONLY.
3) SOME DATA POINTS ARE PROJECTED ONTO PROFILE.
4) 51MW2 AND 13MW2 LITHOLOGY FROM DAMES AND MOORE.
5) LITHOLOGY PATTERNS DO NOT MATCH DRILL LOG PATTERNS BECAUSE OF DIFFERING GRAPHICS SYSTEMS.
6) CONTACT LINES DASHED WHERE INFERRED.
7) BRECCIA LOCATIONS ARE EXTRAPOLATED BASED UPON THE OUTCROP OBSERVATIONS AND REGIONAL OCCURRENCE.

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feet amsl. The ML layer, which was interbedded with a gravel lens (GM), overlaid a weathered siltstone bedrock beneath the upper disposal area. In the eastern portion of the cross section, the orange-brown ML layer is shown grading into a silt, sand, and gravel layer (GM/SM) before becoming the red-orange silt and clay ML layer found beneath the western portion of the cross section. However, before encountering the weathered siltstone below the lower disposal area, a thick orange-brown clay and silt (CL) layer, interbedded with some siltstone, was found. This CL layer extended to approximately 1755 feet amsl before the siltstone bedrock interface was encountered. The western portion of the cross section shows the bedrock interface at approximately 1770 feet amsl. The siltstone was red-brown-green and contained interbedded dolomite.

9.4.2.5. The siltstone, which is thicker in the western portion of the study area than in the eastern end, overlies a weathered gray dolomite or gray-brown limestone. The limestone was not encountered beneath the upper disposal area (48MW4 boring). Toward the eastern end of the study area, a thick argillaceous dolomite was found above the limestone. Below the limestone, the weathered gray dolomite which was present at approximately 1740 feet amsl in the western end, was encountered at 1705 feet amsl. In general, the bedrock below the study area consisted of interbedded siltstone, limestone, and dolomite, variably hard and soft, moderately to highly weathered, containing numerous fractures, and ranging in color from red-green to brown-gray. Hydrochloric acid testing was performed to distinguish dolomite from limestone.

9.4.2.6. Geologic cross section B-B' (Figure 9.4) is a north to south depiction of strata relative to the New River. The figure generally displays the same trends of overburden and bedrock as the west to east section. However, the 48MW2 well boring shows a lens of dolomite present at a higher elevation than anywhere else in the study area. The slope leading to SWMU 13 was accessible and much of the information concerning the Max Meadows Breccia, fracturing, faulting, and jointing was gathered from studying the outcroppings along the hillside.

9.4.3 Hydrogeology

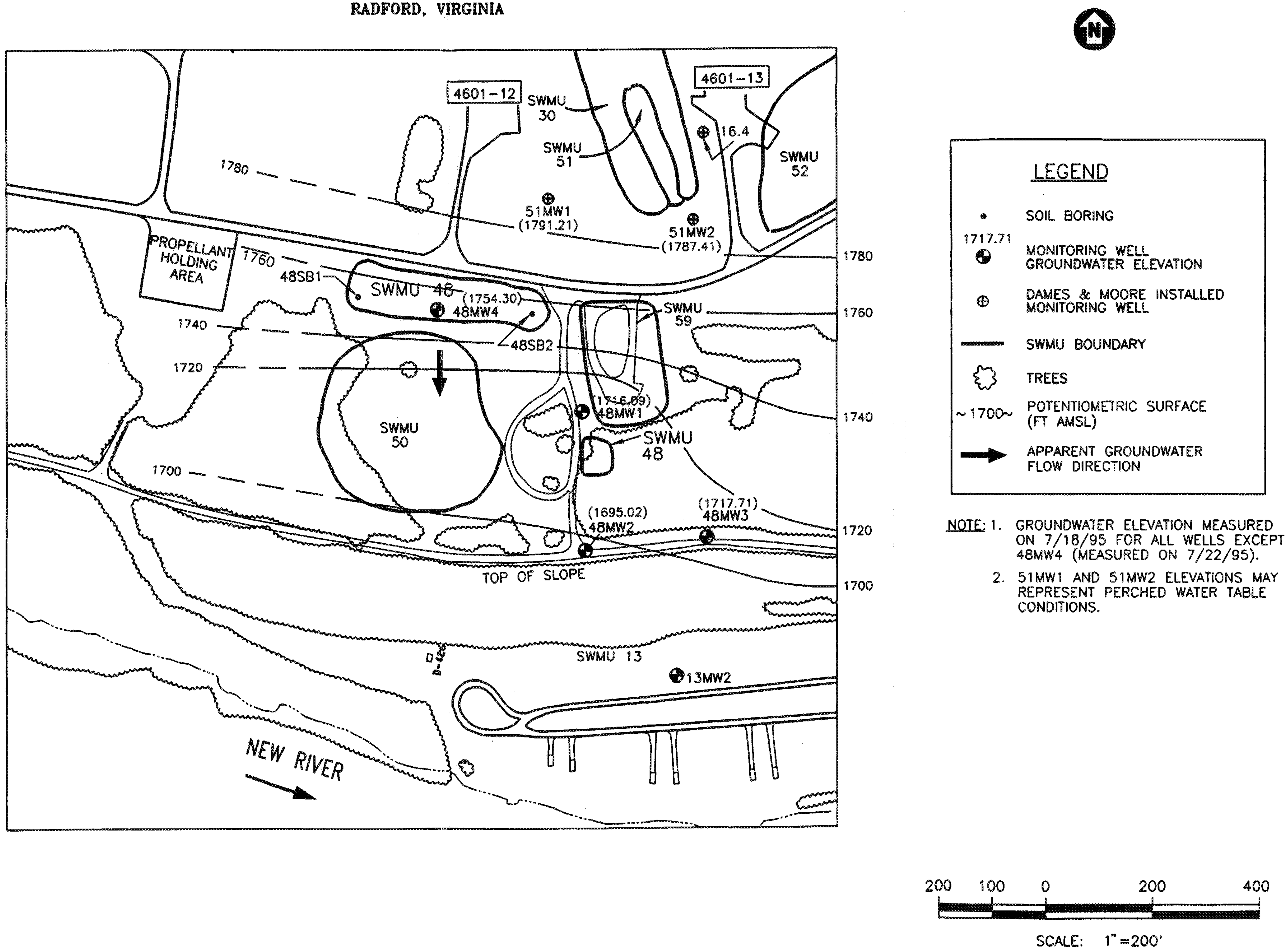
9.4.3.0.1. The four monitoring wells installed at SWMU 48 were screened in the interbedded limestone and dolomite of the Elbrook Formation. 48MW1, 48MW2, and 48MW3 were installed in January 1995; 48MW4 was installed in July 1995. The January wells were screened mostly in the dolomite, while the July well, which encountered groundwater at a higher elevation than the others, was screened mostly in a weathered siltstone interbedded with dolomite. This siltstone section was not as extensive in the vicinity of the January wells. Groundwater occurrence was unpredictable during the drilling activities. Therefore, longer well screens were used in an attempt to position the top of the screen above the stabilized groundwater level. However, due to relatively slow infiltration rates, this was not always possible. Well construction details for the monitoring wells are given in Table 4.1.

9.4.3.0.2. Groundwater occurrence and movement in the vicinity of SWMU 48 is complex. Observations and measurements of the groundwater are consistent with karst subsurface features. The following discussion of the groundwater table is presented to support observations of flow directions and flow rates. Outcroppings of limestone and dolomite along the slope immediately south of SWMU 48 contained numerous solution cavities and fractures that were oriented in various directions. Prominent exposures of the Max Meadows tectonic breccia found along the slope displayed extensive solution cavities forming a sponge-like texture indicative of intergranular dissolution. The breccia may be the site of preferential pathways for groundwater flow due to solutionization. These features demonstrate the complexity of the karst aquifer underlying SWMU 48. A fracture trace connecting several sinkholes has been identified immediately west of SWMU 48 (see Figure 3.10). In the vicinity of SWMU 48 this fracture trace is oriented north to south. A less prominent east to west fracture trace has been identified east of the SWMU. Although these features can have significant impact on groundwater occurrence and movement, within the vertical limits of the drilling activities, no major voids were encountered, and the monitoring wells apparently did not intersect these fractures.

9.4.3.0.3. The potentiometric surface (groundwater table) at SWMU 48 is shown in cross-section in Figures 9.3 and 9.4 and in plan view in Figure 9.5. Field data used to prepare Figure 9.5, photoionization detector (PID) readings of the well headspace in parts

FIGURE 9.5
SWMU 48 GROUNDWATER POTENTIOMETRIC SURFACE MAP

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



NOTE: 1. GROUNDWATER ELEVATION MEASURED ON 7/18/95 FOR ALL WELLS EXCEPT 48MW4 (MEASURED ON 7/22/95).

2. 51MW1 AND 51MW2 ELEVATIONS MAY REPRESENT PERCHED WATER TABLE CONDITIONS.

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per million (ppm), pH, temperature, and conductivity of the groundwater, are summarized in Table 9.3.

9.4.3.0.4. Based on potentiometric surface maps (Figure 9.5 and Plate 2) it appears that the direction of groundwater flow is ultimately toward the New River. The hydraulic gradient as determined from Figure 9.5 is approximately 0.13 ft/ft. However, groundwater occurrence in the vicinity of SWMUs 16, 30, and 51, slightly north of the study area, is not consistent with the bedrock groundwater table found in the SWMU 48 wells. Groundwater in monitoring wells 16-4, 51MW1 and 51MW2 was encountered as much as 70 feet higher in elevation than the SWMU 48 wells. It is possible that this area represents a different groundwater zone and that a perched water table may be present in the sediments overlying the bedrock (although these wells were partially screened in rock). It is likely that this groundwater zone eventually discharges to the New River as well, but the hydraulic relationship between the shallow groundwater and the groundwater measured in the SWMU 48 wells is not completely understood.

9.4.3.1 Aquifer Testing Results

9.4.3.1.1. In order to further investigate the groundwater characteristics at SWMU 48, three falling-head (injection) and one rising-head (withdrawal) slug tests were performed on wells 48MW1 through 48MW3 in January 1995. Wells 48MW1, 48MW2 and 48MW3 intercept groundwater flow through competent limestone and dolomite bedrock. Fracture flow is likely in these wells through fractures from open conduits. The hydraulic conductivity and transmissivity data for SWMU 48 are summarized in Table 9.4; calculations and type curves from the slug test data are located in Appendix E.

9.4.3.1.2. The highest hydraulic conductivity value calculated at SWMU 48 was at well 48MW1 (4.66×10^{-5} cm/sec), and the lowest value was at well 48MW2 (1.48×10^{-6} cm/sec). The average hydraulic conductivity (2.65×10^{-5} cm/sec) calculated at SWMU 48 falls into the range of limestone and dolomite for bedrock groundwater flow (Freeze and Cherry, 1979).

TABLE 9.3
SWMU 48: GROUNDWATER FIELD DATA
RADFORD ARMY AMMUNITION PLANT

Well Name	Date	Depth to Bottom (ft)	Depth to Water (ft)	Groundwater Elevation* (ft)	PID (ppm)	pH	Temperature (degrees F)	Conductivity (us/cm)
48MW1	1-18-95	142.0	117.49	1817.79	0.9	7.88	61.1	0.97
48MW2	1-19-95	135.7	92.71	1817.62	0.3	7.81	51.2	0.96
48MW3	1-19-95	122.3	106.70	1809.96	0.2	8.49	53.3	0.98
48MW4 (1)								
48MW1	7-18-95	142.0	103.86	1716.09	0.0	6.86	NA	5.4
48MW2	7-18-95	135.7	123.86	1695.02	0.0	7.55	77.6	461
48MW3	7-21-95	122.3	94.46	1717.71	0.0	7.72	68.2	532
48MW4	7-27-95	96.1	78.30	1754.30	0.0	7.71	77.9	361

* Feet above mean sea level

(1) 48MW4 was not constructed until July 1995.

NA: No data due to instrument malfunction.

TABLE 9.4

SUMMARY OF SLUG TESTING DATA SWMU 48 (OILY WASTEWATER DISPOSAL AREA)

RADFORD ARMY AMMUNITION PLANT

WELL	TEST DATE	SLUG TEST TYPE	HYDRAULIC CONDUCTIVITY (K) IN:		TRANSMISSIVITY (T) IN FT^2/DAY
			FT/MIN	CM/SEC	
48MW1	1-13-95	Injection/falling-head	9.18×10^{-5}	4.66×10^{-5}	6.60
48MW1	1-13-95	Withdrawal/rising-head	4.11×10^{-5}	2.08×10^{-5}	2.95
48MW2	1-13-95	Injection/falling-head	2.92×10^{-6}	1.48×10^{-6}	0.21
48MW3	1-13-95	Injection/falling-head	7.27×10^{-5}	3.71×10^{-5}	5.25
Average for SWMU 48:			5.21×10^{-5}	2.65×10^{-5}	3.75

9.4.3.1.3. Assuming that the representative water-bearing unit at SWMU 48 is in limestone and dolomite bedrock, the horizontal groundwater flow velocity can be determined by using the Darcy Equation, as discussed in Subsection 8.4.3. The horizontal groundwater flow velocity is calculated by using the average calculated hydraulic conductivity (2.65×10^{-5} cm/sec), the hydraulic gradient (12.5 percent) as measured from Figure 9.4, and the estimated effective porosity (10 percent). The estimated porosity of 10 percent for the bedrock wells is based on a range of porosities typical for limestone and dolomite bedrock (Freeze and Cherry, 1979). By utilizing the Darcy Equation and standard equation of hydraulics ($V=Ki/n$), the estimated groundwater flow velocity at SWMU 48 was calculated to be 3.31×10^{-5} cm/sec or 34.25 ft/yr. This velocity is an estimate only since measurements of the bedrock conductivity will be variable due to irregular water-bearing fractures and solution features. Groundwater flow velocity will be significantly greater where bedrock is highly fractured and contains more solution channels. Estimated groundwater velocity values in karst environments, as found at SWMU 48, should be considered approximations.

9.4.4 Surface Water

9.4.4.1. Based on topography, surface water runoff from SWMU 48 is expected to flow approximately 700 feet southwest to the New River. The New River in this area of the facility is relatively shallow and fast-moving with numerous sections of rapids. According to RAAP utility maps, there does not appear to be any manholes, catch basins, or storm drains located in the immediate vicinity of SWMU 48.

9.5 NATURE AND EXTENT OF CONTAMINATION

9.5.0.1. A summary of all positive results (detected compounds) for soil and aqueous samples collected at SWMU 48 is presented in Tables 9.5 and 9.6, respectively. The chemicals of concern (COCs) for SWMU 48 were determined in accordance with the methods described in Section 6. The focus of this section is on the COCs identified as potential human health threats as detailed in the subsequent Risk Assessment subsections.

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TABLE 9.5
POSITIVE RESULTS TABLE OF SWMU 48 - Solid Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	48MW1A22	48MW1B54	48MW2A42	48MW2B46	48MW3A22	48MW3B32	48SB4A11
METALS (ug/g)							
Arsenic							
Selenium							
Lead							
Silver							
Barium							
Beryllium							
Chromium							
Nickel							
Mercury							
SEMIVOLATILES (ug/g)							
50 Bis(2-ethylhexyl) phthalate	8.14	7.17	1.96		3.77	2.49	3.57
Chrysene							
1000 Di-n-butyl phthalate					2.31		
Naphthalene / Tar camphor							
100 N-Nitrosodiphenylamine							1.79
Phenanthrene							
1000 Phenol			0.14				
Pyrene							
OTHER							
Total Organic Carbon (ug/g)		1353.18		39281.80		1243.78	
Total Petroleum Hydrocarbons (ug/g)							
pH							

TABLE 9.5
POSITIVE RESULTS TABLE OF SWMU 48 - Solid Samples
RADFORD ARMY AMMUNITION PLANT

	Field Sample Number	48SB4B21	48SB5A19	48SB5B37	48SS1	48SS2	48SS3	48SS4
	METALS (ug/g)							
0.5	Arsenic				4.53 J4	9.78 J4		4.35 J4
200	Selenium							0.79 J4
200	Lead				5.83 J6	196.32 J6	20.88 J6	25.53 J6
200	Silver					0.03 J4	0.03 J4	0.03 J4
1000	Barium				757.62 J1	100.98 J1	125.29 J1	135.39 J1
0.1	Beryllium				2.15 J4	0.91 J4	1.01 J4	
400	Chromium				7.07 J6	58.65 J6	28.19 J6	17.10 J6
200	Nickel				11.83 J4	31.17 J4	7.11 J4	7.17 J4
20	Mercury				1.47 J4	0.54 J4		0.59 J4
	SEMIVOLATILES (ug/g)							
	Bis(2-ethylhexyl) phthalate	4.35	48.60	12.33	1.99	1.60		
	Chrysene				0.11			0.09
	Di-n-butyl phthalate	7.26				12.27		
	Naphthalene / Tar camphor		24.30					
	N-Nitrosodiphenylamine	2.06						
	Phenanthrene		12.15		0.36			0.37
	Phenol							
	Pyrene		0.97					
	OTHER							
	Total Organic Carbon (ug/g)	1209.19		1233.05				
	Total Petroleum Hydrocarbons (ug/g)		4337.79					14.25
	pH							

TABLE 9.5
POSITIVE RESULTS TABLE OF SWMU 48 - Solid Samples
RADFORD ARMY AMMUNITION PLANT

	Field Sample Number	48SS5	48SS6	48SS8*
	METALS (ug/g)			
0.5	Arsenic		4.46 J4	4.76 J4
200	Selenium			0.78 J4
200	Lead	27.19 J6	16.49 J6	38.55 J6
200	Silver		0.03 J4	0.02 J4
1000	Barium	66.63 J1	139.18 J1	110.72 J1
0.1	Beryllium	0.77 J4	0.87 J4	1.31 J4
400	Chromium	37.45 J6	18.60 J6	37.59 J6
200	Nickel	12.73 J4	6.75 J4	14.22 J4
20	Mercury	0.13 J4		0.39 J4
	SEMIVOLATILES (ug/g)			
	Bis(2-ethylhexyl) phthalate		1.40	1.57
	Chrysene		0.08	0.09
	Di-n-butyl phthalate			8.55
	Naphthalene / Tar camphor			
	N-Nitrosodiphenylamine			
	Phenanthrene		0.33	
	Phenol			
	Pyrene			
	OTHER			
	Total Organic Carbon (ug/g)			16747.00
	Total Petroleum Hydrocarbons (ug/g)	414.09		
	pH			

* 48SS8 is a duplicate sample of 48SS2

TABLE 9.6
POSITIVE RESULTS TABLE OF SWMU 48 - Aqueous Samples
RADFORD ARMY AMMUNITION PLANT

	Field Sample Number	48MW1	48MW1 Dissolved	48MW2	48MW2 Dissolved	48MW3	48MW3 Dissolved	48MW4	48MW4 Dissolved	48MWTB	48MWTB2
	METALS (ug/l)										
200	Lead			9.29				12.40			
200	Selenium	2.72									
1000	Barium	81.00	69.70	1070.00	816.00	70.70	69.80	299.00	295.00		
0.1	Beryllium	4.16	4.05	10.70	2.69						
400	Chromium			42.80							
	VOLATILES (ug/l)										
10000	1,1,1-Trichloroethane	4.10		0.98							
10	1,1-Dichloroethene	1.10									
8	1,1-Dichloroethane	2.30									
1000	Acetone									40.00	54.00
50	Carbon tetrachloride			92.00		100.00					
90	Methylene chloride			1.10						2.90	2.60
100	Chloroform			6.70		30.00					
100	Tetrachloroethylene	1.20									
66	Trichloroethylene	17.00		11.00		37.00					
	SEMIVOLATILES (ug/l)										
60	Bis(2-ethylhexyl) phthalate			12.00		23.00					
	OTHER (ug/l)										
	Total Hardness	445000		268000		368000					
	Chemical Oxygen Demand	10000.00		41200.00		10000.00					
	Total Organic Carbon			2620.00		1610.00					
	Total Petroleum Hydrocarbons	143.00		480.00		247.00					
	Total Organic Halogens	13.7		33.6		178					
	Chloride	9300		5480		2990					

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9.5.1 Nature of Contamination

9.5.1.1 Surface Soils

9.5.1.1.1. Thirteen COCs were identified in the surface soils at SWMU 48, including arsenic, barium, beryllium, chromium (as chromium III), lead, mercury, nickel, selenium, silver, and the semivolatile compounds (SVOCs), bis (2-ethyl hexyl) phalate, chrysene, di-n-butyl phthalate, and phenanthrene. Of these, arsenic and beryllium were found at concentrations considered to be a potential human health risk. Arsenic and beryllium were also considered to be the risk drivers for surface soils at SWMU 48.

9.5.1.1.2. Arsenic was detected in four of the six surface soil samples at SWMU 48, ranging in concentration from 4.35 ug/g in 48SS4 to 9.78 ug/g in 48SS2. Beryllium was detected in five surface soil samples, ranging in concentration from 0.77 ug/g in 48SS5 to 2.15 ug/g in 48SS1. Only one sample (48SS2) had a detected arsenic value greater than the background level for arsenic, which was established at 9.00 ug/g by Dames & Moore for upland soils (Table 9.1).

9.5.1.1.3. The four semivolatile compounds detected in surface soils at SWMU 48 were considered COCs. However, none of these was found at levels considered to pose a human health threat. Bis (2-ethyl hexyl) phalate was detected at three surface soil sampling locations ranging in concentration from 1.40 ug/g to 1.99 ug/g. Chrysene was detected at three surface soil sampling locations with all concentrations less than or equal to 0.11 ug/g. Di-n-butyl phthalate was only detected at 48SS2 at a concentration of 12.27 ug/g. Phenanthrene was detected at three surface soil sampling locations with all concentrations less than or equal to 0.37 ug/g.

9.5.1.1.4. Other COCs, which were not considered to be a human health threat, included barium, mercury, chromium III, nickel, selenium, lead, and silver. Barium was found in all six surface soil samples, ranging in concentration from 66.63 ug/g in 48SS5 to 757.62 ug/g in 48SS1. Mercury was detected in four surface soil samples, ranging in concentration from 0.13 ug/g in 48SS5 to 1.47 ug/g in 48SS1. Chromium III was detected in all six surface soil samples, ranging in concentration from 58.65 ug/g in 48SS2 to 7.07 ug/g in 48SS1. Nickel was found in all six surface soil samples, ranging in concentration from 6.75 ug/g in 48SS6 to 31.17 ug/g in 48SS2. However, no samples had nickel concentrations greater than the background level for this metal, which was established at 37.23 ug/g (Dames & Moore, 1992a). Selenium had a maximum detected value of 0.79 ug/g at 48SS4. Lead was detected in all samples, ranging in concentration from 5.83 ug/g in 48SS1 to 196.33 ug/g in 48SS2. Silver was found at concentrations at or below 0.03 ug/g. Although total petroleum hydrocarbons (TPH) were detected at 48SS5 at a concentration of 414.09 ug/g, these compounds were not considered COCs.

9.5.1.2 Subsurface Soils

9.5.1.2.1. Because all the subsurface soil samples from SWMU 48 were collected at depths greater than ten feet bgs, these soils were not considered in the baseline risk assessment presented in Section 6. Therefore, no COCs for the subsurface soils at SWMU 48 have been identified.

9.5.1.2.2. Seven SVOCs and total petroleum hydrocarbons were detected in the subsurface soils at SWMU 48 (Table 9.5). Bis (2-ethyl hexyl) phalate was detected in nine of ten samples, ranging in concentration from 1.96 ug/g in 48MW2A42 to 48.60 ug/g in 48SB5A19. Di-n-butyl phthalate was detected in only two samples, at 2.31 ug/g in 48MW3A22 and at 7.26 ug/g in 48SB4B21. Naphthalene was only detected in 48SB5A19 at 24.30 ug/g. N-nitrosodiphenylamine was detected in only two samples, at 1.79 ug/g in 48SB4A11 and at 2.06 ug/g in 48SB4B21. Phenanthrene was only detected in 48SB5A19 at 12.15 ug/g. Phenol was only detected in 48MW2A42 at 0.14 ug/g. Pyrene was only detected in 48SB5A19 at 0.97 ug/g. TPH was only detected in 48SB5A19 at 4337.79 ug/g. A level of 100 ug/g has been established by the State of Virginia for TPH in soils as a general guideline; TPH action levels are established in accordance with identified risk.

9.5.1.3 Groundwater

9.5.1.3.1. Eleven COCs were identified in the groundwater in SWMU 48. They included barium, beryllium, the SVOC bis(2-ethyl hexyl)phthalate, and the volatile compounds (VOCs) 1,1,1-trichloroethane, 1,1-dichloroethane, 1,1-dichloroethene, carbon tetrachloride, methylene chloride, chloroform, tetrachloroethylene, and trichloroethylene. Of these compounds, beryllium, 1,1-dichloroethene, and carbon tetrachloride were found at concentrations considered to be a potential human health risk. Beryllium and carbon tetrachloride were considered to be the risk drivers for groundwater at SWMU 48.

9.5.1.3.2. Beryllium was detected in two well samples. Dissolved beryllium was detected at concentrations of 4.05 ug/l in 48MW1 and 2.69 ug/l in 48MW2. Carbon tetrachloride was found at relatively high concentrations at two wells, but was not detected in the other two wells at SWMU 48. This compound was detected at a concentration of 92 ug/l in 48MW2 and at 100 ug/l in 48MW3. 1,1-dichloroethene was only detected in 48MW1 at 1.10 ug/l.

9.5.1.3.3. Other COCs in groundwater at SWMU 48 that were not considered to be a potential human health risk include, barium, 1,1,1-trichloroethane, 1,1-dichloroethane, chloroform, methylene chloride, tetrachloroethene, and trichloroethylene. Of these compounds, 1,1-dichloroethane and tetrachloroethylene were only detected in 48MW1 at concentrations less than 2.5 ug/l (Table 9.6). Methylene chloride was only detected in 48MW2, at a concentration of 1.10 ug/l. Trichloroethylene was detected in three of the four well samples at SWMU 48, ranging in concentration from 11 ug/l in 48MW2 to 37 ug/l in 48MW3. 1,1,1-trichloroethane was detected in two wells, at a concentration of 4.10 ug/l in 48MW1 and at 0.98 ug/l in 48MW2. Chloroform was detected in two wells at SWMU 48. Chloroform was detected at a concentration of 6.70 ug/l in 48MW2 and at 30.00 ug/l in 48MW3. Barium was detected in all four well samples. The maximum dissolved concentration was 816 ug/l, found in the sample from 48MW2. In the remaining samples dissolved barium concentrations ranged from 69.70 ug/l in 48MW1 to 295 ug/l in 48MW4. Bis(2-ethyl hexyl)phthalate was detected in 48MW2 and 48MW3. Positive results for groundwater samples at SWMU 48 that were not COCs include the unfiltered (total) metals lead, selenium, and chromium.

9.5.2 Extent of Contamination

9.5.2.1 Surface Soils

9.5.2.1.1. All six surface soil samples at SWMU 48 were collected within the top 0.5 feet of soil. The maximum concentration of arsenic in the surface soils at SWMU 48 (9.78 ug/g) was found in 48SS2. This sample was collected at the center of the mound which makes up the upper disposal area. Approximately 150 feet west of that sampling location, within the upper disposal area, the next highest concentration of arsenic was found, 4.53 ug/g in 48SS1. The other two sampling locations at which arsenic was detected were 48SS4 and 48SS6, both located along the perimeter of the lower disposal area at SWMU 48. These samples had detected arsenic concentrations of slightly less than 4.5 ug/g.

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9.5.2.1.2. Several of the COC metals for surface soils at SWMU 48 (barium, beryllium, and mercury) were detected at their maximum concentrations in sample 48SS1. The concentration of these three metals in 48SS1 were at least twice as high as the concentrations detected at any of the other surface soil sampling localities. Barium was detected in all the surface samples collected. The concentration of barium at 48SS1 was 757.62 ug/g; it ranged in concentration from 66.63 ug/g to 139.18 ug/g for all other sampling locations. Beryllium, the other risk driver metal, was detected in all the surface samples collected except 48SS4. The concentration of beryllium at 48SS1 was 2.15 ug/g, while it was detected at a concentration of approximately 1.00 ug/g or less for all other sampling locations. Mercury was detected in all the surface samples collected except 48SS3 and 48SS6. The concentration of mercury at 48SS1 was 1.47 ug/g; it ranged in concentration from 0.13 ug/g to 0.59 ug/g for all other sampling locations.

9.5.2.1.3. In general, all of the metals of primary concern were detected at 48SS1 and 48SS2, located in the western and central regions of the upper disposal area,respectively. The most significant results were in the samples from 48SS1. Neither arsenic or mercury was detected in the surface soil sample from the eastern region of the upper disposal area (48SS3). The surface soil samples from the lower disposal area (48SS4, 48SS5, and 48SS6) showed less contamination than those from the upper area. Sample 48SS4 displayed the most significant contamination in the lower area, having relatively high levels of arsenic, barium and mercury.

9.5.2.2 Subsurface Soils

9.5.2.2.1. Seven SVOCs and total petroleum hydrocarbons were detected in the subsurface soils at SWMU 48. Of these eight compounds, four were only detected in sample 48SB5A19. These compounds include naphthalene, phenanthrene, pyrene, and total petroleum hydrocarbons. Bis (2-ethyl hexyl) phalate was detected in 9 of the 10 subsurface soil samples at SWMU 48; however, the maximum concentration (48.60 ug/g) was also observed in 48SB5A19. The next two highest detected concentrations of bis (2-ethyl hexyl) phalate (8.14 ug/g and 7.17 ug/g) were observed in the two samples from soil boring 48MW1, 48MW1A22 and 48MW1B54, respectively. N-nitrosodiphenylamine was detected at the maximum concentration (2.06 ug/g) in 48SB4B21. The only sample with a detection of di-n-butyl phthalate was also 48SB4B21.

9.5.2.2.2. Generally, the highest concentration of subsurface soil contamination was observed in the shallow (17-19 feet bgs) sample from 48SB5, located in the lower disposal area. The deeper sample (19-21 feet bgs) from 48SB4, located in the upper disposal area, displayed next highest concentration of subsurface soil contamination. Breakdown products from the oily wastewater dumped at SWMU 48 may be accumulating at approximately 17-21 feet bgs across the SWMU.

9.5.2.3 Groundwater

9.5.2.3.1. The maximum concentration of dissolved beryllium was found at 48MW1 (4.05 ug/l). The only other sample with detected dissolved beryllium was 48MW2 (2.69 ug/l). Carbon tetrachloride was observed at relatively high concentrations at two wells, but was not detected in the other two wells at SWMU 48. This compound was detected at a concentration of 92 ug/l in 48MW2 and at 100 ug/l in 48MW3. The maximum dissolved concentration of barium was 816 ug/l, found in the sample from 48MW2. The next highest concentration of barium was 295 ug/l, in 48MW4. This was the only COC detected in 48MW4. Barium was also detected at 48MW1 and 48MW3 at a concentration of about 70 ug/l.

9.5.2.3.2. Generally, the most significant groundwater contamination at SWMU 48 was found in 48MW2, which can be considered to be downgradient from both the upper and lower disposal areas. Significant VOC contamination was also apparent in 48MW3. However, based on the potentiometric surface map for this site (Figure 9.4) it does not appear that groundwater contamination from SWMU 48 would migrate in the direction of 48MW3.

9.5.2.3.3. It is possible that the contaminants detected in SWMU 48 groundwater originated from some other upgradient source. Numerous other SWMUs, which are not part of this investigation, are in the vicinity of SWMU 48. However, the source of the VOC contamination in groundwater at SWMU 48 has not been determined. Carbon tetrachloride and chloroform were not detected in monitoring wells upgradient from SWMU 48 during previous investigations. Furthermore, these compounds are not components of oily wastewater. Carbon tetrachloride and chloroform were detected in downgradient monitoring wells at SWMU 13 during previous investigations (Dames & Moore, 1992a), at concentrations lower than those observed at SWMU 48. Carbon tetrachloride was detected at

10.5 ug/l in 13MW3. Chloroform was detected at 1.33 ug/l in 13MW3 and at 0.605 ug/l in 13MW4. The highest concentration of beryllium and the second highest concentration of barium in groundwater at SWMU 48 were observed in the upgradient monitoring wells.

9.6 CONTAMINANT FATE AND TRANSPORT

9.6.0.1. The environmental fate and transport of chemicals is dependent on the physical and chemical properties of the compounds, the environmental transformation processes affecting them, and the media through which they migrate. At SWMU 48, both surface water and groundwater are potential migration pathways to the New River. The areas of surface soil contamination are susceptible to transport by surface water runoff. Although groundwater movement is controlled by karst subsurface features, and is therefore unpredictable, direct discharge to the New River is likely. However, the exact location where SWMU 48 groundwater might enter the New River is uncertain. The estimated groundwater flow velocity at SWMU 48 is 34.25 feet/year.

9.6.0.2. Metals of concern identified at SWMU 48 (arsenic and beryllium) are generally immobile in the clay-rich residuum underlying this SWMU. A low solubility is expected for arsenic due to coprecipitation of the arsenate anion with iron species in the soil. Surface water runoff could be effective in mobilizing metals present in the surface soils at SWMU 48, either as dissolved ions or absorbed on suspended sediment. Dissolved metals present in groundwater are mobile.

9.6.0.3. The VOC of concern at SWMU 48 (carbon tetrachloride) tends to have a low residence time in surface soil and surface water environments. VOCs can be persistent in groundwater. However, there is evidence that non-chlorinated volatile organic compounds may degrade rapidly in the vadose zone above groundwater plumes. Carbon tetrachloride has not been detected upgradient from SWMU 48, but these compounds have been detected in groundwater sampled downgradient from this area, at SWMU 13 (Dames & Moore, 1992a). This suggests a hydrologic connection between these two areas.

9.6.0.4. The sample collected from the New River near the likely discharge point of groundwater (in the vicinity of SWMU 13) contained barium in the surface water, and numerous metals and some SVOCs in the associated sediment sample. However, many of these same compounds were also found in the SWMU 13 samples. It is not possible to differentiate between possible impacts to the quality of the New River from SWMU 48 and SWMU 13 where the contaminants are similar. Surface water and sediment sampling results for the New River are discussed in Section 12.

9.7 RISK ASSESSMENT

9.7.0.1. The Oily Wastewater Disposal Area (SWMU 48) was used to dispose of wastewater from oil/water separators into trenches that were dug on site. This site has been inactive since 1985; currently, site workers can be exposed to surface soils at the facility. Future land use at this SWMU is uncertain; this area may be used for further commercial development. Consequently, groundwater and surface soils are potential sources of concern at SWMU 48.

9.7.1 Summary of Chemicals of Potential Concern

9.7.1.0.1 . The chemicals considered in the risk evaluation for groundwater at SWMU 48 include 2 metals (barium and beryllium), one semivolatile (bis(2ethylhexyl)phthalate) and 8 volatiles (1,1,1-trichloroethane, 1,1-dichloroethane, 1,1-dichloroethylene, carbon tetrachloride, chloroform, methylene chloride, tetrachloroethylene, and trichloroethylene).

9.7.1.0.2 . The chemicals considered in the risk evaluation for surface soils at SWMU 48 include 9 metals (arsenic, barium, beryllium, chromium III, lead, mercury, nickel, selenium, and silver), and 4 semivolatiles (bis (2-ethylhexyl) phthalate, di-n-butyl phthalate, chrysene, and phenanthrene).

9.7.1.1 Comparison to ARARs and TBCs for Groundwater and Soils

9.7.1.1.1. Groundwater in the vicinity of RAAP is not used for drinking water serving more than 25 people and therefore MCLs and MCLGs are not considered as ARARs for SWMU 48. In addition, there are no federal or Commonwealth of Virginia standards relating chemical concentrations in soils to toxic effects on vegetation or wildlife. TBC criteria considered for human health risk evaluation included reference doses (RfDs) and slope factors (SFs) from USEPA's Integrated Risk Information System and Health Effects Assessment Summary Table (USEPA, 1995a).

9.7.2 Exposure Assessment

9.7.2.1 Potential Pathways and Receptors

9.7.2.1.1. Current exposure pathways considered at SWMU 48 include site workers, construction workers and hunters. The remaining potential receptors have a low probability of completion and therefore, are not quantified for current receptors (area residents and recreational users). SWMU 48 is completely contained within RAAP property which effectively limits public access to potential contaminants. Subsurface soil samples were taken at this SWMU, but all samples were taken at depths that are not appropriate for inclusion in this risk evaluation (>10 feet below ground surface). In addition, the current groundwater pathway is not complete as this water is not used for drinking purposes. Potential future routes of human exposure which were considered for SWMU 48 include site worker ingestion, inhalation and dermal exposure to potentially contaminated groundwater. However, this exposure scenario is expected to have a low probability of completion due to present drinking water use.

9.7.2.1.2. The conceptual site model summary for SWMU 48 is presented in Figure 9.6 and includes exposure routes, potential receptors and the medium containing the potential contaminants of concern. All chemicals not eliminated by data validation were considered in the risk assessment for this SWMU.

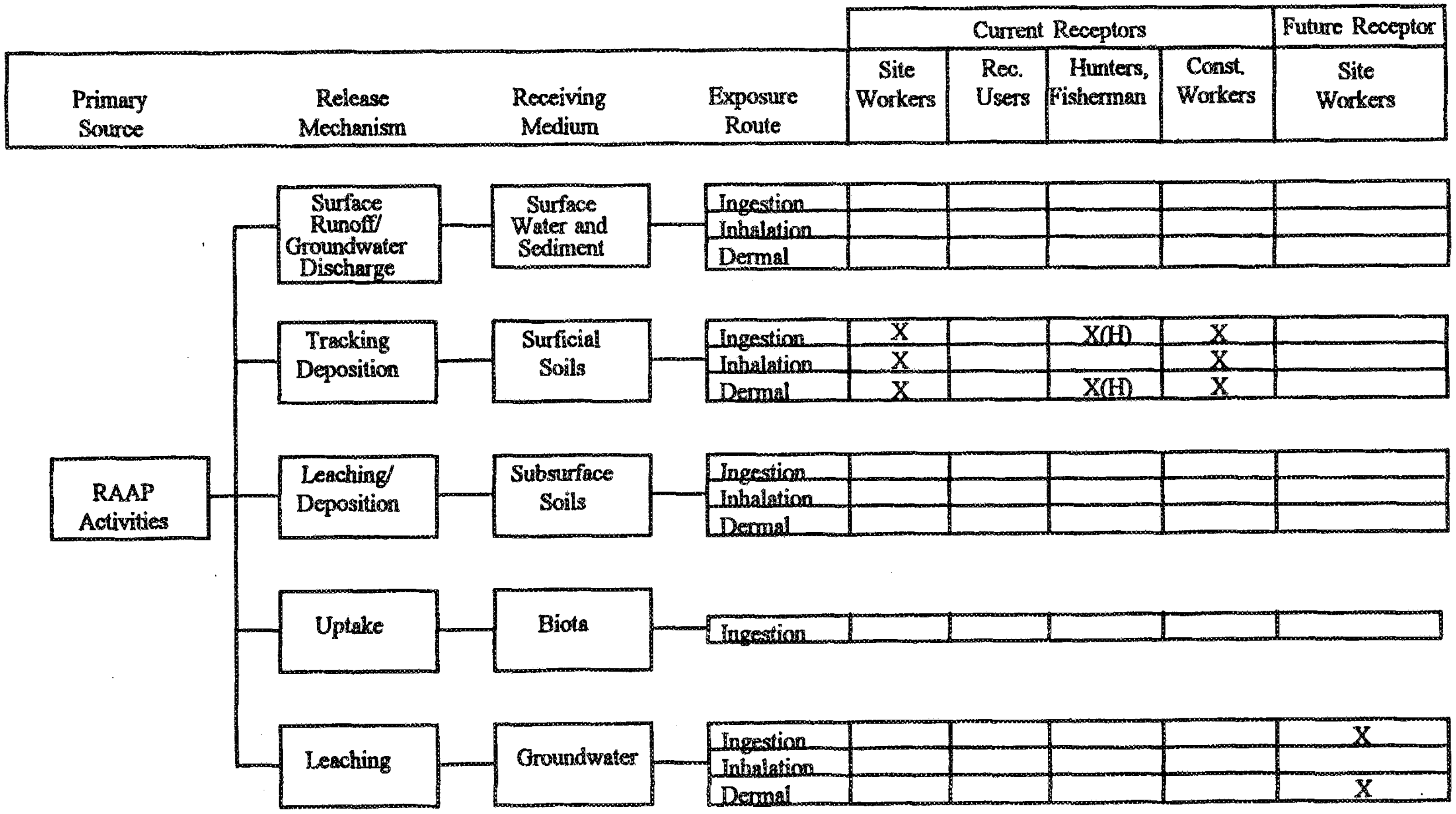
9.7.2.2 Exposure Point Concentrations and Chronic Daily Intakes

9.7.2.2.1. Exposure point concentrations for the chemicals of concern evaluated for SWMU 48 are listed in the tables in Appendix I. These concentrations range from 0.000609 mg/L (methylene chloride, 1,1-dichloroethylene) to .185 mg/L (barium) in groundwater and .0645 mg/kg (silver) to 758 mg/kg (barium) in surface soils.

9.7.3 Risk Characterization

9.7.3.0.1. The carcinogenic risk and hazard index were calculated for the groundwater ingestion and dermal contact pathways. These calculations are presented in Appendix I. A discussion of the results of each pathway for non-carcinogenic and carcinogenic effects is presented below.

Figure 9.6
Conceptual Site Model for Current and Future Exposure Pathways
SWMU 48
Radford Army Ammunition Plant
Radford, Virginia



Primary Source	Release Mechanism	Receiving Medium	Exposure Route	Current Receptors: Site Workers	Current Receptors: Rec. Users	Current Receptors: Hunters, Fisherman	Current Receptors: Const. Workers	Future Receptor: Site Workers
RAAP Activities	Surface Runoff/ Groundwater Discharge	Surface Water and Sediment	Ingestion					
			Inhalation					
			Dermal					
	Tracking Deposition	Surficial Soils	Ingestion	X		X(H)	X	
			Inhalation	X			X	
			Dermal	X		X(H)	X	
	Leaching/ Deposition	Subsurface Soils	Ingestion					
			Inhalation					
			Dermal					
	Uptake	Biota	Ingestion					
	Leaching	Groundwater	Ingestion					X
			Inhalation					
			Dermal					X

X = Pathways of potential concern
H = Hunter scenario

9.7.3.1 Non-carcinogenic Effects

9.7.3.1.1. The calculated hazard indices for the current site worker exposure to surface soils through ingestion and dermal contact exposure scenarios do not exceed acceptable levels. Hazard indices for this receptor are generally one to two orders of magnitude below acceptable levels.

9.7.3.1.2 . Scenarios for surface soil exposure to construction workers and hunters were analyzed at SWMU 48. The calculated hazard indices for construction worker exposure to surface soils through ingestion, dermal contact and inhalation are all below acceptable levels. The construction worker dermal contact exposure scenario calculations showed the highest hazard indices. However, these calculations were one order of magnitude below acceptable levels.

9.7.3.1.3 . The calculated hazard indices for the current scenario of hunter exposure to surface soils through ingestion and dermal contact at SWMU 48 do not exceed acceptable levels for CT and RME receptors. The totals for this site are at least two orders of magnitude below acceptable levels.

9.7.3.1.4 . The calculated hazard indices for the hypothetical future scenario of site worker exposure to groundwater through ingestion and dermal contact while showering at SWMU 48 do not exceed acceptable levels for CT and RME receptors. Calculated hazard indices are at least one order of magnitude below acceptable levels. The inhalation of volatiles hazard index exceeds one for the site worker RME receptor, due to trichloroethene (HI = 3.38).

9.7.3.2 Carcinogenic Effects

9.7.3.2.1 . The calculated cancer risks for the current site worker exposure to surface soil through dermal contact scenario are above USEPA target risk range primarily due to arsenic and beryllium, for CT and RME receptors. All other chemicals of concern evaluated do not exhibit an increased cancer risk due to a lack of toxicity information or because they are below the USEPA target range for cancer risk. Beryllium was calculated to have the highest cancer risk for the exposure through dermal contact scenario with calculations of 1.02×10^{-5} for CT and 1.32×10^{-4} for RME. Arsenic also shows cancer risk within the target risk range with calculations of 3.06 x 10^{-6} for RME. The cancer risk for RME current site worker ingestion is also within the USEPA target range for cancer risk.

9.7.3.2.2 . The calculated cancer risks for the hunter exposure to surface soil through dermal contact scenario are within USEPA target risk range primarily due to beryllium, for CT and RME receptors. All other chemicals of concern evaluated do not exhibit an increased cancer risk due to a lack of toxicity information or because they are below the USEPA target range for cancer risk. Beryllium was calculated to have the highest cancer risk for the exposure through dermal contact scenario with calculations of 2.30 x 10^{-6} for CT and 2.50 x 10^{-5} for RME. The calculated cancer risks for the hypothetical future hunter exposure to surface soil through the ingestion of surface soil scenario are within the USEPA target risk range for RME receptors, primarily due to beryllium.

9.7.3.2.3 . The calculated cancer risks for the hypothetical future site worker exposure to groundwater through ingestion are within the USEPA target risk range, for CT and RME receptors, primarily due to beryllium. All other chemicals of concern evaluated do not exhibit an increased cancer risk due to a lack of toxicity information or because they are below the USEPA target range for cancer risk. Beryllium was calculated to have the highest cancer risk for the exposure through ingestion exposure scenario with calculations of 1.02 x 10^{-6} for CT and 2.04 x 10^{-5} for RME. Carbon tetrachloride also has cancer risks within the target risk range for ingestion with calculations of 3.15 x 10^{-6} for RME. The calculated cancer risks for the hypothetical future site worker exposure to groundwater through dermal contact exposure scenario are within USEPA target risk range primarily due to high levels of beryllium, for RME receptors. The cancer risks for beryllium for this exposure scenario were 9.32 x 10^{-6} for RME.

9.7.3.2.4 The calculated cancer risks for the construction worker exposure scenario to surface soil through ingestion and dermal contact are within the USEPA target risk range, for CT and RME receptors, with the exception of the CT receptor for the ingestion exposure scenario. This is primarily due to beryllium. All other chemicals of concern evaluated do not exhibit an increased cancer risk due to a lack of toxicity information or because they are below the USEPA target range for cancer risk. The cancer risk for beryllium for the dermal contact exposure scenario was 2.04 x 10^{-6} for CT and 1.06 x 10^{-5} for RME. Arsenic and beryllium exhibit cancer risks within the target risk range for the ingestion exposure scenario for RME receptors, with cancer risks being 1.97 x 10^{-6} and 1.24 x 10^{-6}, respectively.

9.7.4 Uncertainty Analysis

9.7.4.0.1. Data collection/evaluation uncertainty may be relevant at SWMU 48 due to the types and numbers of samples collected. Many metals detected at this site in groundwater and surface soils are naturally occurring and no analysis was accomplished to differentiate between site-related and non-site-related concentrations. In this case, all metals detected in groundwater and surface soils were retained as if they were site-related. Some calculations have shown to present unacceptable risks due to these metals and this could be an overestimate due to natural metals concentration in groundwater and surface soils.

9.7.4.0.2. One of the main areas of uncertainty is in exposure assessment as relates to determining future land uses at a contaminated site. The majority of the land at RAAP is classified as commercial or industrial to support the explosives manufacturing process, with few scattered residential communities located in Montgomery and Pulaski counties. Access to SWMU 48 is restricted and therefore a current residential exposure scenario is unlikely. A future residential exposure scenario is also unlikely; therefore, future land use was assumed to remain industrial.

9.7.4.0.3. Another area of uncertainty in evaluating human health risk from SWMU 48 is toxicity assessment. Oral and dermal slope factors are not available for seven of the nine metals which were detected in groundwater, including lead. Most studies are based on animal data and extrapolated to humans and also subchronic studies may be used assess chronic effects. In addition, extrapolations are characterized by uncertainty factors which can be as large as four orders of magnitude. This may tend to over- or underestimate risk.

9.7.4.0.4. Modeled concentrations used in exposure assessment also have a certain degree of uncertainty. The inhalation of volatiles from groundwater while showering exposure scenario uses modeled concentrations of airborne volatiles to assess human health risk. These modeled concentrations use assumptions which are based on the physical and chemical properties of trichloroethylene. Therefore, the model is more precise when showing risks due to the presence of trichloroethylene in groundwater, and less precise for other volatile chemicals detected in groundwater. This may tend to over- or underestimate risk.

9.8 RISK SUMMARY

9.8.0.1. Carcinogenic risks and non-carcinogenic hazard indices were calculated for site worker receptors potentially exposed to multiple chemicals in groundwater during domestic use. The groundwater pathway calculations were summarized and are presented in Table 9.7. Under the NCP, the probability of excess cancers over a lifetime of exposure within or below USEPA's target risk range of 1×10^{-4} to 1×10^{-6} are considered to pose a low threat while a probability of excess cancers over a lifetime of exposures greater than 1×10^{-4} may pose an unacceptable threat of adverse health effects. For noncarcinogens, a hazard index below one is considered to pose a low threat of adverse health effects, while a hazard index greater than one may pose an unacceptable threat of adverse health effects.

9.8.0.2. At SWMU 48, construction worker and hunter cancer risks are within the target risk range. The hazard index for the site worker is greater than one for RME receptors. The site worker RME receptor is also greater than 1×10^{-4}. These values indicate a potential for noncarcinogenic and carcinogenic adverse human health effects for the exposure scenarios discussed above at SWMU 48.

9.9 SWMU 48 SUMMARY

9.9.0.1. The groundwater associated with SWMU 48 is contained within the limestone and dolomite of the karst aquifer underlying this area. Although the groundwater flow direction appears to be toward the New River, groundwater movement and occurrence has not been completely defined in this vicinity Groundwater, surface soils, and subsurface soils were collected to characterize this SWMU. Additionally, a surface water and sediment sample were collected from the New River at the likely discharge point of groundwater from SWMU 48.

9.9.0.2. Arsenic and beryllium were considered to be the risk drivers for surface soils at SWMU 48. Seven SVOCs and total petroleum hydrocarbons were detected in the subsurface soils at SWMU 48. Subsurface soils were not considered in the risk assessment, however, because the samples were collected at depths greater than 10 feet bgs. Beryllium and carbon tetrachloride were identified as the risk drivers for groundwater at SWMU 48. Carbon tetrachloride was not detected in monitoring wells upgradient from SWMU 48 during previous investigations. However, this compound was detected, at concentrations lower than

Table 9.7
Summary of Human Health Risk
SWMU 48
Radford Army Ammunition Plant

Receptor	Pathways	HI		Cancer Risk	
		CT	RME	CT	RME
Site Worker	Ingestion of Groundwater	0.03	0.13	1.27E-06	2.54E-05
	Dermal Contact with Groundwater	0	0	4.70E-07	9.44E-06
	Inhalation of Volatiles from Groundw	0.69	3.38	8.61E-08	2.10E-06
	Ingestion of Surface Soil	0.01	0.05	4.18E-07	8.36E-06
	Dermal Contact with Surface Soil	0.13	0.33	1.04E-05	1.35E-04
	Inhalation of Surface Soil Volatiles	0	0	5.32E-17	8.01E-16
	Inhalation of Surface Soil Particulates	0	0	6.98E-15	1.05E-13
Total for Site Worker		0.86	3.89	1.26E-05	1.80E-04
Hunter	Ingestion of Surface Soil	0	0.01	1.50E-07	2.61E-06
	Dermal Contact with Surface Soil	0.02	0.03	2.35E-06	2.56E-05
Total for Hunter		0.02	0.04	2.50E-06	2.82E-05
Construction Worker	Ingestion of Surface Soil	0.05	0.24	1.67E-07	3.21E-06
	Dermal Contact with Surface Soil	0.26	0.33	2.09E-06	1.08E-05
	Inhalation of Surface Soil Volatiles	0	0	2.56E-17	1.79E-16
	Inhalation of Surface Soil Particulates	0	0	3.36E-15	2.35E-14
Total for Construction Workers		0.31	0.57	2.26E-06	1.40E-05

those observed at SWMU 48, in downgradient monitoring wells at SWMU 13 during previous investigations.

9.9.0.3. In general, the greatest surface soil metals concentrations were observed in the western and central regions of the upper disposal area. The highest concentration of subsurface soil contamination was observed in the 17-19 foot interval in both the upper and lower disposal areas. The highest concentrations of VOCs and metals were observed in the downgradient monitoring well sample and in the side-gradient monitoring well sample at SWMU 48. However, the highest beryllium concentration and second highest barium concentration was observed in the upgradient wells. This suggests the possibility of an upgradient source impacting groundwater quality at SWMU 48. SWMU 48 is situated in a cluster of SWMUs within the Horseshoe Area.

9.9.0.4. The human health risk assessment indicated a potential for noncarcinogenic and carcinogenic adverse human health effects for ingestion, dermal contact or volatile inhalation of groundwater for site worker receptors. A potential for carcinogenic adverse human health effects for dermal contact or ingestion of surface soil was also identified for site worker, hunters and construction worker receptors at SWMU 48.

SECTION 10

SITE CHARACTERIZATION OF SWMU 54 (PROPELLANT ASH DISPOSAL AREA)

10.1 HISTORY AND OPERATIONS

10.1.0.1. The Propellant Ash Disposal Area (SWMU 54) is located in the easternmost section of the Horseshoe Area, just outside Gate 19-D of the RAAP fence. Plate 1 shows SWMU 54 in relation to the rest of the facility. A detailed location map of SWMU 54 is presented as Figure 10.1. The total area of the unit is estimated to be less than 1 acre. Ash from propellant burning operations at the Waste Propellant Burning Ground (SWMU 13) was reportedly disposed of at this unit during the late 1970s, prior to startup of the Hazardous Waste Landfill (SWMU 16) in 1980. The quantity of ash disposed of in this unit is estimated to be 10 tons (USATHAMA, 1976). According to plant personnel, disposal occurred on the surface with no routine disposal in pits or trenches. Ash residue is visible where surface soils have been disturbed.

10.1.0.2. The propellant ash is the residue of the burning of waste explosives, propellants, and laboratory wastes (propellant and explosive residues, samples, and analytical residues). A sample of the ash disposed of in the Hazardous Waste Landfill was analyzed for RCRA metals (EP toxicity leachate analysis). Results indicated that the ash content exceeded the Virginia maximum allowable TCLP concentration for lead (51 mg/l, compared to the maximum allowable concentration of 5 mg/l) (USEPA, 1987). It is likely that ash disposed of in SWMU 54 exhibits similar characteristics.

10.2 PREVIOUS INVESTIGATIONS

10.2.0.2. Dames & Moore conducted a VI at this SWMU in August 1991. During this investigation, three wells were installed, one upgradient (54MW1) and two downgradient (54MW2 and 54MW3) of the disposal area, to evaluate whether groundwater quality has been impacted by ash disposed in the unit. Locations for the three wells are shown in Figure 10.1. Initially, the upgradient well was 54MW1A. However, it was replaced by 54MW1

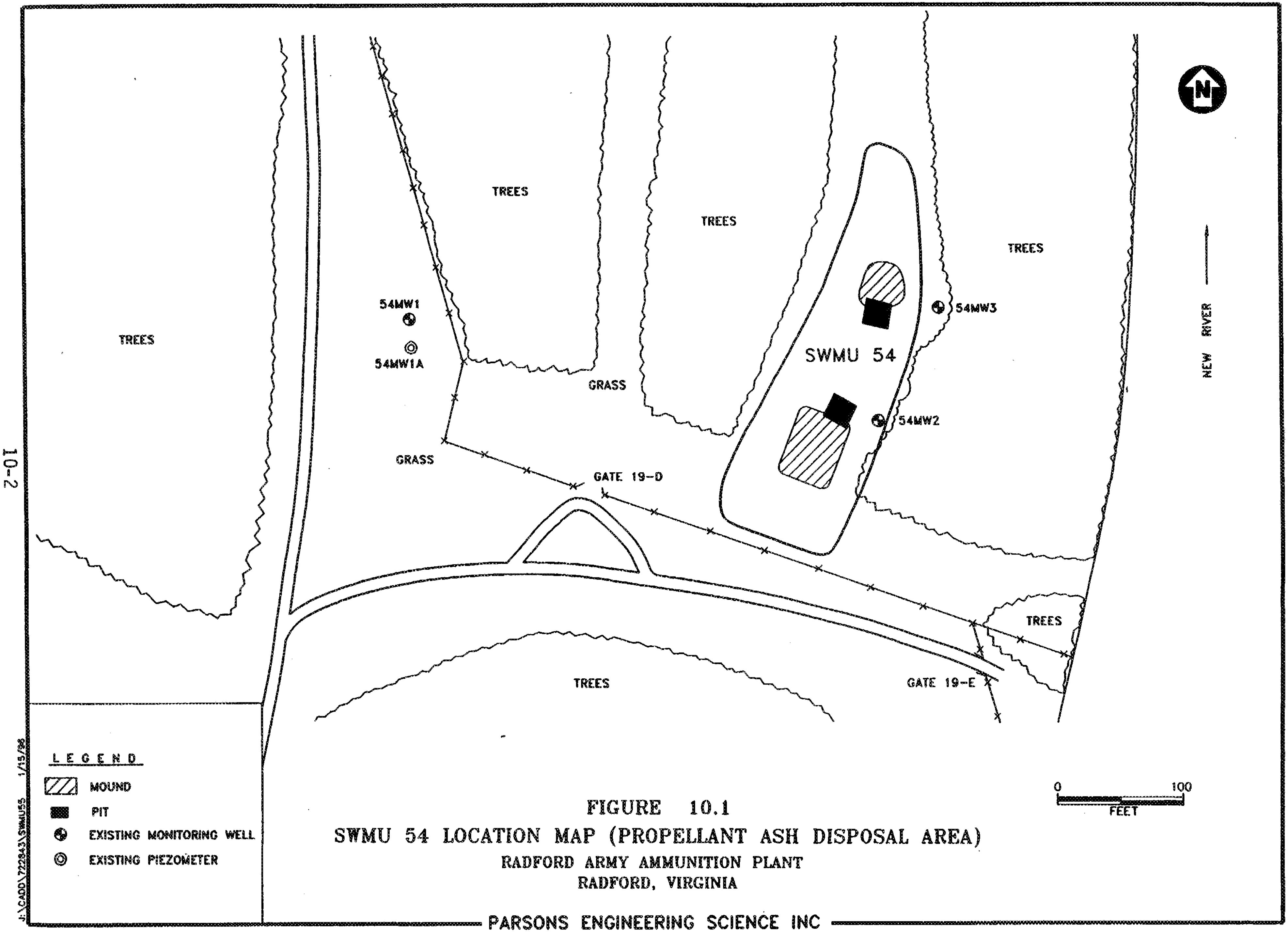


FIGURE 10.1

SWMU 54 LOCATION MAP (PROPELLANT ASH DISPOSAL AREA)

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

PARSONS ENGINEERING SCIENCE INC

when it was discovered that problems encountered during construction of the well had compromised the quality of the groundwater. 54MW1A is still used as a piezometer.

10.2.0.3. Results of the 1992 groundwater sampling at SWMU 54 are summarized in Table 10.1. Upgradient well data, HBNs (from the RCRA permit), and RBCs for tap water (USEPA, 1994) are also listed in the table for comparison. The results of the chemical analysis of the groundwater samples collected during the VI by Dames & Moore (1992b) indicated that low concentrations of two explosives and one VOC were present in groundwater samples collected downgradient from the disposal area. Eleven metals were detected in the three groundwater samples collected at SWMU 54. Four of the metals (aluminum, arsenic, silver, and zinc) were detected in the upgradient sample only, but were reported at levels slightly greater than the analytical detection limits. Concentrations of metals in both downgradient samples were similar to those in the upgradient sample (54MW1). Concentrations of all metals in downgradient wells were one or more orders of magnitude less than HBN or RBC criteria and were not identified as a concern. Two explosives, 2,4,6-TNT and HMX, were detected in downgradient groundwater samples 54MW2 and 54MW3, respectively, but were not detected in the upgradient sample. The concentration of 2,4,6-TNT was nearly one order of magnitude less than the HBN criterion but exceeded the RBC. HMX was detected at a concentration nearly three orders of magnitude less than the HBN criterion.

10.2.0.4. Geophysical methods were employed at SWMU 54 during the VI to delineate the boundaries of the area or locate buried materials. Electromagnetic (EM) and magnetic surveys were conducted to map possible locations of ash disposal. The survey covered an area 135 feet by 300 feet. Dames & Moore concluded that the anomalies in the EM and magnetic data centered at the southern mound and pit appear to be from a combination of buried conductive materials and metals, and the anomaly in the EM data found at the northern mound and pit appears to indicate burial of non-metallic material (Dames & Moore, 1992b). The pits in these two areas appear to be borrow areas for cover material for the mounds (Dames & Moore, 1992b).

TABLE 10.1
VI DATA 1992
SUMMARY OF ANALYTICAL DATA
FOR GROUNDWATER SAMPLES COLLECTED AT SWMU 54
RADFORD ARMY AMMUNITION PLANT, VIRGINIA

	PQLs	No. of Samples	Concentration Range 6 Feb 92 - 7 Feb 92 23.0 ft - 25.0 ft	Upgradient (54MW1) 6 Feb 92 45.0 ft	HBN	RBC Tap Water
TAL Inorganics (µg/L)						
Aluminum	141	2	LT 141	154	101,500	110,000
Arsenic	10	2	LT 2.54	5.4	50	0.038
Barium	20	2	104	97.2	1,000	2,600
Calcium	500	2	71,600 - 74,000	59,100	NSA	NA
Iron	38.1	2	63.6 - 74.5	81.7	NSA	NA
Magnesium	500	2	25,000 - 34,500	26,300	NSA	NA
Manganese	2.75	2	7.38 - 59.5	17	3,500	180
Potassium	375	2	1,990 - 2,320	1,630	NSA	NA
Silver	2	2	LT 0.25	0.255	50	180
Sodium	500	2	5,400 - 6,350	3,140	NSA	NA
Zinc	50	2	LT 21.1	23.1	7,000	11,000
Explosives (µg/L)						
246 TNT	0.635	2	LT 0.635 - [2.81]	LT 0.635	11.7	2.2
HMX	1.21	2	LT 1.21 - 3.07	LT 1.21	1,750	NA
Volatiles (µg/L)						
Carbon Disulfide	5	2	7.03 - 13.6	1.25	4,000	21
Semivolatiles (µg/L)	NA	2	ND	ND	NSA	NA
Semivolatile TICs (µg/L)						
Cyclopentanone	NA	2	ND - 5 S	10 S	NSA	NA
Mesityl Oxide	NA	2	ND	4 S	NSA	NA
Total Unknown TICs	NA	2	ND	(1)6	NSA	NA
Other						
Total Organic Carbon (µg/L)	1,000	2	3.67 - 5.45	10.5	NSA	NA
Total Organic Halogens (µg/L)	1	2	117 - 138	158	NSA	NA
pH	NA	2		6.99 - 7.02	7.29NSA	NA

HBN	Health-based number as defined in the RCRA permit. HBNs not specified in the permit were derived using standard exposure and intake assumptions consistent with EPA guidelines (51 Federal Register 33992, 34006, 34014, and 34028).10 S
LT	Concentration is reported as less than the certified reporting limit.
NA	Not available;
ND	Analyte was not detected.
NSA	No standard (HBN) available; health effects data were not available for the calculation of a HBN. HBNs were not derived for TICs.
PQL	Practical quantitation limit; the lowest concentration that can be reliably detected at a defined level of precision for a given anaytical method.
RBC	Risk-based concentration provided by USEPA (USEPA 1994)
S	Results are based on an internal standard; flag is used for TICs detected in library scans.
TAL	Target analyte list.
TICs	Tentatively identified compounds that were detected in the GC/MS library scans.
µg/L	Micrograms per liter.
( )	Parentheses are used to indicate the number of unknown TICs that were detected in either the volatile or semivolatile GC/MS library scans. The number beside the parentheses is the total concentration of all TICs detected in each respective scan.
[]	Brackets indicate that the detected concentration exceeds the HBN or RBC.

From Dames & Moore, 1992b

10.3 SUMMARY OF RFI FIELD ACTIVITIES

10.3.0.1. To define the extent of ash and the limits of soil contamination for the RFI, discrete soil samples were collected from around and below the north and south mounds. A total of 16 soil borings were installed. The sample locations shown in Figure 10.2 were based on the previous VI field sampling and geophysical investigations of SWMU 54. The soil boring proposed for the center of the north mound could not be obtained because of drill rig access problems; a hand augered soil sample was collected instead. Two soil samples (shallow and deep) were taken from each boring with the exception of the hand augered one (54SB15).

10.3.0.2. One composite sample of the ash was collected from each mound for waste characterization purposes. Groundwater samples were collected from each of the three monitoring wells. The analytical parameters for all the samples are indicated on Tables 4.3 and 4.4. A summary of the RFI field activities is presented in Table 10.2.

10.4 ENVIRONMENTAL SETTING

10.4.1 Topography and Site Layout

10.4.1.1. SWMU 54 is generally a level area with a ground surface elevation of approximately 1,700 feet above mean sea level. The SWMU is an elongated triangular grass covered area, approximately 300 feet long by 100 feet wide with two prominent piles of soil and ash beside two 3-5 foot deep pits. The soil/ash piles are referred to as the north and south mounds; the pits appear to be associated with borrow areas for each mound. The north mound is approximately 6-10 feet high and the south mound is approximately 4-6 feet high.

10.4.1.2. The SWMU is bordered to the east, west, and north by tree-covered areas and to the south by a grassy flat area which leads to a tree-covered area approximately 150 feet farther south. The triangular area is physically outside of the facility (outside the gate), with direct access from the New River. The river is approximately 150 feet east of the SWMU, flowing directly north before meandering westward. There are essentially no other buildings or active areas in the vicinity.

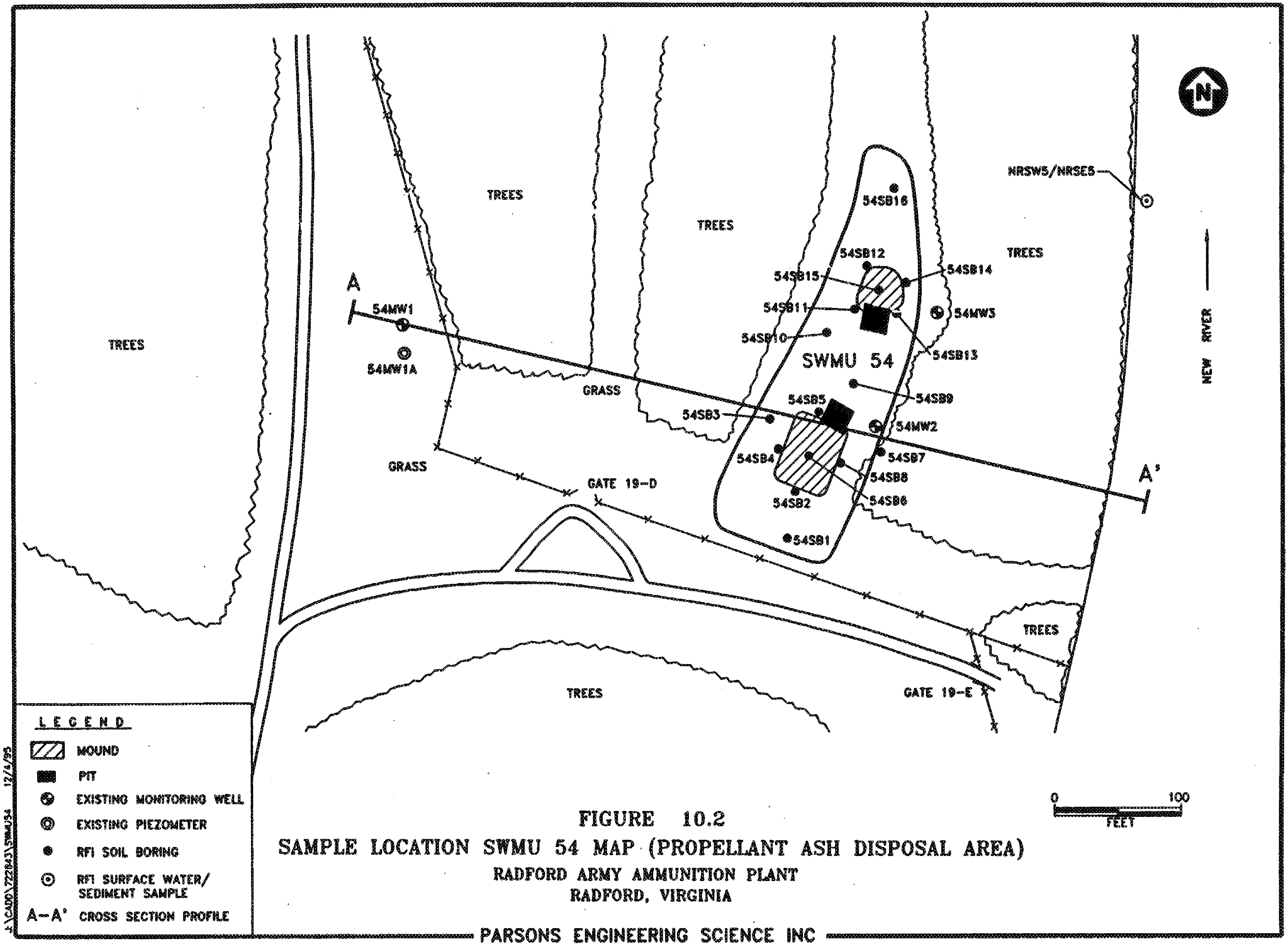


FIGURE 10.2
SAMPLE LOCATION SWMU 54 MAP (PROPELLANT ASH DISPOSAL AREA)
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

PARSONS ENGINEERING SCIENCE INC

TABLE 10.2

SUMMARY OF SWMU 54 RFI FIELD ACTIVITIES
RADFORD ARMY AMMUNITION PLANT

SWMU	Monitoring Wells Sampled*	Soil Boring Samples	Depth (Feet Below Ground Surface)	Geotechnical Samples/Depth	Waste Ash Samples
54	54MW1	54SB1A2	0-2	54SB1 (15-17)	54SS1 (Composite)
	54MW2	54SB1B22	20-22	54SB2 (10-12)	54SS2 (Composite)
	54MW3	54SB2A2	0-2	54SB3 (10-12)	
		542B2B17	15-17	54SB4 (5-7)	
		54SB3A2	0-2	54SB5 (15-17)	
		54SB3B17	15-17	54SB6 (15-20)	
		54SB4A2	0-2	54SB7 (10-12)	
		54SB4B17	15-17	54SB8 (15-17)	
		54SB5A2	0-2	54SB9 (10-12)	
		54SB5B17	15-17	54SB10 (10-12)	
		54SB6A2	0-2	54SB11 (15-17)	
		54SB6B15	10-15	54SB12 (5-7)	
		54SB7A2	0-2	54SB13 (5-7)	
		54SB7B17	15-17	54SB14 (7-9)	
		54SB8A2	0-2	54SB16 (10-12)	
		54SB8B17	15-17		
		54SB9A7	5-7		
		54SB9B17	15-17		
		54SB10A2	0-2		
		54SB10B17	15-17		
		54SB11A2	0-2		
		54SB11B17	15-17		
		54SB12A2	0-2		
		54SB12B17	15-17		
		54SB13A2	0-2		
		54SB13B22	20-22		
		54SB14A2	0-2		
		54SB14B15	11-12		
		54SB15A6	4-6		
		54SB16A2	0-2		
		54SB16B12	10-12		
		54SB10B20 (Dup. of 54SB10B17)			
		54SB16B25 (Dup. of 54SB16B12)			

*Field measurements of pH, temperature and conductivity were also collected.

10.4.2 Geology

10.4.2.1. The geology of SWMU 54 was characterized by drilling 16 soil borings for the RFI and utilizing existing information obtained from the installation of three monitoring wells for the VI (Dames & Moore, 1992a). The vertical extent of all drilling activities was approximately 60 feet, ranging from 1708 feet above mean sea level (amsl) to 1648 feet amsl.

10.4.2.2. Geological samples were categorized under the Unified Soil Classification System (USCS) in accordance with the work plan. One geotechnical sample per boring was collected from 15 of the 16 borings at different discrete depths (see Table 4.5) and submitted for laboratory analysis to determine USCS designation. All other samples, including those obtained for chemical analysis or general characterization by split spoon or Moss spoon, were given a USCS designation by the project geologist. This information, supplemented by the lithologic logs from the monitoring wells, was used to prepare the geologic cross section presented as Figure 10.3. A west to east (A-A') cross section profile line is shown on Figure 10.2.

10.4.2.3. The geology of SWMU 54 generally consisted of unconsolidated alluvial sediments (river terrace deposits) overlying a weathered limestone of the Elbrook Formation. The geology was very consistent across the study area. The cross section displays sediments gently dipping toward the New River. Generally, a dark brown silt with some sand and clay (ML), 5 to 15 feet thick, overlaid a brown silt and sand (SM). Below the SM layer, a thin gravel sequence (GM) with some silt and little sand was encountered. The GM layer was typically wet. The bedrock beneath the GM layer was limestone, but in some cases a weathered gray siltstone was found. Directly below the SWMU, the limestone bedrock was encountered at approximately 20-23 feet below ground surface (bgs). The limestone was a distinctive gray-green in color. It was penetrated by the monitoring well borings, but not the 16 soil borings which encountered auger refusal at the bedrock interface. The rock samples at the bedrock interface were determined by hydrochloric acid effervescence to be limestone.

10.4.3 Hydrogeology

10.4.3.1. The three monitoring wells present at SWMU 54 (Figure 10.1) were installed during the VI conducted by Dames & Moore. In July 1995, groundwater was measured at 18.7 feet bgs at the upgradient well (54MW1) and at about 23 feet bgs at the two downgradient wells (54MW2 and 54MW3). In the soil boring locations, the groundwater table was encountered within a gravel layer. The gravel layer was consistently observed directly above the weathered limestone bedrock, between 17 and 22 feet bgs.

10.4.3.2. Groundwater occurrence and movement at SWMU 54 does not appear to be complex. Groundwater at this SWMU is present within a relatively shallow unconfined aquifer consisting of unconsolidated alluvial sediments and the underlying weathered siltstone and limestone of the Elbrook Formation. The potentiometric surface of the groundwater for SWMU 54 is shown in cross-section in Figure 10.3 and in plan view in Figure 10.4. Groundwater consistently occurs in the gravel layer overlying the bedrock. Groundwater flows to the east, toward the New River, at a hydraulic gradient of approximately 0.026 ft/ft. Groundwater appears to discharge directly into the New River.

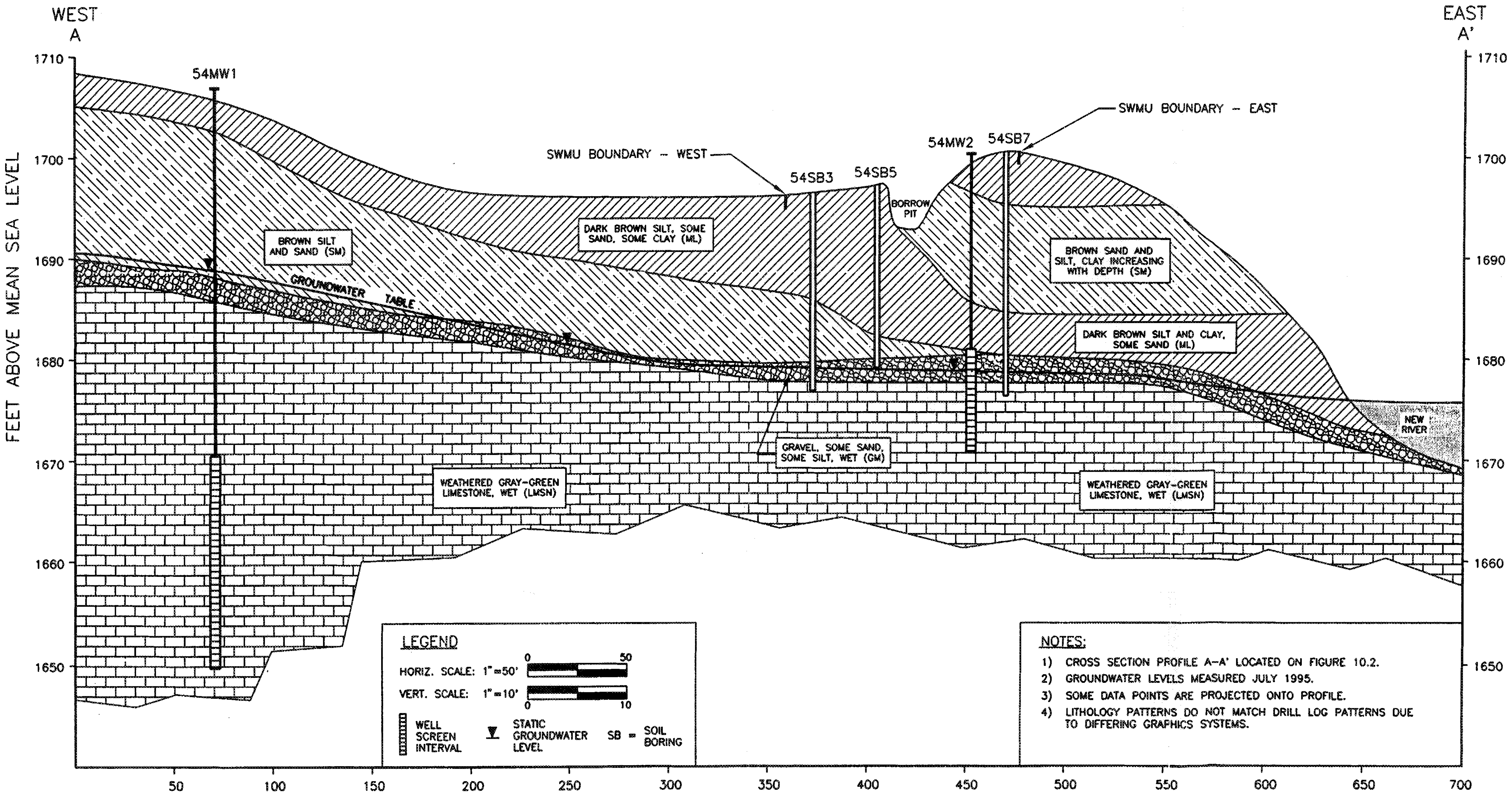
10.4.3.3. Well construction details for the SWMU 54 monitoring wells are shown in Table 4.1. Field data collected during the July 1995 sampling event is summarized in Table 10.3. Field data included photoionization detector (PID) readings of the well headspace in parts per million (ppm), pH, temperature, and conductivity of the groundwater. The groundwater elevations used to construct the potentiometric surface map (Figure 10.3) are also shown.

10.4.4 Surface Water

10.4.4.1. The New River is approximately 150 feet east of SWMU 54. In this vicinity, the New River flows parallel to SWMU 54 to the north before, meandering westward. Based on topography, surface water runoff is expected to flow eastward toward the river. According to RAAP utility maps, there are no manholes, catch basins, or storm drains located in the vicinity of SWMU 54.

FIGURE 10.3
SWMU 54 GEOLOGIC CROSS SECTION (A–A')

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



NOTES:

1) CROSS SECTION PROFILE A–A' LOCATED ON FIGURE 10.2.
2) GROUNDWATER LEVELS MEASURED JULY 1995.
3) SOME DATA POINTS ARE PROJECTED ONTO PROFILE.
4) LITHOLOGY PATTERNS DO NOT MATCH DRILL LOG PATTERNS DUE TO DIFFERING GRAPHICS SYSTEMS.

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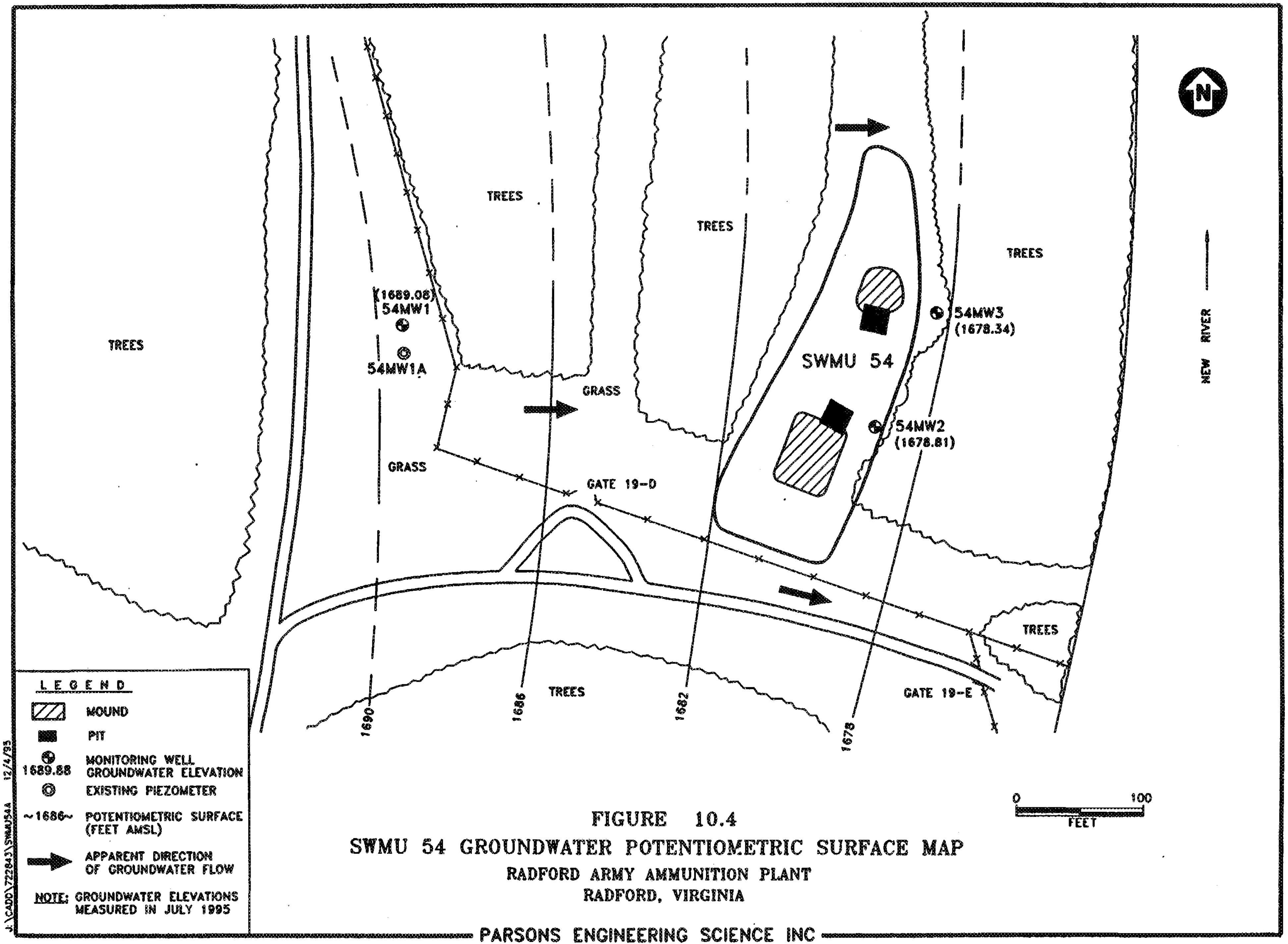

FIGURE 10.4
SWMU 54 GROUNDWATER POTENTIOMETRIC SURFACE MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

PARSONS ENGINEERING SCIENCE INC

TABLE 10.3
SWMU 54: GROUNDWATER FIELD DATA
RADFORD ARMY AMMUNITION PLANT

Well Name	Date	Depth to Bottom (ft)	Depth to Water (ft)	Groundwater Elevation*(ft)	PID (ppm)	pH	Temperature (degrees F)	Conductivity us/cm
54MW1	7-15-95	52.0	18.70	1689.08	0.0	7.77	76.0	490
54MW2	7-17-95	28.0	22.60	1678.81	0.0	NA	NA	NA
54MW3	7-17-95	30.0	23.81	1678.34	0.0	6.98	81.0	406

* Feet above mean sea level
NA: No data due to instrument malfunction.

10.5 NATURE AND EXTENT OF CONTAMINATION

10.5.0.1. A summary of all positive results (detected compounds) for soil and aqueous samples collected at SWMU 54 is presented in Tables 10.4 and 10.5, respectively. The chemicals of concern (COCs) for SWMU 54 were determined in accordance with the methods described in Section 6. The focus of the section is on the COCs identified as potential human health threats as detailed in the subsequent Risk Assessment subsections.

10.5.1 Nature of Contamination

10.5.1.1 Subsurface soils

10.5.1.1.1. Six COCs were identified in the subsurface soils at SWMU 54, including mercury, lead, and the explosives, 2,4-Dinitrotoluene, 2,4,6-Trinitrotoluene, HMX, and RDX. Mercury and 2,4,6-Trinitrotoluene were found at concentrations considered to be a potential human health risk. Both compounds were considered to be the risk drivers for soils at SWMU 54.

10.5.1.1.2. 2,4,6-TNT was detected in eight soil boring samples, ranging in concentration from 2.85 ug/g in 54SB7A2 to 6527.78 ug/g in 54SB6B15. Mercury was found in six soil boring samples, ranging in concentration from 0.09 ug/g in 54SB1A2 to 72.13 ug/g in 54SB6A2. The background concentration for mercury in soils at shallow depths (B horizon) is 1.5 ug/g. The C horizon background for mercury is 2 ug/g.

10.5.1.1.3. Lead was not found at levels considered to pose a human health threat, although it did exceed background. The B horizon background concentration is 161.81 ug/g; the C horizon background level is 140.67 ug/g. Lead was detected in all samples from all soil borings at SWMU 54. Concentrations ranged from 5.77 ug/g in 54SB1B22 to 3789.73 ug/g in 54SB6A2. The TCLP lead concentration exceeded regulatory levels in a composite waste ash sample collected from the southern mound. Positive results for 2,4-Dinitrotoluene were found in three samples at this SWMU. The maximum concentration (56.67 ug/g) was detected in sample 54SB615. This explosive was also detected in the shallow sample taken from boring 54SB6 at a concentration of 25.31 ug/g. The third positive result was in sample 54SB3A2.

TABLE 10.4
POSITIVE RESULTS TABLE OF SWMU 54 - Solid Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	54SB1A2	54SB1B22	54SB2A2	54SB2B17	54SB3A2	54SB3B17	54SB4A2
METALS (ug/g)							
Arsenic			3.27 J4				
Lead	716.80 J6	5.77 J6	2354.26 J6	14.23 J6	321.84 J6	14.74 J6	84.26 J6
Silver	0.07 J4		0.03 J4	0.03 J4	0.03 J4	0.04 J4	0.04 J4
Barium	164.51 J1	307.44 J1	224.22 J1	175.46 J1	178.16 J1	87.63 J1	313.51 J1
Beryllium	0.93 J4		1.76 J4	1.33 J4	1.11 J4		1.78 J4
Cadmium	2.40 J4						
Chromium	25.38 J6	9.80 J6	27.91 J6	29.45 J6	28.16 J6	37.76 J6	35.56 J6
Nickel	11.66 J4	6.23 J4	10.25 J4	16.69 J4	13.45 J4	10.26 J4	21.44 J4
Mercury	0.09 J4		0.13 J4		5.06 J4	0.21 J4	
EXPLOSIVES (ug/g)							
2,4,6-Trinitrotoluene			4.41 J4		2988.51 J4	48.42 J4	
2,4-Dinitrotoluene					12.76 J4		
2,6-Dinitrotoluene							
Cyclotetramethylenetetranitramine (HMX)					4.68		
Cyclonite (RDX)					1.98 J4		
OTHER (ug/g)							
Total Organic Carbon		95514.20					

TABLE 10.4
POSITIVE RESULTS TABLE OF SWMU 54 - Solid Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	54SB4B17	54SB5A2	54SB5B17	54SB6A2	54SB6B15	54SB7A2	54SB7B17
METALS (ug/g)							
Arsenic				4.08 J4			
Lead	8.36 J6	39.90 J6	16.82 J6	3789.73 J6	430.56 J6	50.29 J6	22.79 J6
Silver	0.03 J4	0.04 J4	0.05 J4	0.30 J4			
Barium	108.30 J1	281.80 J1	244.59 J1	1077.02 J1	362.50 J1	138.29 J1	420.91 J1
Beryllium		1.55 J4	1.61 J4	1.11 J4	2.43 J4	0.82 J4	2.47 J4
Cadmium				11.75 J4			
Chromium	21.30 J6	34.54 J6	40.64 J6	136.92 J6	70.14 J6	24.00 J6	57.10 J6
Nickel	9.19 J4	21.20 J4	24.46 J4	16.99 J4	30.14 J4	12.34 J4	34.72 J4
Mercury				72.13 J4			
EXPLOSIVES (ug/g)							
2,4,6-Trinitrotoluene				4.71 J4	6527.78 J4	2.85 J6	
2,4-Dinitrotoluene				25.31 J4	56.67 J4		
2,6-Dinitrotoluene					112.50		
Cyclotetramethylenetetranitramine (HMX)					7.28 J9		
Cyclonite (RDX)							
OTHER (ug/g)							
Total Organic Carbon							

TABLE 10.4
POSITIVE RESULTS TABLE OF SWMU 54 - Solid Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	54SB8A2	54SB8B17	54SB9A7	54SB9B17	54SB10A2	54SB10B17	54SB10B20*
METALS (ug/g)							
Arsenic					4.28 J4		
Lead	229.75 J6	21.20 J6	20.85 J6	15.83 J6	205.56 J6	11.69 J6	13.16 J6
Silver				0.04 J4	0.07 J4	0.03 J4	0.03 J4
Barium	188.63 J1	243.14 J1	193.90 J1	201.01 J1	319.23 J1	158.09 J1	141.88 J1
Beryllium	1.15 J4	1.72 J4	1.39 J4	1.53 J4	1.81 J4	1.20 J4	1.03 J4
Cadmium							
Chromium	27.69 J6	40.15 J6	27.93 J6	37.56 J6	33.86 J6	29.78 J6	27.23 J6
Nickel	15.60 J4	25.56 J4	17.68 J4	22.61 J4	19.71 J4	18.01 J4	15.45 J4
Mercury						0.12 J4	
EXPLOSIVES (ug/g)							
2,4,6-Trinitrotoluene			48.54 J4				11.67 J4
2,4-Dinitrotoluene							
2,6-Dinitrotoluene							
Cyclotetramethylenetetranitramine (HMX)							
Cyclonite (RDX)							
OTHER (ug/g)							
Total Organic Carbon						3088.24	1830.66

* 54SB10B20 is a duplicate sample of 54SB10B17

TABLE 10.4
POSITIVE RESULTS TABLE OF SWMU 54 - Solid Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	54SB11A2	54SB11B17	54SB12A2	54SB12B17	54SB13A2	54SB13B22	54SB14A2
METALS (ug/g)							
Arsenic							
Lead	91.13 J6	12.11 J6	21.22 J6	13.28 J6	134.97 J6	8.23 J6	36.56 J6
Silver					0.07 J4		
Barium	223.57 J1	175.55 J1	235.96 J1	248.34 J1	226.99 J1	118.64 J1	153.30 J1
Beryllium	1.49 J4	1.34 J4	1.54 J4	1.82 J4	1.42 J4		0.89 J4
Cadmium							
Chromium	33.17 J6	32.93 J6	36.08 J6	46.48 J6	31.29 J6	32.32 J6	20.52 J6
Nickel	20.05 J4	18.89 J4	20.10 J4	26.43 J4	18.90 J4	13.20 J4	12.38 J4
Mercury							
EXPLOSIVES (ug/g)							
2,4,6-Trinitrotoluene							
2,4-Dinitrotoluene							
2,6-Dinitrotoluene							
Cyclotetramethylenetetranitramine (HMX)							
Cyclonite (RDX)							
OTHER (ug/g)							
Total Organic Carbon							

TABLE 10.4
POSITIVE RESULTS TABLE OF SWMU 54 - Solid Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	54SB14B15	54SB15A6	54SB16A2	54SB16B12	54SB16B25*
METALS (ug/g)					
Arsenic					
Lead	13.25 J6	28.40 J6	31.82 J6	14.81 J6	13.68 J6
Silver					
Barium	166.27 J1	338.27 J1	231.33 J1	203.70 J1	237.56 J1
Beryllium	1.08 J4	1.93 J4	1.47 J4	1.48 J4	1.77 J4
Cadmium					
Chromium	34.10 J6	45.93 J6	34.27 J6	34.20 J6	43.53 J6
Nickel	20.12 J4	26.05 J4	20.56 J4	20.12 J4	24.25 J4
Mercury					
EXPLOSIVES (ug/g)					
2,4,6-Trinitrotoluene					
2,4-Dinitrotoluene					
2,6-Dinitrotoluene					
Cyclotetramethylenetetranitramine (HMX)					
Cyclonite (RDX)					
OTHER (ug/g)					
Total Organic Carbon	1903.61			2740.74	2860.70

* 54SB16B25 is a duplicate sample of 54SB16B12

TABLE 10.5
POSITIVE RESULTS TABLE OF SWMU 54 - Aqueous Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	54MW1	54MW1 Dissolved	54MW2	54MW2 Dissolved	54MW3	54MW3 Dissolved
METALS (ug/l)						
Arsenic	20.7	15.1				
Lead	16.6	6.33	9.31			
Barium	1060	519	144	89.5	175	106
Beryllium	20	13.2	3.19	2.96	4.09	2.82
Chromium	66.7	26.6				
Nickel	37.4					
Antimony	110	97.5				
EXPLOSIVES (ug/l)						
Cyclotetramethylenetetranitramine (HMX)			4.63		3.18 J10	
OTHER (ug/l)						
Total Organic Carbon	1170					
Total Organic Halogens	10.8		13 J7			

10.5.1.1.4. HMX was detected in two soil boring samples, 54SB3A2 and 54SB6B15. The maximum concentration was 7.28 ug/g in 54SB6B15. RDX was only found in 54SB3A2 at 1.98 ug/g. Other compounds with positive results, which did not exceed background levels or levels considered to be a human health threat, included arsenic, silver, barium, beryllium, cadmium, chromium, nickel, and 2,6-Dinitrotoluene.

10.5.1.2 Groundwater

10.5.1.2.1. Seven COCs (six metals and one explosive) were identified in the groundwater in SWMU 54. They included antimony, arsenic, barium, beryllium, chromium (as chromium III), lead, and the explosive, HMX. Antimony, arsenic, and beryllium were found at concentrations considered to be a potential human health risk. All of these compounds were categorized as the risk drivers for the groundwater at SWMU 54.

10.5.1.2.2. Arsenic and antimony were only detected in the sample from 54MW1, at a concentration of 15.1 ug/l (dissolved) and 97.5 ug/l (dissolved), respectively. Beryllium was found in the samples from all three monitoring wells, ranging from 2.82 ug/l to 13.2 ug/l beryllium (dissolved). The maximum concentration was detected in the sample from 54MW1. Barium was also found in the samples from all three wells. The maximum detection was from the 54MW1 dissolved sample, 519 ug/l. The explosive, HMX, was found in the samples from 54MW2 (4.63 ug/l) and 54MW3 (3.18 ug/l).

10.5.1.2.3. Of the remaining COCs, dissolved lead was only detected in the sample from 54MW1 (6.33 ug/l). Total lead was detected in 54MW1 and 54MW2 at 16.6 ug/l and 9.31 ug/l, respectively. Chromium was only detected in the sample from 54MW1. A positive result for nickel was not at levels considered to be a COC. It was detected in the total nickel sample from 54MW1.

10.5.2 Extent of Contamination

10.5.2.1 Subsurface Soils

10.5.2.1.1. The maximum concentration of 2,4,6-TNT was found in the 12-13 feet bgs sample (taken from that interval in a five foot Moss spoon) of boring 54SB6. This boring was located in the center of the southern ash disposal mound. Approximately 40 feet west of that boring, the next highest concentration was found, 2988.51 ug/g in 54SB3A2. However, this sample was collected from 1-2 feet bgs. The next highest results were found in the deep sample from 54SB3 and in 54SB9A7 (mid-way between the two mounds at 5-7 feet bgs). The other explosives identified as COCs, RDX and HMX, were only found together in 54SB3A2; HMX was also found in the deep sample from boring 54SB6. That boring sample was also positive for 2,6-Dinitrotoluene.

10.5.2.1.2. The highest mercury detection was found in 54SB6A2, in the southern mound; this sample also contained the maximum lead concentration. The next highest mercury concentration, 5.06 ug/g was detected in the 54SB3A2 sample. Mercury was generally found at significant levels in the shallow B horizon samples. None of the deep boring samples exceeded the mercury background level.

10.5.2.1.3. In general, the metals and explosives contamination was found in the shallow samples, approximately 1-3 feet bgs. The most significant results were in the samples from two borings, 54SB3 and 54SB6. Of these two, only 54SB6 contained notable contaminant concentrations in the deep sample (12-13 feet bgs). These borings are either in or near the southern disposal mound; the sample from the center of the northern mound, 54SB15 contained only one COC, but at levels below background.

10.5.2.2 Groundwater

10.5.2.2.1. Of the risk driver compounds, all of the maximum metals concentrations were found in the samples from 54MW1. This well has been shown to be upgradient from the ash disposal areas of SWMU 54. Only one of the risk driver metals (beryllium) was found in the downgradient well samples. The explosive COC compound, HMX, was found in the samples from 54MW2 and 54MW3. The highest concentration was found in the sample from the well (54MW2) nearest the southern mound where most of the soil contamination was identified.

10.6 CONTAMINANT FATE AND TRANSPORT

10.6.0.1. The environmental fate and transport of chemicals is dependent on the physical and chemical properties of the compounds, the environmental transformation processes affecting them, and the media through which they migrate. At SWMU 54, both the surface water and groundwater are potential migration pathways to the New River. The areas of shallow soil contamination and ash layers are susceptible to periodic flooding of the New River and transport downstream. The river is approximately 150 feet from the SWMU. Groundwater appears to be discharging directly to the river.

10.6.0.2. Soil and sediment are important media for chemical transport of the explosives compounds since they have a high affinity for organic matter and a low water solubility. When present in soil or sediments, explosives tend to remain bound to the soil particles and dissolve slowly into groundwater. Because of the high affinity for organic matter, the fate of these explosive compounds is often controlled by transport of particulates. 2,4,6-TNT, the explosive risk driver compound for subsurface soils at SWMU 54 was also found in the sediment sample (NRSE5) collected from the New River, just downstream of the SWMU; the concentration of 2,4,6-TNT in that sample was the highest detected in the New River sediments. Explosives, however, are not readily bioaccumulated by living organisms.

10.6.0.3. Mercury is generally immobile in the types of relatively clayey soils at the SWMU; it was not found in the New River sediments downstream of SWMU 54. Dissolved metals in the groundwater are mobile, but the risk driver compounds in SWMU 54 groundwater were not found in the surface water samples downstream of the SWMU. Only barium, which was identified as a COC for dissolved concentrations at SWMU 54, was found in downstream surface water samples. Arsenic and beryllium, which were risk drivers for dissolved groundwater at SWMU 54 were detected in the sediment sample NRSE5.

10.6.0.4. Subsurface transport of lead is generally minimal because of its low solubility and tendency to sorb to aquifer materials. However, lead was determined to be a COC in groundwater and subsurface soils at SWMU 54; although lead was not detected in the New River surface water sample, it was found in the associated sediment sample. Lead also exceeded the TCLP regulatory limit in the waste ash sample.

10.7 RISK ASSESSMENT

10.7.0.1. The propellant ash disposal area is unlined and contains areas where ash residue is visible on surface soils. Ash disposal reportedly occurred on the soil surface at this area. This does not limit the potential for emissions to the atmosphere and contaminants migrating from disposed ash to surface and subsurface soils, surface waters and groundwater.

10.7.0.2. At present, future land use at this SWMU is uncertain; SWMU 54 is located outside the RAAP fence and within 200 feet of the New River. Currently, ash is no longer disposed at this area. Potential future scenarios may consist of removing the ash and any associated contaminated soils, or installing a cap and closing this disposal area.

10.7.1 Summary of Chemicals of Potential Concern

10.7.1.0.1. The chemicals considered in the risk evaluation for groundwater at SWMU 54 include 6 metals (antimony, arsenic, barium, beryllium, chromium III and lead) and one explosive (HMX). The chemicals of concern for subsurface soils include 2 metals (lead and mercury), one volatile (2,4-dinitritoluene) and three explosives (2,4,6-trinitrotoluene, HMX and RDX).

10.7.1.1 Comparison to ARARs and TBCs for Groundwater and Soils

10.7.1.1.1. Groundwater in the vicinity of RAAP is not used for drinking water serving more than 25 people and therefore MCLs and MCLGs are not considered as ARARs for SWMU 31. In addition, there are no Federal or Commonwealth of Virginia standards relating chemical concentrations in soils to toxic effects on vegetation or wildlife. TBC criteria considered for human health risk evaluation included reference doses (RfDs) and slope factors (SFs) from USEPA's Integrated Risk Information System and Health Effects Assessment Summary Table (USEPA, 1995).

10.7.2 Exposure Assessment

10.7.2.1 Potential Pathways and Receptors

10.7.2.1.1. Current exposure pathways at SWMU 54 are considered to have a low probability of completion, with the exception of the construction worker exposure scenario. At present, this area is no longer used for propellant ash disposal. Although current site workers have access to potentially contaminated surface soils with and areas of uncovered ash, surface soil samples from this SWMU did not exhibit positive detects for analytes other than reactive sulfite. SWMU 54 is located outside the RAAP boundary and within 200 feet of the New River; thus public access is not limited to exclude recreational users of the New River. However, the area between this SWMU and the river is densely vegetated which would prohibit contaminant exposure by recreational river users. This exposure pathway was determined to have a low probability of completion and was not quantified. In addition, the current groundwater pathway is not complete as this water is not used for drinking purposes.

10.7.2.1.2. Potential future routes of human exposure which were considered for SWMU 54 include site worker ingestion and dermal exposure to potentially contaminated groundwater.

10.7.2.1.3. The conceptual site model summary for SWMU 54 is presented in Figure 10.5 and includes exposure routes, potential receptors and the medium containing the potential contaminants of concern. All chemicals not eliminated by data validation were considered in the risk assessment for this SWMU.

10.7.2.2 Exposure Point Concentrations and Chronic Daily Intakes

10.7.2.2.1. Exposure point concentrations for the seven metals and one explosive detected in SWMU 54 (see Subsection 10.7.1) groundwater are listed in the tables in Appendix I. These concentrations range from 0.00158 mg/L (HMX) to 0.17 mg/L (barium). Exposure point concentrations for the contaminants of concern in subsurface soils (also see Section 10.7.1) range from 0.943 ppm (RDX) to 2,210 ppm (lead).

10.7.3 Risk Characterization

10.7.3.0.1. The carcinogenic risk and hazard index were calculated for the groundwater ingestion and dermal contact pathways (future site worker receptor) and subsurface soil ingestion, dermal contact, and inhalation of volatiles and particulates (construction worker). These calculations are presented in Appendix I. A discussion of the results of each pathway for non-carcinogenic and carcinogenic effects is presented below.

10.7.3.1 Non-carcinogenic Effects

10.7.3.1.1. The calculated hazard indices for the hypothetical future site worker groundwater ingestion scenario exceed acceptable levels primarily due to antimony and arsenic for CT and RME receptors. The primary risk driver for the ingestion scenario is

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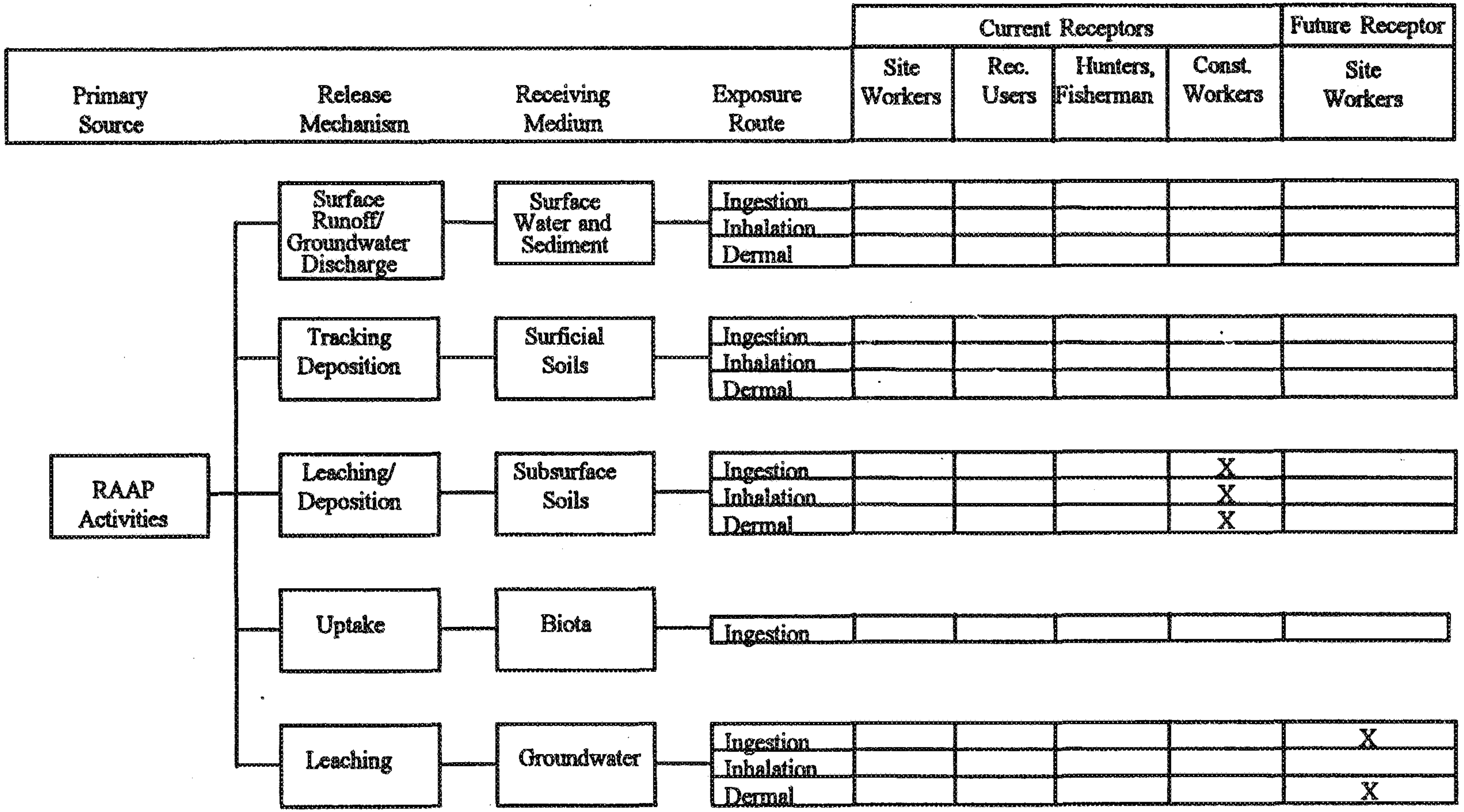
Figure 10.5
Conceptual Site Model for Current and Future Exposure Pathways
SWMU 54
Radford Army Ammunition Plant
Radford, Virginia



				Current Receptors				Future Receptor
Primary Source	Release Mechanism	Receiving Medium	Exposure Route	Site Workers	Rec. Users	Hunters, Fisherman	Const. Workers	Site Workers
RAAP Activities	Surface Runoff/ Groundwater Discharge	Surface Water and Sediment	Ingestion					
			Inhalation					
			Dermal					
	Tracking Deposition	Surficial Soils	Ingestion					
			Inhalation					
			Dermal					
	Leaching/ Deposition	Subsurface Soils	Ingestion				X	
			Inhalation				X	
			Dermal				X	
	Uptake	Biota	Ingestion					
	Leaching	Groundwater	Ingestion					X
			Inhalation					
			Dermal					X

X = Pathways of potential concern
H = Hunter scenario

antimony, with calculated hazard indices for CT and RME receptors being 0.27 and 1.09, respectively.

10.7.3.1.2. The calculated hazard index for the construction worker subsurface soil ingestion scenario exceeds acceptable levels primarily due to 2,4,6-trinitrotoluene (2,4,6-TNT) for RME receptors (HI = 3.64). Mercury is the only other compound which shows a hazard index, and this is below one for both CT and RME receptors. The primary risk drivers for the construction worker dermal contact exposure scenario are mercury and 2,4,6-TNT. The calculated hazard indices for CT and RME receptors for mercury are 1.77 and 2.29, respectively. The calculated hazard indices for CT and RME receptors for 2,4,6-TNT are 1.20 and 1.55, respectively. The construction worker inhalation of volatiles and particulates exposure scenarios did not result in hazard indices exceeding one.

10.7.3.2 Carcinogenic Effects

10.7.3.2.1. The calculated cancer risks for the hypothetical future site worker groundwater dermal contact scenario are within the USEPA target risk range primarily due to beryllium, for CT and RME receptors. Beryllium was calculated to have the highest cancer risk, with calculations for CT and RME receptors being 1.64×10^{-6} and 3.28×10^{-5}, respectively. Total cancer risks for the hypothetical future site worker groundwater ingestion scenario are also within the USEPA target risk range due to arsenic and beryllium. Again, the primary risk driver for this exposure scenario was beryllium, with risks for CT and RME receptors being 3.60×10^{-6} and 7.20×10^{-5}, respectively.

10.7.3.2.2. The calculated cancer risks for the construction worker subsurface soil ingestion exposure scenario are within the USEPA target risk range for RME receptors, due to 2,4,6-TNT (1.57×10^{-6}). Calculated cancer risks for the dermal contact exposure scenario were below the USEPA target risk range. There were no calculated cancer risks for the future construction worker inhalation of volatiles and particulates exposure scenarios.

10.7.4 Uncertainty Analysis

10.7.4.0.1. Data collection/evaluation uncertainty may be relevant at SWMU 54 due to the types and numbers of samples collected. Analyses performed on the surface soil samples from the propellant ash disposal area only yielded positive results for reactive sulfite and these results are not quantifiable for risk assessment purposes. It has also been reported that the propellant ash is uncovered in several places at this SWMU and current site workers may be exposed to residual ash. Current site worker risks from potential contamination through exposure to surface soils are not quantifiable and unknown, and this may underestimate the risk from this site.

10.7.4.0.2. Many metals detected at this site in groundwater and subsurface soils are naturally occurring and in some cases (i.e., subsurface soil), statistical methods were used to distinguish site-related from non-site-related metals. In this case, all metals detected in groundwater were retained as if they were site-related. The calculations have shown to present unacceptable risks due to these metals and this could be an overestimate due to natural metals concentration in groundwater.

10.7.4.0.3. SWMU 54 is located outside the RAAP boundaries and is within 150 feet of the New River, which is used by recreational users and fishermen. Although there is dense vegetation serving as a natural barrier which may prevent recreational users from coming into contact with potentially contaminated surface soils, there is the possibility of the completion of this exposure pathway. This pathway was determined to be low probability and was not quantified. This may tend to underestimate risk from this SWMU.

10.7.4.0.4. Another area of uncertainty in evaluating human health risk from SWMU 54 is toxicity assessment. Oral and dermal slope factors are not available for some of the metals and explosives which were detected in groundwater and subsurface soils. Most studies are based on animal data and extrapolated to humans and also subchronic studies may be used assess chronic effects. In addition, extrapolations are characterized by uncertainty factors which can be as large as four orders of magnitude. This may tend to over- or underestimate risk.

10.7.4.0.5. The inhalation of volatiles and particulates from soils may also be another source of uncertainty for this SWMU. This exposure scenario was evaluated for construction workers in this area. The chemicals of concern in subsurface soils do not have associated inhalation RfDs or slope factors, and therefore the risks from this pathway are not quantifiable. This may tend to underestimate the risk.

10.8 RISK SUMMARY

10.8.0.1. Carcinogenic risks and non-carcinogenic hazard indices were calculated for site worker receptors potentially exposed to multiple chemicals in groundwater during domestic use, and construction workers potentially exposed to multiple chemicals in subsurface soils. The groundwater and subsurface soil pathway calculations were summarized and are presented in Table 10.6. Under the NCP, the probability of excess cancers over a lifetime of exposure within or below USEPA's target risk range of 1×10^{-4} to 1×10^{-6} are considered to pose a low threat while a probability of excess cancers over a lifetime of exposures greater than 1×10^{-4} may pose an unacceptable threat of adverse health effects. For noncarcinogens, a hazard index less than one is considered to pose a low threat of adverse health effects, while a hazard index greater than one may pose an unacceptable threat of adverse health effects.

10.8.0.2. At SWMU 54, the site worker RME receptors' total hazard index is greater than one for ingestion of groundwater. Also, the total cancer risk value for these scenarios is within the USEPA target risk range of 1×10^{-6} to 1×10^{-4}. These values indicate a potential for noncarcinogenic and carcinogenic adverse human health effects for this receptor.

10.8.0.3. The construction worker CT and RME receptors' total hazard index is greater than one. The RME receptors' total cancer risk is within the USEPA target risk range. These values indicate a potential for noncarcinogenic and carcinogenic adverse human health effects for the exposure scenarios for the RME.

10.9 SWMU 54 SUMMARY

10.9.0.1. The groundwater associated with SWMU 54 appears to reside in the alluvial sediments overlying the limestone bedrock; groundwater flow direction is toward the New River. Groundwater, subsurface soils, and waste ash samples were collected to characterize SWMU 54. Additionally, a surface water and sediment sample was collected from the New River at the likely discharge point of groundwater from beneath the SWMU.

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Table 10.6
Summary of Human Health Risk
SWMU 54
Radford Army Ammunition Plant

Receptor	Pathways	HI		Cancer Risk	
		CT	RME	CT	RME
Site Worker	Ingestion of Groundwater	0.30	1.21	4.32E-06	8.65E-05
	Dermal Contact with Groundwater	0.13	0.50	1.64E-06	3.29E-05
Total for Site Workers		0.43	1.71	5.96E-06	1.19E-04
Construction Worker	Ingestion of Subsurface Soil	0.82	3.92	8.20E-08	1.57E-06
	Dermal Contact with Subsurface Soil	2.97	3.85	1.29E-07	6.72E-07
	Inhalation of Subsurface Soil Volatile	0	0	0.00E+00	0.00E+00
	Inhalation of Subsurface Soil Particul	0	0	0.00E+00	0.00E+00
Total for Construction Workers		3.79	7.77	2.11E-07	2.24E-06

10.9.0.2. Mercury and 2,4,6-TNT were determined to be risk drivers for the subsurface soils. Antimony, arsenic, and beryllium were identified as the risk drivers for the groundwater. A waste ash sample contained a TCLP lead concentration which exceeded the regulatory level. Lead was categorized as a COC in the subsurface soils and in the groundwater.

10.9.0.3. In general, the metals and explosives contamination was found in the shallow subsurface soil samples. The highest concentrations appeared to be in the samples in or near the southern disposal mound. The upgradient groundwater sample contained all of the risk driver compounds suggesting an upgradient source contributing to SWMU 54 groundwater quality; however, only the downgradient monitoring well samples contained detectable concentrations of the explosive risk driver compound, HMX. Arsenic, beryllium, and 2,4,6-TNT, which were risk driver compounds in either the subsurface soil or the groundwater, were found in the New River sediment sample collected downstream of the SWMU, indicating contaminant migration.

10.9.0.4. The human health risk assessment indicated a potential for noncarcinogenic and carcinogenic adverse human health effects by the dermal and ingestion exposure scenarios for groundwater and subsurface soils for construction worker and site worker receptors. SWMU 54 is outside of the facility security fence and is accessible from the New River.

SECTION 11

SITE CHARACTERIZATION OF STROUBLES CREEK

11.1 ENVIRONMENTAL SETTING

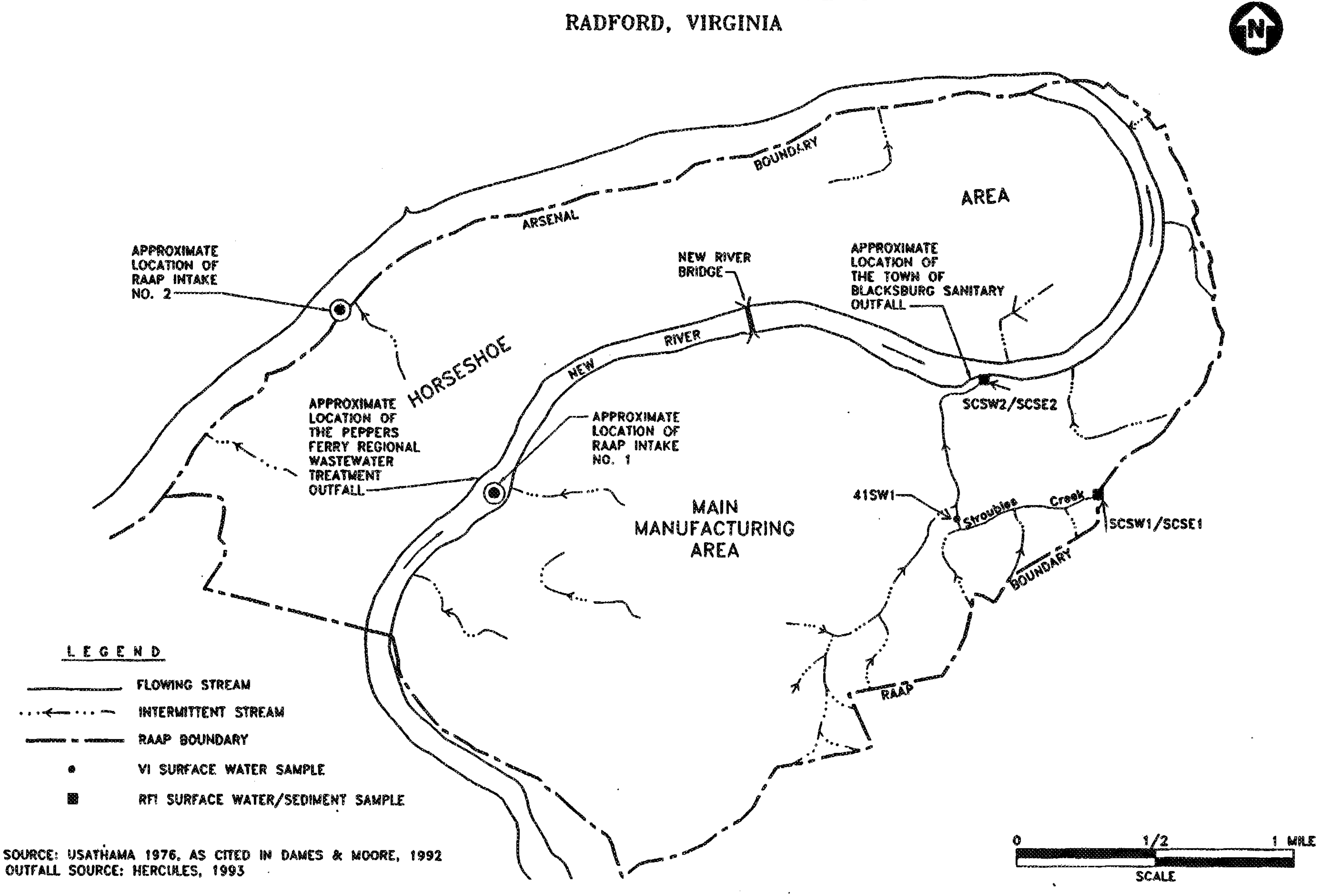
11.1.0.1. Stroubles Creek is the largest local tributary of the New River and flows through the southeast sector of RAAP (Figure 11.1). This creek is fed by several branches that originate on and off the facility. Stroubles Creek consists primarily of stormwater runoff. Groundwater discharging from the karst bedrock may also supply significant stream flow. Prior to entering the facility, branches of Stroubles Creek flow through rural areas and through the City of Blacksburg. The creek empties into the New River within RAAP and contributes significant loading of domestic and industrial wastewater (USATHAMA, 1976). The Blacksburg Municipal Wastewater Treatment Plant discharges approximately 5.7 million gallons per day (mgd) of water into the New River just upstream of where Stroubles Creek empties into the river (Personal Communication, 1995). The Commonwealth of Virginia has classified Stroubles Creek and the portion of the New River passing through the confines of RAAP as water generally satisfactory for beneficial uses; these include, public or municipal water supply, secondary contact recreation, and propagation of fish and aquatic life (USATHAMA, 1976).

11.2 PREVIOUS INVESTIGATIONS

11.2.0.1. A verification investigation (VI) of the Red Water Ash Landfill (SWMU 41) was conducted by Dames & Moore in the Fall of 1991. SWMU 41 is located in the eastern section of the Main Manufacturing Area near a portion of Stroubles Creek. During the VI, one surface water sample was collected from Stroubles Creek at a location approximately 75 feet east of the SWMU 41 lagoon. No other sampling of Stroubles Creek is known to have occurred.

11.2.0.2. Figure 11.1 shows the approximate location of the Stroubles Creek sampling point (41SW1). The SWMU 41 lagoon was an ash disposal unit. Leachate from the lagoon had reportedly been observed along the downslope bank; sample 41SW1 was

FIGURE 11.1
STROUBLES CREEK LOCATION MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



SOURCE: USATHAMA 1976, AS CITED IN DAMES & MOORE, 1992
OUTFALL SOURCE: HERCULES, 1993

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collected at a point where the seep may have entered the creek. The sample was analyzed for metals, explosives, SVOCs, TOC, TOX, and pH.

11.2.0.3. In total, seven metals were detected above the PQLs in the surface water sample (Table 11.1). The metals are common earth elements that were reported at concentrations less than the HBN criteria. One explosive (2,4,6-TNT) was detected in the sample but was reported at a level less than the HBN criterion. The source for the 2,4,6-TNT in the surface water could not be attributed to SWMU 41 since no explosives were detected in any of the on-site samples. Dames & Moore suggested that material in Stroubles Creek or a tributary was adversely impacted when the TNT area was destroyed by the explosion in 1974. TOC and TOX were reported at 6,010 μg/l and 82.4 μg/l. No SVOCs were detected in the creek sample.

11.3 SUMMARY OF RFI FIELD ACTIVITIES

11.3.0.1. Two surface water samples and their associated sediment samples were collected from Stroubles Creek at two locations for the RFI in January 1995. Samples SCSW1 and SCSE1 (surface water and sediment, respectively) were taken at the upstream facility boundary. This location is upstream of all active areas of RAAP. Samples SCSW2 and SCSE2 were taken downstream just prior to Stroubles Creek's discharge to the New River. A duplicate surface water and sediment sample were also collected at this location. Both sampling locations are shown in Figure 11.1. The aqueous samples were analyzed for total metals, explosives, VOCs, SVOCs, TOC, TOX, chloride, and hardness. The sediment samples were analyzed for the same parameters with the exception of chloride and hardness (see Tables 4.3 and 4.4). Field measurements of pH, conductivity, and temperature were also recorded.

11.4 NATURE AND EXTENT OF CONTAMINATION

11.4.0.1. A summary of all positive results (detected compounds) for sediments and surface water of Stroubles Creek is presented in Tables 11.2 and 11.3, respectively. The chemicals of concern (COCs) for Stroubles Creek were determined by the methods discussed in Section 6. This section focuses on those COCs identified as potential human health threats as detailed in the subsequent Risk Assessment subsections.

TABLE 11.1

Summary of Analytical Data For Surface Water Samples Collected At SWMU 41
Radford Army Ammunition Plant, Virginia

SITE ID		41SW1	
FIELD ID		RDWC*76	
S. DATE		10-mar-92	
DEPTH (ft)		0.0	
MATRIX	PQLs	CSW	HBN
UNITS	UGL	UGL	UGL
TAL Inorganics			
BARIUM	20	55.9	1000
CALCIUM	500	58500	NSA
IRON	38.1	199	NSA
MAGNESIUM	500	29300	NSA
MANGANESE	2.75	27.8	3500
POTASSIUM	375	1850	NSA
SODIUM	500	14900	NSA
Explosives			
246TNT	0.635	1.38	11.7
Semivolatiles	NA	None Detected	NSA
Other			
TOTAL ORGANIC CARBON	1000	6010	NSA
TOTAL ORGANIC HALOGENS	1	82.4	NSA
pH	NA	7.99	NSA

Footnotes:

CSW = Chemical surface water.

HBN = Health based number as defined in the RCRA permit. HBNs not specified in the permit were derived using standard exposure and intake assumptions consistent with EPA guidelines (51 Federal Register 33992, 34006, 34014, and 34028).

NA = Not available; PQLs are not available for TICs detected in the library scans.

NSA = No standard (HBN) available; health effects data were not available for the calculation of a HBN. HBNs were not derived for TICs.

PQL = Practical quantitation limit; the lowest concentration that can be reliably detected at a defined level of precision for a given analytical method.

TAL = Target Analyte List.

UGL = Micrograms per liter.

REFERENCE: Dames & Moore, Verification Investigation, August 1992

TABLE 11.2
POSITIVE RESULTS TABLE OF STROUBLES CREEK - Sediment Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	SCSE1	SCSE2	SCSE3 *
METALS (ug/g)			
Arsenic	10.59 J4	9.03 J4	6.70 J4
Lead	13.41 J6	95.87 J6	31.21 J6
Silver	0.03 J4	0.18 J4	0.21 J4
Barium	141.45 J1	240.41 J1	262.41 J1
Beryllium	1.38 J4	1.45 J4	1.39 J4
Chromium	27.80 J6	39.53 J6	36.17 J6
Nickel	32.60 J4	26.99 J4	26.10 J4
SEMIVOLATILES (ug/g)			
Chrysene		0.22	
Di-n-butyl phthalate		7.82 J1	5.53 J1
Fluoranthene		0.27	0.16
Phenanthrene		0.29	0.13
OTHER (ug/g)			
Total Organic Carbon	2841.33	63274.30	43829.80
Extractable Organic Halides (total)	123.00	147.49	141.84

* SCSE3 is a duplicate sample of SCSE2

TABLE 11.3
POSITIVE RESULTS TABLE OF STROUBLES CREEK - Aqueous Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	SCSW1	SCSW2	SCSW3*
METALS (ug/l)			
Barium	44.7 J4	47.3 J4	48 J4
Beryllium	1.95	2.22	2.23
Chromium		30.9 J4	
EXPLOSIVES (ug/l)			
Cyclotetramethylenetetranitramine (HMX)	5.3 J9	5.3 J9	5.3 J9
OTHER (ug/l)			
*TOTAL HARDNESS	148000	152000	153000
*TOTAL ORGANIC CARBON	2690	2490 J7	2370
*TOTAL ORGANIC HALOGENS	16.9	18 J7	16
CHLORIDE	11000	10000	11000

* SCSW3 is a duplicate sample of SCSW2

11.4.1 Nature of Contamination

11.4.1.1 Sediments

11.4.1.1.1. Eleven COCs were identified in the sediments of Stroubles Creek: arsenic, barium, beryllium, chromium (as chromium III), chrysene, di-n-butyl phthalate, fluoranthene, lead, nickel, phenanthrene, and silver. Arsenic and beryllium were considered to pose potential human health risks. Arsenic and beryllium were considered to be the risk drivers for sediment in Stroubles Creek.

11.4.1.1.2. Arsenic was found at 10.59 ug/g in the sample from SCSE1 and at 9.03 ug/g in the sample from SCSE2. A beryllium concentration of 1.38 ug/g was detected in the sample from SCSE1 and 1.45 ug/g in the sample from SCSE2. Barium was detected at 141.45 ug/g in the sample from SCSE1 and at 240.41 ug/g in the sample from SCSE2. Nickel was also found in both sediment samples; SCSE1 contained 32.60 ug/g and SCSE2 contained 26.99 ug/g.

11.4.1.1.3. The other metals categorized as COCs were detected in maximum concentrations as follows: chromium at 39.53 ug/g, lead at 95.87 ug/g, and silver at 0.18 ug/g. All of these results were found in sample SCSE2. Other maximum concentrations of COCs were for SVOcs as follows: chrysene at 0.22 ug/g, di-n-butyl phthalate at 7.82 ug/g fluoranthene at 0.27 ug/g, and phenanthrene at 0.29 ug/g. These SVOCs were only detected in sample SCSE2.

11.4.1.2 Surface Water

11.4.1.2.1. Four COCs were identified for the surface water of Stroubles Creek: barium, beryllium, chromium (as chromium III), and HMX. Of these, only beryllium was categorized as a risk driver. Barium was detected in both samples. The maximum concentration was 47.3 ug/l in SCSW2. Beryllium was also found in both samples; the maximum detection was 2.22 ug/l in SCSW2. HMX was found in both samples at 5.3 ug/l. Chromium was only detected in the SCSW2 sample (30.9 ug/l).

11.4.2 Extent of Contamination

11.4.2.1 Sediment

11.4.2.1.1. Sample SCSE1 was collected upstream from the facility. All of the metals COCs were found in this upstream sample. Arsenic, a risk driver, and nickel were detected at higher levels in this sample than in the downstream sample. None of the SVOC COCs were found in the upstream sample. Upstream from the SCSE1 location, Stroubles Creek has flowed through rural areas and the City of Blacksburg.

11.4.2.1.2. The downstream sample, SCSE2, contained the SVOC COCs, as well as the maximum concentrations of the risk driver beryllium. The upstream barium concentration was 141.45 ug/g and the downstream concentration was 240.41 ug/g. The upstream beryllium concentration was 1.38 ug/g and the downstream concentration was 1.45 ug/g. Downstream lead and silver concentrations were much higher than upstream concentrations, but they were not found at levels considered to pose a potential threat to human health.

11.4.2.2 Surface Water

11.4.2.2.1. The risk driver compound for Stroubles Creek surface water (beryllium), barium, and HMX, were found in both samples. Concentrations of these compounds were at similar levels in both samples. The downstream sample, SCSW2, was the only sample which contained chromium.

11.5 CONTAMINANT FATE AND TRANSPORT

11.5.0.1. The environmental fate and transport of chemicals is dependent on the physical and chemical properties of the compounds, the environmental transformation processes affecting them, and the media through which they migrate. Contaminants detected in Stroubles Creek are subject to transport downstream as dissolved constituents, particulates or suspended solids. Stroubles Creek discharges to the New River within the facility boundaries. Dilution of contaminants, when considering New River receptors downstream of RAAP, will be significant.

11.5.0.2. The source of the explosive COC compound, HMX, in the surface water is not known. Dames & Moore suggested in the previous sampling investigation of Stroubles Creek that residual explosives from the TNT area may have filtered into the creek as a result of the 1974 explosion. However, this would not account for the presence of HMX in the upstream sample. HMX does not show up in the New River samples downstream of the Stroubles Creek sample locations. Explosive compounds are not readily bioaccumulated by living organisms. Explosives are usually transported through the movement of particulates, however, no explosives were found in the associated sediment sample. This may indicate migration to the creek by surface water runoff.

11.5.0.3. Barium and beryllium surface water concentrations are slightly higher in the downstream samples than the upstream ones. However, the difference in concentrations do not suggest that the SWMU 41 ash disposal lagoon has contributed significant amounts of metals to Stroubles Creek. Barium was also found in the New River samples downstream of the Stroubles Creek sample locations.

11.5.0.4. The downstream sediment sample does appear to contain levels of contaminants not present in the upstream sample, particularly SVOCs. When present in sediments, SVOCs tend to remain bound to the soil particles and dissolve slowly into the overlying water. Because of their affinity for organic matter, SVOCs are readily bioaccumulated by living organisms. Barium and beryllium concentrations are higher downstream than upstream. Those metals have also been found in the New River sediments downstream of the Stroubles Creek sample locations. The mobilization of metals would most likely be through suspended sediment.

11.6 RISK ASSESSMENT

11.6.0.1. Stroubles Creek is the largest tributary running into the New River. The creek runs through the RAAP and is largely made up of stormwater run-off. As a result, the water quality of the creek can be greatly affected by on-site operations. Moreover, Stroubles Creek also feeds the New River and has an affect on the surface water and sediment in the river.

11.6.0.2. Future land use in the Stroubles Creek area of the RAAP is uncertain; the area may be used for additional commercial development. It is unlikely that this area will

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undergo residential development. Consequently, surface water and sediment was analyzed for all current exposure possibilities.

11.6.1 Summary of Chemicals of Potential Concern

11.6.1.1. The chemicals considered in the risk evaluation for sediment at Stroubles Creek include 7 metals (arsenic, barium, beryllium, chromium III, lead, nickel, and silver) and 4 semivolatiles (chrysene, di-n-butyl phthalate, fluoranthene, and phenanthrene).

11.6.1.2. The chemicals considered in the risk evaluation for surface water at Stroubles Creek include 3 metals (barium, beryllium, and chromium III), and one explosive (HMX).

11.6.1.1 Comparison to ARARs and TBCs for Groundwater and Soils

11.6.1.1.1. Groundwater in the vicinity of RAAP is not used for drinking water serving more than 25 people and therefore MCLs and MCLGs are not considered as ARARs for Stroubles Creek. In addition, there are no federal or Commonwealth of Virginia standards relating chemical concentrations in soils to toxic effects on vegetation or wildlife. TBC criteria considered for human health risk evaluation included reference doses (RfDs) and slope factors (SFs) from USEPA's Integrated Risk Information System and Health Effects Assessment Summary Table (USEPA, 1995a).

11.6.2 Exposure Assessment

11.6.2.1 Potential Pathways and Receptors

11.6.2.1.1. Current exposure pathways considered at Stroubles Creek are site workers, construction workers, fishermen, and other recreational users of the creek. The remaining potential receptors have a low probability of completion and therefore, are not quantified for current receptors (area residents). Stroubles Creek runs through the RAAP and public access is allowed to recreational users of surface water in the area. Current routes of human exposure which were considered for Stroubles Creek include ingestion, and dermal exposure to potentially contaminated surface water and sediment through the uses described above.

11.6.2.1.2. The conceptual site model summary for Stroubles Creek is presented in Figure 11.2 and includes exposure routes, potential receptors and the medium containing the potential contaminants of concern. All chemicals not eliminated by data validation were considered in the risk assessment for this SWMU.

11.6.2.2 Exposure Point Concentrations and Chronic Daily Intakes

11.6.2.2.1. Exposure point concentrations for the chemicals of concern evaluated for Stroubles Creek are listed in the tables in Appendix I. These concentrations range from 0.00208 mg/L (beryllium) to 0.046 mg/L (barium) in surface water and 0.066 mg/kg (chrysene) to 184 mg/kg (barium) in sediment.

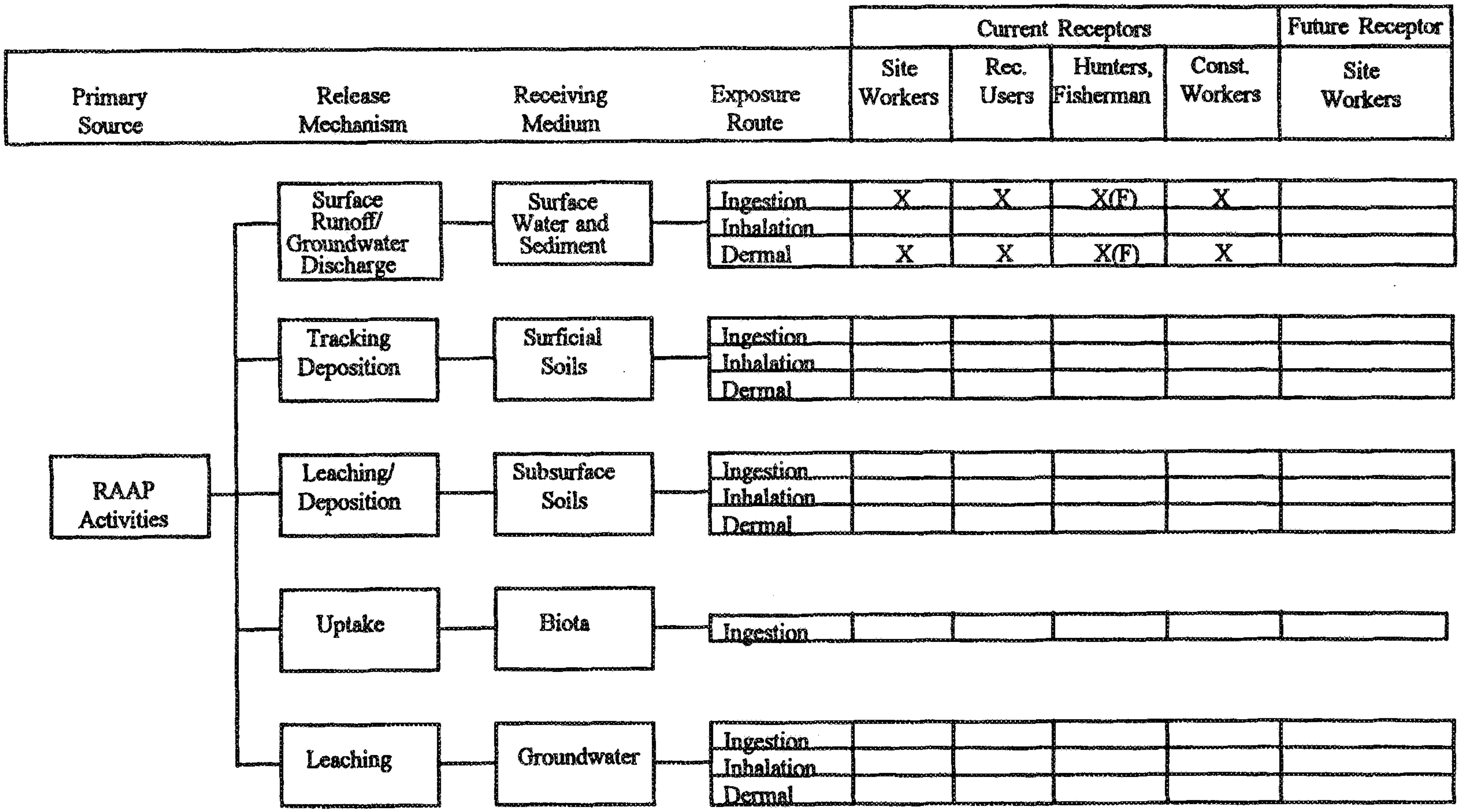
11.6.3 Risk Characterization

11.6.3.0.1. The carcinogenic risk and hazard indices were calculated for the surface water ingestion and dermal contact pathways. These calculations are presented in Appendix I. The calculated hazard indices for the sediment pathway exposure through dermal contact are below risk levels for CT and RME receptors. Moreover, the hazard indices for the surface water pathway exposure through ingestion amd dermal contact are below risk levels for both receptor groups. The cancer risk numbers are also outside the USEPA target risk range of 1 x 10^{-4} to 1 x 10^{-6} by at least one order of magnitude for the CT. For a few exposure scenarios, the cancer risk values are with the USEPA's target range for RME receptors. A discussion of the results of each pathway for non-carcinogenic and carcinogenic effects is presented below.

11.6.3.1 Non-carcinogenic Effects

11.6.3.1.1. The calculated hazard indices for the current site worker exposure to surface water through ingestion and dermal contact scenarios are below acceptable risk levels. The hazard indices calculated for the current site worker exposure to sediment through ingestion and dermal contact scenarios are also below acceptable risk levels for both CT and RME receptors.

Figure 11.2
Conceptual Site Model for Current and Future Exposure Pathways
Stroubles Creek
Radford Army Ammunition Plant
Radford, Virginia



Primary Source	Release Mechanism	Receiving Medium	Exposure Route	Current Receptors: Site Workers	Current Receptors: Rec. Users	Current Receptors: Hunters, Fisherman	Current Receptors: Const. Workers	Future Receptor: Site Workers
RAAP Activities	Surface Runoff/ Groundwater Discharge	Surface Water and Sediment	Ingestion	X	X	X(F)	X	
			Inhalation					
			Dermal	X	X	X(F)	X	
	Tracking Deposition	Surficial Soils	Ingestion					
			Inhalation					
			Dermal					
	Leaching/ Deposition	Subsurface Soils	Ingestion					
			Inhalation					
			Dermal					
	Uptake	Biota	Ingestion					
	Leaching	Groundwater	Ingestion					
			Inhalation					
			Dermal					

X = Pathways of potential concern
F = Fisherman scenario

11.6.3.1.2 The hazard indices for current recreational user of surface water do not exceed acceptable risk levels for either of the exposure scenarios (ingestion or dermal contact) analyzed for Stroubles Creek.

11.6.3.1.3 The calculated hazard index for the fisherman exposure to surface water through dermal contact at Stroubles Creek does not exceed acceptable levels for RME or CT receptors. The hazard index for fisherman exposure to surface water through ingestion also does not exceed acceptable risk levels at Stroubles Creek for either receptor group.

11.6.3.1.4. The calculated hazard indices for the construction worker exposure scenario to surface water through ingestion or dermal contact at Stroubles Creek do not exceed acceptable levels for both CT and RME receptors.

11.6.3.2 Carcinogenic Effects

11.6.3.2.1. The calculated cancer risks for the current site worker exposure to surface water through ingestion and dermal contact scenarios are below USEPA target risk range. The calculated cancer risks for the current site worker exposure to sediment through dermal contact scenario are within USEPA target risk range due to the presence of beryllium and arsenic for RME receptors. All other chemicals of concern evaluated do not exhibit an increased cancer risk due to a lack of toxicity information or because they are below the USEPA target range for cancer risk. Current site worker exposure to sediment through ingestion scenario also exhibits elevated cancer risks for Stroubles Creek for RME receptors. However, the cancer risk is within the USEPA target range due to the presence of arsenic and beryllium in the sediment.

11.6.3.2.2. The calculated cancer risks for the current recreational user exposure to surface water through dermal contact and ingestion scenarios are below USEPA target risk range for acceptable cancer risks levels for these exposure scenarios at Stroubles Creek.

11.6.3.2.3. The calculated cancer risk for the current fisherman exposure to surface water through dermal contact scenario is above the USEPA target risk range for RME receptors due to the presence of beryllium. All other chemicals of concern evaluated do not exhibit an increased cancer risk due to a lack of toxicity information or because they are within the USEPA target range for cancer risk. The cancer risks for current fisherman exposure to surface water through ingestion scenario are below the USEPA target range for cancer risk.

11.6.3.2.4. The calculated cancer risks for the construction worker exposure to surface water through ingestion and dermal contact scenarios are below USEPA target risk range for RME and CT receptors.

11.6.4 Uncertainty Analysis

11.6.4.0.1. Data collection/evaluation uncertainty may be relevant at Stroubles Creek due to the types and numbers of samples collected. Many metals detected at this site in surface water and sediment are naturally occurring and no analysis was accomplished to differentiate between site-related and non-site-related concentrations. In this case, all metals detected in sediment and surface water were retained as if they were site-related. The calculations have shown to present unacceptable risks due to these metals and this could be an overestimate due to natural metals concentration in surface water and sediments.

11.6.4.0.2. One of the main areas of uncertainty is in exposure assessment as relates to determining future land uses at a contaminated site. The majority of the land at RAAP is commercial or industrial to support the explosives manufacturing process, with few scattered residential communities located in Montgomery and Pulaski counties. Access to the Stroubles Creek within RAAP is restricted, and therefore a current residential exposure scenario is unlikely. For the purpose of assessing risk, future land use was assumed to be industrial.

11.6.4.0.3. Another area of uncertainty in evaluating human health risk from Stroubles Creek is toxicity assessment. Oral and dermal slope factors are not available for seven of the nine metals which were detected in groundwater, including lead. Most studies are based on animal data and extrapolated to humans and also subchronic studies may be used assess chronic effects. In addition, extrapolations are characterized by uncertainty factors which can be as large as four orders of magnitude. This may tend to over- or underestimate risk.

11.6.4.0.4. For the chemicals detected in surface water at Stroubles Creek, an exposure scenario was evaluated for fishermen ingesting contaminated fish. This was accomplished using USEPA (1989) standard default exposure values and calculating an expected concentration in fish due to uptake. As with all modeled concentrations, there is a degree of uncertainty associated with these calculations and assumptions. Only chromium III could be quantified in this manner due to the lack of information concerning bioconcentration of the other detected chemicals. This may tend to underestimate the risk for this exposure scenario at Stroubles Creek.

11.7 RISK SUMMARY

11.7.0.1. Carcinogenic risks and non-carcinogenic hazard indices were calculated for current site worker, current fisherman, current recreational, and current construction worker receptors potentially exposed to multiple chemicals in surface water and sediment during use. The surface water pathway calculations were summarized and are presented in Table 11.4. Under the NCP, the probability of excess cancers over a lifetime of exposure within or below USEPA's target risk range of 1 x 10^{-4} to 1 x 10^{-6} are considered to pose a low threat while a probability of excess cancers over a lifetime of exposures greater than 10^{-4} may pose an unacceptable threat of adverse health effects. For noncarcinogens, a hazard index below one is considered to pose a low threat of adverse health effects, while a hazard index greater than one may pose an unacceptable threat of adverse health effects.

11.7.0.2 . At Stroubles Creek, no pathway presents a total hazard index for the creek of greater than one. The total cancer risk values for one exposure scenario was in the USEPA target risk range (site worker RME). Total cancer risks for fishermen (RME) were above the USEPA target risk range. Consequently, these values indicate low potential for noncarcinogenic and a greater potential for carcinogenic adverse human health effects for exposure to surface water or sediment at Stroubles Creek.

Table 11.4
Summary of Human Health Risk
Stroubles Creek
Radford Army Ammunition Plant

Receptor	Pathways	HI		Cancer Risk	
		CT	RME	CT	RME
Site Worker	Ingestion of Surface Water	0	0	3.13E-08	3.13E-07
	Dermal Contact with Surface Water	0	0	7.88E-09	1.06E-07
	Ingestion of Sediment	0	0.01	7.25E-08	1.45E-06
	Dermal Contact with Sediment	0	0	3.69E-07	4.97E-06
Total for Site Worker		0	0.01	4.81E-07	6.84E-06
Fisherman	Ingestion of Surface Water	0	0	7.20E-10	1.44E-07
	Dermal Contact with Surface Water	0	0	4.55E-07	1.18E-04
Total for Fisherman		0	0	4.56E-07	1.18E-04
Construction Worker	Ingestion of Surface Water	0	0	1.56E-08	1.25E-07
	Dermal Contact with Surface Water	0	0	2.96E-08	1.54E-07
Total for Construction Workers		0	0	4.52E-08	2.79E-07
Recreational User	Ingestion of Surface Water	0	0	8.78E-11	5.78E-09
	Dermal Contact with Surface Water	0	0	3.41E-09	2.63E-07
Total for Recreational User		0	0	3.50E-09	2.69E-07

11.8 STROUBLES CREEK SUMMARY

11.8.0.1. Stroubles Creek flows through the southeast section of RAAP; it is the largest local tributary of the New River. Upstream of the facility, Stroubles Creek flows through the City of Blacksburg. Two surface water and sediment samples, upstream of RAAP and downstream at the point of discharge to the New River, were collected to help characterize the creek.

11.8.0.2. Arsenic and beryllium were determined to be the risk driver compounds for Stroubles Creek sediments. Several SVOCs were categorized as COCs for the sediments. Beryllium was determined to be the risk driver compound for the surface water.

11.8.0.3. The upstream sediment sample contained all the metals COCs and higher levels of arsenic and nickel than the downstream sample, but no SVOCs. The downstream sediment sample contained all of the SVOCs detected in the creek and the maximum concentration of one of the sediment risk driver compounds. Beryllium was detected in both the upstream and downstream surface water samples.

11.8.0.4. The human health risk assessment indicated a potential for carcinogenic adverse human health effects for ingestion and dermal contact of sediments for site workers, and for dermal contact with surface water for fishermen. Both sample locations were within the fenced facility boundary, and were therefore from areas of the creek which have limited public access.

SECTION 12

SITE CHARACTERIZATION OF THE NEW RIVER

12.1 ENVIRONMENTAL SETTING

12.1.0.1. The New River is the most significant surface water feature within RAAP. The facility is built within and adjacent to a prominent meander loop of this river. Within RAAP, the river width varies from 200 to 1,000 feet, but averages approximately 400 feet. The river flow varies due to water management at Claytor Dam, approximately 9 miles upgradient (south) from RAAP. Downstream from the Claytor Dam, typical flows of the New River range between 3,200 and 8,000 million gallons per day (mgd). During typical flow conditions, the depth is approximately 4 to 6 feet; however, pools may be 10 feet deep. There are 13 miles of river shoreline within the RAAP boundaries.

12.1.0.2. The headwaters of the New River are in northwestern North Carolina, near the Tennessee state line. In the vicinity of RAAP, the New River flows northwesterly cutting cliffs through the bedrock. The path of the New River, which is generally perpendicular to the ridge lines of the Valley and Ridge province, indicates that the river existed prior to the Paleozoic folding of these rocks. In some areas, this river has eroded 4000 feet of rock. During the Paleozoic, the erosion rate of the river was higher than the uplift rate of the rocks. This produced the entrenched river channel present today. The New River is perhaps the oldest river in North America, estimated to be 350 million years old.

12.1.0.3. All water used at RAAP is taken from the New River. Separate water systems are provided for the Main Manufacturing Area and the Horseshoe Area. Intake No. 1 is located approximately 2 miles upstream of the mouth of Stroubles Creek. Intake No. 2 is located approximately 6 miles downstream of the mouth of Stroubles Creek (Figure 3.11). Upstream of RAAP, the New River serves as a source of drinking water for the towns of Blacksburg and Christiansburg.

12.1.0.4. Both industrial and domestic wastewaters are discharged into the New River from the Peppers Ferry Regional Wastewater Treatment Plant (PFWWTP). This discharge is located within the boundaries of RAAP, just downstream from intake No. 1. Until 1987, the city of Radford provided only primary sewage treatment before discharging 2.5 mgd into the New River (USATHAMA, 1976). Secondary treatment is now provided at the PFWWTP. Currently this plant discharges approximately 4.5 mgd of water into the New River (Personal Communication, 1995).

12.1.0.5. RAAP discharges approximately 25 mgd at fifteen industrial wastewater outfalls along the New River and Stroubles Creek under VPDES permit number VA0000248. The effluent consists of various treated process water, wash water, cooling water, run off, sanitary wastewater, and stormwater. The approximate locations of the discharge outfalls are shown in Figure 3.11. For internal use and reference, RAAP has identified a total of 135 outfalls to either the New River or Stroubles Creek from the Main Manufacturing and Horseshoe Areas. These outfalls discharge stormwater, spring-fed groundwater, and minor amounts of steam condensate.

12.1.0.6. The upper reaches of the New River and its tributaries have water of excellent quality. These streams have less than 50 parts per million (ppm) of dissolved solids due to the underlying metamorphic rocks, which contribute very little to natural pollution. In the balance of the region, dissolved solids increase to the 50-199 ppm range as water drains from areas underlain by shale, sandstone, and limestone formations. Where carbonate rocks occur, the bicarbonate content of the water is particularly high, resulting in 100-199 ppm of calcium carbonate ($CaCO_3$) found in the waters of Walker Creek, Sinking Creek, Wolf Creek, and the New River downgradient of RAAP (Figure 2.2).

12.2 PREVIOUS INVESTIGATIONS

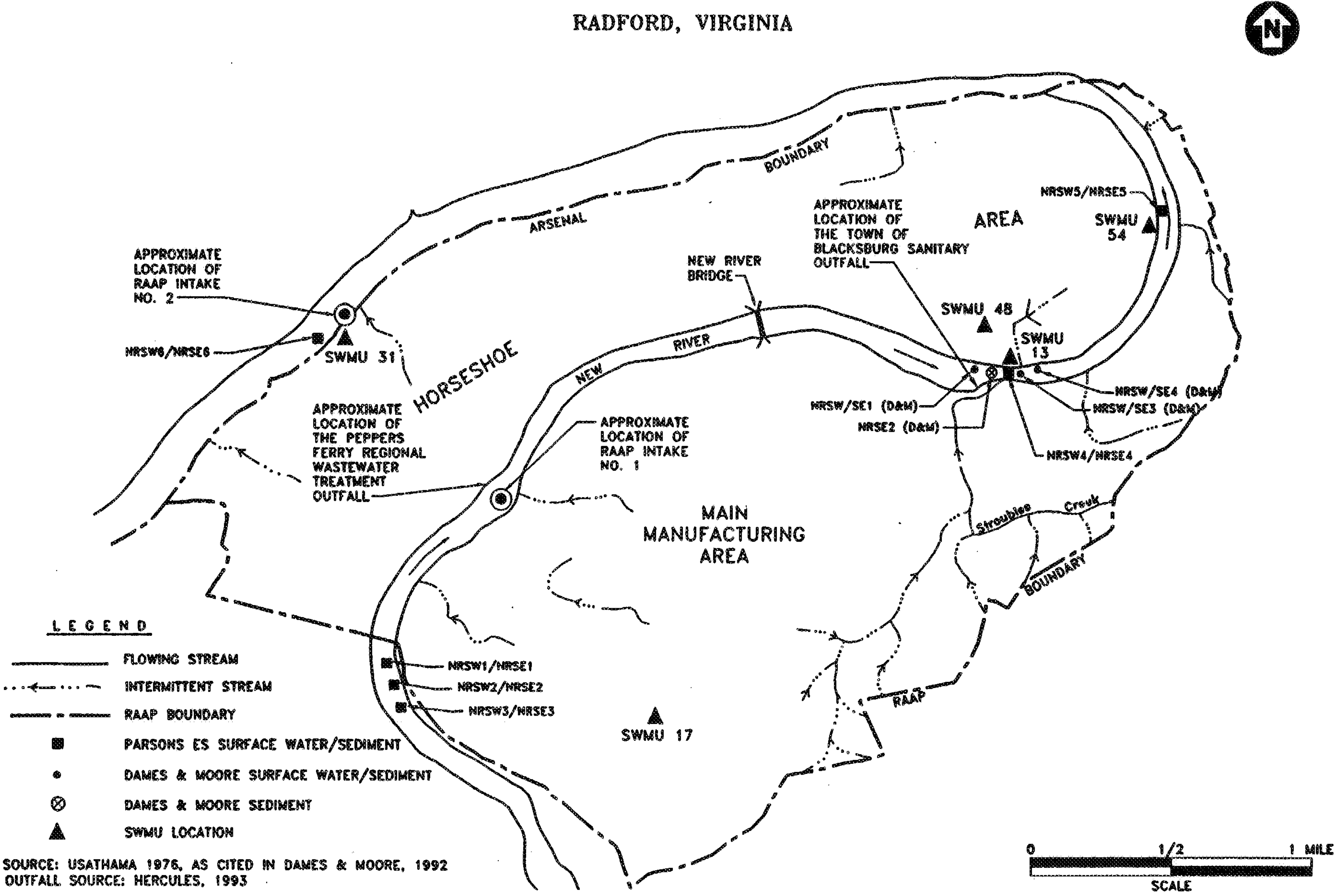
12.2.0.1. In July 1994, fish, clam, sediment and water samples were collected from the New River and analyzed for the propellant ingredients 2,4-DNT and 2,6-DNT (USAEHA, 1994). The samples were collected along the shoreline that receives RAAP discharge. The samples included 12 sediment and water samples, 5 composite clam samples, and 5 composite fish samples. There was no 2,4-DNT or 2,6-DNT detected in the sediment samples. There was no 2,6-DNT detected in any fish or clam samples. However, low levels of 2,4-DNT was detected at two sampling sites for clams (0.07 mg/kg and 0.0093 mg/kg) and one sampling site for fish (0.0081 mg/kg). These levels were determined to be well below the concentration required to exceed the reference dose for 2,4-DNT. No 2,6-DNT was detected in any of the water samples. 2,4-DNT was detected below outfall 29 (Figure 3.11) to a point about 2 miles downstream at 6 discrete sampling locations. For the water samples, 2,4-DNT was observed in the range of 0.11-2.4 μg/l. These levels are well below the 100 μg/l drinking water advisory and the 113 μg/l discharge permit requirements.

12.2.0.2. A RCRA Facility Investigation (RFI) of the Waste Propellant Burning Ground (SWMU 13) was conducted by Dames & Moore in the Fall of 1991. SWMU 13 is a unit where active burning of waste explosives, propellants, and laboratory wastes is conducted. It is situated on a bank of the New River within the 100-year flood plain. As part of the RFI, Dames & Moore collected three surface water samples and their associated sediments from the New River. Additionally, one sediment sample with no associated surface water sample was obtained

12.2.0.3. Figure 12.1 shows the approximate location of SWMU 13 and the surface water and sediment samples collected during the RFI. The New River samples were from up-river, adjacent, and down-river locations in areas predicted to be most impacted by contaminants migrating from SWMU 13 groundwater. The samples were analyzed for TAL metals, explosives, VOCs, and SVOCs.

12.2.0.4. The analytical results of the four sediment samples are presented in Table 12.1. In the sediment samples, arsenic, beryllium, cobalt and lead concentrations exceeded HBNs. Concentrations of arsenic and cobalt were less than half the background comparison criteria for alluvial soils. Beryllium was detected only once, at a concentration less than 5 percent greater than the comparison criterion. Lead was detected at a concentration 2 percent above the HBN in NRSE3, but at a concentration less than the background comparison criterion. According to Dames & Moore, even though lead concentrations are anomalously high in SWMU 13 soils, the lead concentrations in the four New River samples are essentially the same as the five background alluvial soil samples collected from New River alluvium off-post. No explosives or VOCs were detected in the four New River sediment samples. Five SVOCs were detected in the downgradient sample NRSE4, but each SVOC was detected at concentrations less than their respective HBNs. Two SVOCs are phthlates and three SVOCs are likely fuel related.

FIGURE 12.1
NEW RIVER LOCATION MAP
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA



SOURCE: USATHAMA 1976, AS CITED IN DAMES & MOORE, 1992
OUTFALL SOURCE: HERCULES, 1993

517762-7 11/20/95

TABLE 12.1

Summary of Analytical Data For Sediment Samples Collected At SWMU 13
Radford Army Ammunition Plant, Virginia

SITE ID		NRSE1	NRSE2	NRSE3	NRSE3D	NRSE4	
FIELD ID		RDSE*1	RDSE*2	RDSE*3	RDSE*7	RDSE*4	
S. DATE		16-apr-92	16-apr-92	16-apr-92	16-apr-92	16-apr-92	
DEPTH (ft)		1.0	1.0	1.0	1.0	1.0	
MATRIX	PQLs	CSE	CSE	CSE	CSE	CSE	HBN
UNITS	UGG	UGG	UGG	UGG	UGG	UGG	UGG
TAL Inorganics							
ALUMINIUM	14.1	2910	2250	4520	NT	7860	230000
ARSENIC	30	[2.29]	[1.86]	[2.86]	NT	[2.67]	0.5
BARIUM	1	37.8	40	54.9	NT	112	1000
BERYLLIUM	0.2	LT 0.5	LT 0.5	LT 0.5	NT	[0.943]	0.1
CALCIUM	100	1200	558	1180	NT	2120	NSA
CHROMIUM	4	16.9	10.1	12.3	NT	21.3	400
COBALT	3	[4.15]	[3.9]	[5.27]	NT	[10]	0.8
COPPER	7	8.88	7.14	29.8	NT	15.9	2900
IRON	1000	32200	20900	18600	NT	29500	NSA
LEAD	2	113	62.9	[204]	NT	136	200
MAGNESIUM	50	1210	751	1810	NT	2870	NSA
MANGANESE	0.275	414	376	193	NT	1250	8000
NICKEL	3	5.98	5	8.55	NT	10.7	1000
POTASSIUM	37.5	388	282	673	NT	1250	NSA
SODIUM	150	162	138	226	NT	264	NSA
VANADIUM	0.775	14.3	11.4	16.1	NT	27.8	560
ZINC	30.2	447	272	374	NT	414	16000
Explosives (a)	NA	None Detected	None Detected	None Detected	None Detected	None Detected	NSA
Volatiles (a)	NA	None Detected	None Detected	None Detected	None Detected	None Detected	NSA
Semivolatiles							
BIS(2-ETHYLHEXYL) PHTHALATE	0.3	2.94	LT 0.62	1.62	NT	15.5	50
DI-N-BUTYL PHTHALATE	0.3	LT 0.061	LT 0.061	LT 0.061	NT	1.96	1000
FLUORANTHENE	0.3	LT 0.068	LT 0.068	LT 0.068	NT	0.16	500
PHENANTHRENE	0.5	LT 0.033	LT 0.033	LT 0.033	NT	0.089	40
PYRENE	0.3	LT 0.033	LT 0.033	LT 0.033	NT	0.181	1000

SOURCE: DAMES & MOORE, DRAFT RCRA FACILITY INVESTIGATION, SEPT 1992

TABLE 12.1 (Cont'd)

SITE ID		NRSE1	NRSE2	NRSE3	NRSE3D	NRSE4	
FIELD ID		RDSE*1	RDSE*2	RDSE*3	RDSE*7	RDSE*4	
S. DATE		16-apr-92	16-apr-92	16-apr-92	16-apr-92	16-apr-92	
DEPTH (ft)		1.0	1.0	1.0	1.0	1.0	
MATRIX	PQLs	CSE	CSE	CSE	CSE	CSE	HBN
UNITS (#)	UGG	UGG	UGG	UGG	UGG	UGG	UGG
Semivolatile TICs							
CYCLOHEXENE OXIDE	NA	0.39 S	0.388 S	ND	NT	ND	NSA
TOTAL UNKNOWN TICs	NA	ND	(7)20.3	(2)17.2	NT	ND	NSA

Footnotes :

C = Indicates that analysis was confirmed using a second column.
CSE = Chemical sediment.
HBN = Health based number as defined in the RCRA permit. HBNs not specified in the permit were derived using standard exposure and intake assumptions consistent with EPA guidelines (51 Federal Register 33992, 34006, 34014, and 34028).
LT = Concentration is reported as less than the certified reporting limit.
NA = Not available; PQLs are not available for TICs detected in the library scans.
ND = Analyte was not detected.
NSA = No standard (HBN) available; health effects data were not available for the calculation of a HBN. HBNs were not derived for TICs.
NT = Not tested; parameters were not tested (included) in the sample analyses.
PQL = Practical quantitation limit; the lowest concentration that can be reliably detected at a defined level of precision for a given analytical method
S = Results are based on an internal standard; flag is used for TICs detected in library scans.
TAL = Target Analyte List.
TICs = Tentatively identified compounds that were detected in the GC/MS library scans.
UGG = Micrograms per gram.
(a) = Level 2 Data.
( ) = Parenthesis are used to indicate the number of unknown TICs that were detected in either the volatile or semivolatile GC/MS library scans. The number beside the parenthesis is the total concentration of all TICs detected in each respective scan.
[ ] = Brackets indicate that the detected concentration exceeds the HBN.

SOURCE: DAMES & MOORE, DRAFT RCRA FACILITY INVESTIGATION, SEPT 1992

12.2.0.5. The analytical results of the three surface water samples are presented in Table 12.2. Nine TAL metals were detected, but of the four metals with established HBNs, none were found at concentrations exceeding the HBN. No explosives or SVOCs were detected in any samples. Carbon disulfide (a VOC) was detected in samples NRSW1 and NRSW3 at concentrations less than one percent of the HBN. Carbon disulfide has not been associated with the contaminants found at SWMU 13.

12.3 SUMMARY OF RFI FIELD ACTIVITIES

12.3.0.1. Six surface water samples and their associated sediment samples were collected in July 1995 from the New River at various points for the Parsons ES RFI. The locations are shown in Figure 12.1. The samples were generally collected from locations up-river of the facility or at the potential entry point of contaminants from the four SWMUs addressed in this report. In some cases, the sample locations were in areas where the river was likely to be impacted by more than one SWMU. The sediment samples were analyzed for total metals, explosives, VOCs, SVOCs, TOC, and TOX. The surface water samples were analyzed for the same parameters plus chloride and hardness (see Tables 4.3 and 4.4). Field measurements of pH, conductivity, and temperature were also recorded.

12.3.0.2. Samples NRSW1, NRSW2, and NRSW3 (and their associated sediment samples NRSE1, NRSE2, and NRSE3) were collected up-river of the facility. Samples NRSW4/NRSE4 were taken at an area down-river of SWMU 48, in the general vicinity of SWMU 13. Samples NRSW5/NRSE5 were collected down-river of SWMU 54, and samples NRSW6/NRSE6 were taken down-river of SWMU 31. The locations of the river samples associated with SWMUs 48, 54, and 31 are also shown on the SWMU sample location maps (Figures 9.2, 10.2, and 8.2, respectively) for better scale. A duplicate of NRSW5/NRSE5 was collected for QA/QC purposes. Table 12.3 presents a summary of the field activities conducted on the New River for this RFI.

TABLE 12.2

Summary of Analytical Data For Surface Water Samples Collected At SWMU 13
Radford Army Ammunition Plant, Virginia

SITE ID		13SW1	NRSW1	NRSW3	NRSW3D	NRSW4	
FIELD ID		RDWA*11	RDSW*1	RDSW*2	RDSW*4	RDSW*3	
S. DATE		15-jan-92	16-apr-92	16-apr-92	16-apr-92	16-apr-92	
DEPTH (ft)		0.0	0.0	0.0	0.0	0.0	
MATRIX	PQLs	CSW	CSW	CSW	CSW	CSW	HBN
UNITS	UGL	UGL	UGL	UGL	UGL	UGL	UGL
TAL Inorganics							
ALUMINIUM	141	47500	168	LT 141	NT	LT 141	101500
ARSENIC	10	2.99	LT 2.54	LT 2.54	NT	LT 2.54	50
BARIUM	20	495	22.8	18.6	NT	19.2	1000
CALCIUM	500	22200	16100	13600	NT	13600	NSA
CHROMIUM	10	[78.8]	LT 6.02	LT 6.02	NT	LT 6.02	50
COBALT	70	[30.6]	LT 25	LT 25	NT	LT 25	0.35
COPPER	60	143	LT 8.09	LT 8.09	NT	LT 8.09	1295
IRON	38.1	59700	416	217	NT	170	NSA
LEAD	10	[500]	1.95	2.06	NT	2.39	50
MAGNESIUM	500	12400	6190	5230	NT	5320	NSA
MANGANESE	2.75	1940	62.4	22.1	NT	11	3500
NICKEL	50	43.8	LT 34.3	LT 34.3	NT	LT 34.3	700
POTASSIUM	375	13600	2130	2400	NT	2360	NSA
SODIUM	500	1830	7630	5220	NT	5300	NSA
VANADIUM	40	89.9	LT 11	LT 11	NT	LT 11	245
ZINC	50	893	LT 21.1	LT 21.1	NT	LT 21.1	7000
Explosives (a)							
135TNB	0.449	1.18	LT 0.611	LT 0.611	LT 0.611	LT 0.611	1.75
246TNT	0.635	[32.9]	LT 0.635	LT0.635	LT0.635	LT0.635	11.7
24DNT	0.064	[15.8]	LT 0.064	LT 0.064	LT 0.064	LT 0.064	0.05
26DNT	0.074	[3.71]	LT 0.074	LT 0.074	LT 0.074	LT 0.074	0.051
HMX	1.21	12.8	LT 1.21	LT 1.21	LT 1.21	LT 1.21	1750
Volatiles (a)							
CARBON DISULFIDE	0.5	LT 0.50	24	2.3	LT 0.50	LT 0.50	4000

SOURCE: DAMES & MOORE, DRAFT RCRA FACILITY INVESTIGATION, SEPT 1992

TABLE 12.2 (Cont'd)

SITE ID		13SW1	NRSW1	NRSW3	NRSW3D	NRSW4	
FIELD ID		RDWA*11	RDSW*1	RDSW*2	RDSW*4	RDSW*3	
S. DATE		15-jan-92	16-apr-92	16-apr-92	16-apr-92	16-apr-92	
DEPTH (ft)		0.0	0.0	0.0	0.0	0.0	
MATRIX	PQLs	CSW	CSW	CSW	CSW	CSW	HBN
UNITS (#)	UGL	UGL	UGL	UGL	UGL	UGL	UGL
Semivolatiles							
24DNT	10	[13.6]	LT 4.5	LT 4.5	NT	LT 4.5	0.05
26DNT	10	[2.39]	LT 0.79	LT 0.79	NT	LT 0.79	0.051
Semivolatile TICs							
1,1,2,2-TETRACHLOROETHANE	NA	6 S	ND	ND	NT	ND	NSA
1,1,2-TRICHLOROETHANE	NA	6 S	ND	ND	NT	ND	NSA
TOTAL UNKNOWN TICs	NA	(1)10	(1)7	ND	NT	ND	NSA
Other							
NITRITE,NITRATE	100	530	NT	NT	NT	NT	10000
TOTAL ORGANIC CARBON	1000	12	NT	NT	NT	NT	NSA
TOTAL ORGANIC HALOGENS	1	33.5	NT	NT	NT	NT	NSA
pH	NA	7.68 K	NT	NT	NT	NT	NSA

SOURCE: DAMES & MOORE, DRAFT RCRA FACILITY INVESTIGATION, SEPT 1992

TABLE 12.2 (Cont'd)

Footnotes :

CSW = Chemical surface water.
HBN = Health based number as defined in the RCRA permit. HBNs not specified in the permit were derived using standard exposure and intake assumptions consistent with EPA guidelines (51 Federal Register 33992, 34006, 34014, and 34028).
K = Indicates holding time for extraction and preparation was not met, but data quality is not believed to be affected.
LT = Concentration is reported as less than the certified reporting limit.
NA = Not available; PQLs are not available for TICs detected in the library scans.
ND = Analyte was not detected.
NSA = No standard (HBN) available; health effects data were not available for the calculation of a HBN. HBNs were not derived for TICs.
NT = Not tested; parameters were not tested (included) in the sample analyses.
PQL = Practical quantitation limit; the lowest concentration that can be reliably detected at a defined level of precision for a given analytical method.
S = Results are based on an internal standard; flag is used for TICs detected in library scans.
TAL = Target Analyte List.
TICs = Tentatively identified compounds that were detected in the GC/MS library scans.
UGL = Micrograms per liter.
(a) = Level 2 data.
( ) = Parenthesis are used to indicate the number of unknown TICs that were detected in either the volatile or semivolatile GC/MS library scans. The number beside the parenthesis is the total concentration of all TICs detected in each respective scan.
[ ] = Brackets indicate that the detected concentration exceeds the HBN.

SOURCE: DAMES & MOORE, DRAFT RCRA FACILITY INVESTIGATION, SEPT 1992

TABLE 12.3

SUMMARY OF NEW RIVER RFI FIELD ACTIVITIES

RADFORD ARMY AMMUNITION PLANT

Area	Surface Water Sampled*	Sediment Sampled	Comments
New River	NRSW1	NRSE1	Up-river of facility
	NRSW2	NRSE2	Up-river of facility
	NRSW3	NRSE3	Up-river of facility
	NRSW4	NRSE4	Down-river of SWMU 48
	NRSW5	NRSE5	Down-river of SWMU 54
	NRSW6	NRSE6	Down-river of SWMU 31
	NRSW8	NRSE8	Duplicate of NRSW5/NRSE5

* Field measurements of pH, temperature, and conductivity were also recorded.

12.4 NATURE AND EXTENT OF CONTAMINATION

12.4.0.1. The positive results (detected compounds) for sediment and surface water samples collected from the New River are shown in Tables 12.4 and 12.5, repectively. The spring sample (SPG3SE/SW1) has been discussed as part of the SWMU 17 (Vicinity) section because of the identified hydraulic connection with SWMU 17. However, the analytical results have been presented here because of the proximity of the spring to the New River and the potential for the results to be impacted by the river (SPG3SE/SW1 was not sampled for all the same parameters as the river samples).

12.4.0.2. In order to assess the results statistically, three samples were collected upstream (background) of RAAP. Statistical analysis was performed to determine if the downstream results were significantly different from upstream of the facility. Those compounds not detected at levels greater than the background distribution were not considered further. Those compounds which were not detected in the background samples were analyzed from a risk assessment perspective and are included in the following discussion.

12.4.0.3. The statistical analysis was performed using a tail area probability calculation in the tail area probability calculation, a specific sampling point is compared to the background distribution, and the percentage of the background distribution falling below the sampling point is determined. The null hypothesis is that less than 95% of the background distribution will fall below the sampling point; if this is true, then the sample will be considered to be "within" the background distribution. Conversely, the alternate hypothsis is that more than 95% of the background distribution falls below the sample value; if this is true, then the sample will be considered to be different than background. This concept can be understood simply as determining where the sample value lies relative to the background distribution. For example, if 50% of the background distribution lies below the sample value, then the sample value is in the exact middle of the background distribution and the sample is considered to be "in" the background distribution; if, however, 95% of the background distribution lies below the sample value, then the sample is not in the background distribution.

12.4.0.4. A Tail Area Probability value was calculated for each sample for each analyte which had a positive hit in the background sample; if all background samples were

TABLE 12.4
POSITIVE RESULTS TABLE OF NEW RIVER - Sediment Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	NRSE1	NRSE2	NRSE3	NRSE4	NRSE5	NRSE6	NRSE8*	SPG3SE1
METALS (ug/g)								
Arsenic					6.92		7.83	17.40 J4
Selenium			1.85					
Lead	148.42 J1	136.29 J1	200.00 J1	4415.58	220.08 J1	141.99 J1	245.90 J1	548.59 J6
Silver	0.14	0.09	0.15	0.10	0.10	0.11	0.07	0.22 J4
Barium	226.35 J1	151.82 J1	415.00 J1	97.14	178.82 J1	109.77 J1	187.16 J1	700.63 J1
Beryllium			3.03	0.99	1.31		1.31	4.23 J4
Chromium	46.20 J1	32.01 J1	77.33 J1	37.53	31.50 J1	24.89 J1	33.88 J1	62.70 J6
Nickel	25.05	15.72	41.83	13.25	15.82	12.49	14.89	52.98 J4
Mercury								0.13 J4
SEMIVOLATILES (ug/g)								
Bis (2-ethylhexyl) phthalate				6.62				
Diethyl phthalate				6.23				
Dimethyl phthalate				8.31				
Di-n-butyl phthalate				12.99				
Benzo[a]anthracene	0.58	0.32	0.72			0.40		
Chrysene	1.67	0.35	0.68			0.53		
Fluoranthene		0.30	0.80	0.08		0.50		
Phenanthrene	0.76	0.51	0.82			0.35		
Pyrene	0.80	0.40	1.00			0.76		
N-Nitrosodiphenylamine				2.60				
EXPLOSIVES (ug/g)								
2,4,6-Trinitrotoluene					28.89 J10			
OTHER (ug/g)								
Total Organic Carbon	91651.20	58478.60	36333.30	9831.17	11251.70	22595.40	20218.60	33742.00
Extractable Organic Halides (tot	185.53	158.48	166.67	129.87	82.53	152.67	81.97	244.40

* NRSE8 is a duplicate sample of NRSE5

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TABLE 12.5
POSITIVE RESULTS TABLE OF NEW RIVER - Aqueous Samples
RADFORD ARMY AMMUNITION PLANT

Field Sample Number	NRSW1	NRSW2	NRSW3	NRSW4	NRSW5	NRSW6	NRSW8*	SPG3SW1
METALS (ug/l)								
Lead				9.80				25.20
Barium	24.90	25.10	24.90	26.30	21.10	24.80	21.10	26.60 J4
Beryllium								1.64
VOLATILES (ug/l)								
Methylene chloride								
OTHER (ug/l)								
Total Hardness	42700.00	42800.00	43200.00	44600.00	47800.00	51300.00	47700.00	
Total Organic Carbon	2180.00	2320.00	2080.00	1960.00	1810.00	2310.00	1870.00 J7	1200.00
Total Organic Halogens				10.00				
Chloride	3890.00	3750.00	3810.00	3950.00	4030.00	4120.00	4000.00	

* NRSW8 is a duplicate sample of NRSW5

TABLE 12.5

POSITIVE RESULTS TABLE OF NEW RIVER - Aqueous Samples

RADFORD ARMY AMMUNITION PLANT

Field Sample Number	NRSWTB	NRSWTB2
METALS (ug/l)		
Lead		
Barium		
Beryllium		
VOLATILES (ug/l)		
Methylene chloride	4.20	4.50
OTHER (ug/l)		
Total Hardness		
Total Organic Carbon		
Total Organic Halogens		
Chloride		

nondetect, then the background had no distribution and that analysis could not be run (in these cases, however, the contaminant was analyzed by risk assessment). As described above, if the Tail Area Probability was below 95%, then the null hypothesis was accepted and the sample was not considered to differ from background; however, if the Tail Area Probability was equal to or above 95%, then the null hypothesis was rejected and the sample was considered to be different from background.

12.4.0.5. Results of the tail area probability tests for surface water are summarized in Table 12.6. Barium, beryllium, and lead had positive hits in New River surface water samples and/or the Spring sample (SPG3). All of the background beryllium and lead samples, however, were nondetect, so no further analyses could be conducted for lead or beryllium. Barium had all detect values for the three background and the three downriver samples. Both sample NRSW4 and the spring sample SPG3SW1 exceeded the 95th percentile of the background distribution for barium, indicating that these samples contain significant levels of barium.

12.4.0.6. Results of the tail area probability tests for sediment are summarized in Table 12.7. Several analytes, including arsenic, barium, benzo (a) anthracene, beryllium, bis(2-ethyl hexyl) phthalate, chromium, chrysene, di-n-butyl phthalate, diethyl phthalate, dimethyl phthalate, fluoranthene, lead, mercury, n-nitrosodiphenylamine, nickel, phenanthrene, pyrene, selenium, silver, and 2,4,6-trinitrotoluene, had positive hits in New River sediments. Arsenic, bis(2-ethyl hexyl) phthalate, di-n-butyl phthalate, diethyl phthalate, dimethyl phthalate, mercury, n-nitrosodiphenylamine, and 2,4,6-trinitrotoluene were not detected in the background, so they could not be further analyzed. Tail area probability values were calculated for the other analytes. The 95th percentile of the background distribution was exceeded by sample SPG3SE1 for barium, beryllium, and silver; and by samples NRSW4 and SPG3SE1 for lead. This indicates that sediments from these samples contain significant levels of these contaminants.

12.4.0.7. The positive results and the chemicals of concern (COCs) as identified by the methods described in Section 6 are discussed below. However, the focus of the section is on the COCs identified as potential human health risks as detailed in the subsequent Risk Assessment sections.

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TABLE 12. 6
New River Surface Water
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	NRSW4	NRSW5	NRSW6	SPGSW1	Background Mean	95th Percentile of Background	95th Percentile of Background Exceeded?
METALS (ug/g)							
Barium	26.30	21.10	24.80	26.60	24.97	25.22	Yes

TABLE 12.7
New River Sediments
Samples Exceeding Background
Radford Army Ammunition Plant

Field Sample Number	NRSE4	NRSE5	NRSE6	SPG3SE1	Background Mean	95th Percentile of Background	95th Percentile of Background Exceeded?
METALS (ug/g)							
Barium	97.14	178.82	109.77	700.63	264.39	578.25	Yes
Beryllium	0.99	1.31		4.23	1.26	3.79	Yes
Chromium	37.53	31.50	24.89	62.70	51.85	104.59	No
Lead	4415.58	220.08	141.99	548.59	161.57	223.63	Yes
Nickel	13.25	15.82	12.49	52.98	27.53	77.48	No
Silver	0.10	0.10	0.11	0.22	0.13	0.19	Yes
SEMIVOLATILES (ug/g)							
Benz(a) anthracene			0.40	*	0.54	0.87	No
Chrysene			0.53	*	0.90	2.04	No
Fluoranthene	0.08		0.50	*	0.41	0.98	No
Phenanthrene			0.35	*	0.70	0.96	No
Pyrene			0.76	*	0.73	1.24	No

* Contaminants not analyzed for in this sample

12.4.1 Nature of Contamination

12.4.1.1 Sediment

12.4.1.1.1. Twelve COCs were identified in the sediment samples collected from the New River. They included the metals arsenic, barium, beryllium, lead, mercury, and silver, the SVOCs bis (2-ethyl hexyl) phthalate, di-n-butyl phthalate, diethyl phthalate, dimethyl phthalate, and n-nitrosodiphenylamine, and the explosive 2,4,6-Trinitrotoluene. Two compounds (arsenic and beryllium) were found at levels considered to be a potential human health risk. Of these, beryllium was identified as the risk driver for the New River sediment samples.

12.4.1.1.2. The explosive 2,4,6-TNT was only found in NRSE5 at 28.89 ug/g. Arsenic was found in this same sample at 6.92 ug/g and in SPG3SE1 at 17.40 ug/g. Beryllium was found in four sediment samples ranging from 0.99 ug/g in NRSE4 to 4.23 ug/g in SPG3SE1. Mercury was only detected in sample SPG3SE1 at 0.13 ug/g. Nickel was found in all the samples ranging from 12.49 ug/g in NRSE6 to 52.98 ug/g in SPG3SE1. The other positive results were in samples NRSE3 and NRSE5.

12.4.1.1.3. Barium was detected in all the sediment samples, ranging from 97.14 ug/g in NRSE4 to 700.63 ug/g in SPG3SE1. For the remaining metals COCs, the maximum results and sample are as follows: lead (4415.58 ug/g) in NRSE4 and silver (0.22 ug/g) in SPG3SE1. Chromium was detected in all of the New River sediment samples, but was not considered a COC because the downstream samples did not exceed background.

12.4.1.1.4. For the SVOC COCs, bis (2-ethylhexyl) phthalate, diethyl phthalate, dimethyl phthalate, di-n-butyl phthalate, and n-nitrosodiphenylamine were all detected only in the sample NRSE4. Other positive results were for selenium (found only in sample NRSE3 at 1.85 ug/g) and the SVOCs benzo[a]anthracene, chrysene, fluoranthene, phenanthrene, and pyrene. With the exception of fluoranthene, those SVOCs were all detected in samples NRSE1, NRSE2, NRSE3, and NRSE6. Fluoranthene was not found in NRSE1, but was found in NRSE4.

12.4.1.2 Surface Water

12.4.1.2.1. Barium, beryllium, and lead were the only COCs identified for the New River surface water samples. Of those, only beryllium was detected at levels considered to pose a potential threat to human health. Therefore, beryllium was identified as the risk driver for the surface water of the New River. Barium was found in all of the New River samples and in SPG3SW1. Concentrations ranged from 21.10 ug/l to 26.60 ug/l. The maximum detection was in sample SPG3SW1. Lead was found in samples NRSW4 and SPG3SW1. Beryllium was only detected in the SPG3SW1 sample at 1.64 ug/l.

12.4.2 Extent of Contamination

12.4.2.1 Sediment

12.4.2.1.1. NRSE5 was the only sample where 2,4,6-TNT was detected. It contains all of the metals listed as COCs except mercury. This sample was collected immediately downstream of SWMU 54 where 2,4,6-TNT was identified as a risk driver in the subsurface soils. NRSE4 had the highest lead concentration and contained all of the SVOC COCs. This sample was collected near SWMU 13 and downstream of where SWMU 48 potentially discharges groundwater.

12.4.2.1.2. The maximum beryllium (risk driver), arsenic, nickel, barium, chromium, mercury and silver detections were in sample SPG3SE1. This sample was collected from the spring which has been shown to be hydraulically linked to SWMU 17A. The spring discharge joins the New River at the sample location.

12.4.2.1.3. Samples NRSE1, NRSE2, and NRSE3 were collected upstream of the facility. However, NRSE3 had the only positive selenium detection and contained the second highest beryllium detection (3.03 ug/l). Many of the SVOC detected were from these three upstream samples.

12.4.2.2 Surface Water

12.4.2.2.1. SPG3SW1 contained most of the positive results for the New River surface water samples. It had the highest barium concentration and the only beryllium

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detection. This sample also contained lead, as did NRSW4. SPG3SW1 is hydraulically connected to SWMU 17A. NRSW4 was taken near SWMU 13 and SWMU 48.

12.5 CONTAMINANT FATE AND TRANSPORT

12.5.0.1. The environmental fate and transport of chemicals is dependent on the physical and chemical properties of the compounds, the environmental processes affecting them, and the media through which they migrate. Contaminants found in the sediments or surface water of the New River in the vicinity of RAAP are subject to transport downstream as dissolved constituents, particulates, or suspended solids. The dilution of any of these compounds is significant when considering distant downstream receptors.

12.5.0.2. The explosive compound 2,4,6-TNT was found in one of the sediment samples. Explosives have a high affinity for organic matter and low water solubility. In sediments, explosives tend to remain bound to the soil particles and dissolve slowly into the overlying water; no explosives were detected in any of the surface water samples. Movement of these compounds is usually controlled by the transport of particulates. Explosives are not readily bioaccumulated by living organisms. Metals identified as risk drivers or COCs for New River sediments would most likely mobilize as suspended sediments or possibly as dissolved ions.

12.5.0.3. Beryllium was the identified risk driver compound for the New River surface water. However, beryllium was only found in the spring sample (hydraulically connected to SWMU 17A). Barium and lead were identified as COCs. These metals could be mobilized as dissolved ions or as adsorbed constituents of the sediments.

12.6 RISK ASSESSMENT

12.6.0.1. The New River has not been classified as a SWMU within the RAAP boundaries. The river is being evaluated as the likely receptor of discharges from SWMUs to the surface water and sediment. In addition, connections have been established through a dye tracing study linking SWMU 17A to the New River. Surface waters are open to the atmosphere and therefore, contaminants that migrate to this medium may be transported to the atmosphere. The sediments in this area may fluctuate between being covered and

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uncovered with surface water; this does not limit the potential for emissions to the atmosphere and contaminants migrating sediments to surface waters and groundwater.

12.6.0.2. At present, use of the New River as a recreational water body and a drinking water source is expected to remain unchanged. All water used at RAAP is taken from the New River, from intakes located 2 miles upstream of Stroubles Creek and 6 miles downstream of Stroubles Creek. Water from the New River upstream of RAAP also supplies drinking water for the towns of Blacksburg and Christiansburg. Future uses of the New River are expected to remain consistent with current uses.

12.6.1 Summary of Chemicals of Potential Concern

12.6.1.0.1. The chemicals considered in the risk evaluation for New River surface water are three metals (barium, beryllium and lead). Chemicals considered for New River sediments include 6 metals (arsenic, barium, beryllium, lead, mercury, and silver) one explosive (2,4,6-trinitrotoluene) and five semivolatiles (bis(2ethylhexyl)phthalate, di-n-butyl phthalate, diethyl phthalate, dimethyl phthalate and n-diphenylnitrosamine).

12.6.1.1 Comparison to ARARs and TBCs for Groundwater and Soils

12.6.1.1.1. RAAP discharges approximately 25 million gallons per day (MGD) into the New River from 15 locations along the New River and Stroubles Creek. Effluent from RAAP consists of various treated process waters, wash waters, cooling waters, stormwater runoff and sanitary wastewater. The state water quality criteria establish a maximum allowed concentration for various parameters and these minimum standards are considered state ARARs. Federal water criteria are non-enforceable guidelines and they are considered TBCs for cleanup goals. Other TBC criteria considered for human health risk evaluation included reference doses (RfDs) and slope factors (SFs) from USEPA's Integrated Risk Information System and Health Effects Assessment Summary Table (USEPA, 1995a).

12.6.2 Exposure Assessment

12.6.2.1 Potential Pathways and Receptors

12.6.2.1.1. Current exposure pathways at the New River are considered to have a high probability of completion (site workers, construction workers, recreational users,

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fishermen). At present, recreational users and fishermen have access to the areas of the river characterized by surface water and sediment sampling. Current site workers have access to potentially contaminated surface waters and sediments during the course of their normal activities, since there are approximately 12 miles of shoreline within RAAP. Surface water from the New River is also used by RAAP for drinking water. However, exposure to contaminants through this exposure pathway are potentially incomplete because the surface water is treated prior to being used for domestic purposes. In addition, routine sampling is performed at the water treatment plant to ensure any potential chemicals in drinking water are within acceptable levels.

12.6.2.1.2. The conceptual site model summary for the New River is presented in Figure 12.2 and includes exposure routes, potential receptors and the medium containing potential contaminants of concern. All chemicals not eliminated by data validation were considered in the risk assessment for this body of water.

12.6.2.2 Exposure Point Concentrations and Chronic Daily Intakes

12.6.2.2.1. Exposure point concentrations for the three metals detected in New River (see Subsection 12.7.1) surface water are listed in Appendix I. These concentrations range from 0.000733 mg/L (beryllium) to 0.0246 mg/L (barium). Exposure point concentrations for the contaminants of concern in sediments (also see Section 12.7.1) range from 0.0936 ppm (mercury) to 701 ppm (barium).

12.6.3 Risk Characterization

12.6.3.0.1. The carcinogenic risk and hazard index were calculated for the surface water ingestion and dermal contact pathways (current site worker, recreational user, fisherman and construction worker) and sediment ingestion and dermal contact (current site worker). These calculations are presented in Appendix I. A discussion of the results of each pathway for non-carcinogenic and carcinogenic effects is presented below.

Figure 12.2
Conceptual Site Model for Current and Future Exposure Pathways
New River
Radford Army Ammunition Plant
Radford, Virginia

Primary Source	Release Mechanism	Receiving Medium	Exposure Route	Current Receptors: Site Workers	Current Receptors: Rec. Users	Current Receptors: Hunters, Fisherman	Current Receptors: Const. Workers	Future Receptor: Site Workers
RAAP Activities	Surface Runoff/ Groundwater Discharge	Surface Water and Sediment	Ingestion	X	X	X(F)	X	
			Inhalation					
			Dermal	X	X	X(F)	X	
	Tracking Deposition	Surficial Soils	Ingestion					
			Inhalation					
			Dermal					
	Leaching/ Deposition	Subsurface Soils	Ingestion					
			Inhalation					
			Dermal					
	Uptake	Biota	Ingestion			X(F)		
	Leaching	Groundwater	Ingestion					
			Inhalation					
			Dermal					

X = Pathways of potential concern
F = Fisherman scenario

12.6.3.1 Non-carcinogenic Effects

12.6.3.1.1. The calculated hazard indices for the site worker surface water and sediment ingestion and dermal contact exposure scenarios do not exceed acceptable levels. All calculated hazard indices are at least two orders of magnitude below acceptable levels.

12.6.3.1.2. The calculated hazard indices for the current recreational user and fisherman ingestion and dermal contact of surface water exposure scenarios also do not exceed acceptable risk levels. Again, the calculated hazard indices are at least two orders of magnitude below acceptable levels.

12.6.3.1.3. The calculated hazard indices for the construction worker surface water ingestion exposure scenarios do not exceed acceptable levels for CT and RME receptors. The hazard indices are at least two orders of magnitude below acceptable levels.

12.6.3.2 Carcinogenic Effects

12.6.3.2.1. The calculated cancer risks for the site worker sediment ingestion exposure scenario is within the target risk range primarily due to beryllium for RME receptors. Beryllium RME cancer risks for the ingestion exposure scenario are 1.27 x 10^{-6}. Beryllium was also found to have the highest cancer risks for the site worker dermal contact with sediments scenario, with calculated cancer risks for CT and RME receptors being 1.07 x 10^{-6} and 1.44 x 10^{-5}, respectively. Cancer risks for the site worker surface water ingestion and dermal contact scenarios are below the USEPA target risk range for RME receptors.

12.6.3.2.2. The calculated cancer risks for the recreational user surface water ingestion and dermal contact exposure scenarios are below the USEPA target risk range for CT and RME receptors. The calculated cancer risks for the fisherman dermal contact with surface water exposure scenario is within the USEPA target risk range for RME receptors, due to beryllium. Beryllium RME cancer risks for the dermal contact with surface water exposure scenario are 4.16 x 10^{-5}.

12.6.3.2.3. Construction worker cancer risks do not exceed the USEPA target risk range for ingestion and dermal contact with surface water. Calculated cancer risks are at least two orders of magnitude below the target risk range.

12.6.4 Uncertainty Analysis

12.6.4.0.1. Data collection/evaluation uncertainty may be relevant at the New River due to the types and numbers of samples collected. The New River flows through RAAP and receives point and non-point discharges from the plant. There are approximately 12 miles of New River shoreline within the boundaries of the plant. A limited number of surface water and sediment samples were used to characterize the river from areas related to suspected discharge points from SWMUs or other contaminated areas. This information may not be representative of the risk for the entirety of the river which flows through the plant, and therefore, the risk may be overestimated.

12.6.4.0.2. Standard default exposure values for recreational surface water users or fishermen have not been established by the USEPA as this is not a common exposure pathway that is examined in human health risk assessment. These pathways were quantified using exposure parameters based upon best professional judgment, which may over- or underestimate the representative risk for these two receptors.

12.6.4.0.3. Another area of uncertainty in evaluating human health risk from the New River is toxicity assessment. Oral and dermal slope factors are not available for some of the metals which were detected in surface water and sediment. Most studies are based on animal data and extrapolated to humans and also subchronic studies may be used assess chronic effects. In addition, extrapolations are characterized by uncertainty factors which can be as large as four orders of magnitude. This may tend to over- or underestimate risk.

12.6.4.0.4. The inhalation of volatiles and particulates from surface water and sediments may also be another source of uncertainty for the New River. This exposure scenario was not evaluated for current and future receptors in this area, due to the assumption that exposure times and contact rates would limit the potential completion of this pathway. This may tend to underestimate the risk for these exposure scenarios.

12.6.4.0.5. As with all modeled concentrations, there is a degree of uncertainty involved in assessing exposure scenarios. Fisherman ingestion of contaminated fish was evaluated by assessing uptake of contaminants present in surface water through normal activities. Using a bioconcentration factor, a simulated chemical concentration in fish tissue is derived. However, for the chemicals detected in New River surface water, bioconcentration information is limiting and the risks from this exposure scenario were not quantified. This may tend to underestimate the risk.

12.7 RISK SUMMARY

12.7.0.1. Carcinogenic risks and non-carcinogenic hazard indices were calculated for various receptors potentially exposed to multiple chemicals by various pathways in surface water and sediment. The risk calculations were summarized and are presented in Table 12.8. Under the NCP, the probability of excess cancers over a lifetime of exposure within or below USEPA's target risk range of 10^{-4} to 10^{-6} are considered to pose a low threat while a probability of excess cancers over a lifetime of exposures greater than 10^{-4} may pose an unacceptable threat of adverse health effects. For noncarcinogens, a hazard index below one is considered to pose a low threat of adverse health effects, while a hazard index greater than one may pose an unacceptable threat of adverse health effects.

12.7.0.2. All calculated hazard indices for all exposure pathways evaluated for New River are less than one by at least two orders of magnitude. These values indicate a very low potential for adverse noncarcinogenic health effects from this site.

12.7.0.3. Calculated total cancer risks for exposure pathways at the New River that are within the target risk range are fishermen and current site workers. All other exposure pathways examined are below the target risk range. These values indicate a potential for adverse carcinogenic health effects for the receptors mentioned above.

12.8 NEW RIVER SUMMARY

12.8.0.1 The New River is the most significant surface water feature within RAAP. The New River is the source of all water used at the facility; two intakes on the river are located within the facility boundaries. Industrial and domestic wastewaters are discharged into the river at locations within RAAP. Six surface water and sediment samples were collected from the river upstream of the facility or near likely discharge points of the four SWMUs investigated for the RFI to help characterize the river. Additionally, the spring determined to be hydraulically connected to SWMU 17A was included for discussion in this section since it discharges directly to the river.

Table 12.8
Summary of Human Health Risk
New River
Radford Army Ammunition Plant

Receptor	Pathways	HI		Cancer Risk	
		CT	RME	CT	RME
Site Worker	Ingestion of Surface Water	0	0	1.10E-08	1.10E-07
	Dermal Contact with Surface Water	0	0	2.77E-09	3.73E-08
	Ingestion of Sediment	0.01	0.02	1.58E-07	3.16E-06
	Dermal Contact with Sediment	0.01	0.02	1.10E-06	1.47E-05
Total for Site Worker		0.02	0.04	1.27E-06	1.80E-05
Fisherman	Ingestion of Surface Water	0	0	2.54E-10	5.07E-08
	Dermal Contact with Surface Water	0	0	1.60E-07	4.16E-05
Total for Fisherman		0	0	1.60E-07	4.17E-05
Construction Worker	Ingestion of Surface Water	0	0	5.50E-09	4.40E-08
	Dermal Contact with Surface Water	0	0	1.04E-08	5.42E-08
Total for Construction Workers		0	0	1.59E-08	9.82E-08
Recreational User	Ingestion of Surface Water	0	0	3.09E-11	2.03E-09
	Dermal Contact with Surface Water	0	0	1.20E-09	9.28E-08
Total for Recreational User		0	0	1.23E-09	9.48E-08

12.8.0.2. Beryllium was determined to be the risk driver compound for New River sediment. Numerous metals and 2,4,6-TNT were categorized as COCs (2,4,6-TNT was only found in the sample just downstream of SWMU 54). Several SVOC COCs were detected in various sediment samples, including the upstream samples. Beryllium was identified as the risk driver compound in the New River surface water. Barium was found in all the samples; the maximum detection was in the spring sample. Beryllium was only detected in the spring sample. In general, the spring sediment and surface water sample contained maximum concentrations of most of the COCs identified for the river.

12.8.0.3. The human health risk assessment indicated a potential for carcinogenic adverse human health effects for ingestion and dermal contact of surface water and sediment for site workers and fishermen.

SECTION 13

RECOMMENDATIONS

13.0.0.1 The following recommendations are based on an evaluation of all site characterization data collected during the RFI and the human health risks determined to be associated with each SWMU or area of concern. The rationale for each recommendation considers the nature of observed releases and adverse human health effects, and the practical aspects of an active facility. Table 13.1, which is included at the end of the section, presents a summary of the the human health risks, contaminants of concern, and the recommendations that have been derived from them. The human health risk concerns were determined by the methods described in Section 6; detailed descriptions of the risk analyses are provided in the risk assessment subsection of each SWMU or area of concern.

13.1 SWMU 17/40 (CONTAMINATED WASTE BURNING AREAS AND SANITARY LANDFILL)

13.1.1 Recommendations

1) **Recommendation: Interim Measures**

The human health risk assessment indicates a potential for noncarcinogenic and carcinogenic adverse human health effects for ingestion and dermal contact of surface and subsurface soils and groundwater. The dye tracing study demonstrated a subsurface connection between SWMU 17 and the New River; chemicals of concern found at SWMU 17 were also detected at the discharge point, indicating a release of contaminants. Surface and near surface contamination of soils in areas of active operations indicates the need for interim measures to control potential threats to the health of site workers.

Interim measures are intended to control or abate threats to human health while long term solutions are developed or implemented. The interim measures recommended, which would be classified as non-emergency actions, would consist of the implementation of relatively simple engineering controls to prevent or minimize dermal contact with surface soils, including: protective clothing (appropriate gloves and coveralls) and wash stations at easily accessible locations.

2) Recommendation: Conduct Corrective Measures Study (CMS)

A CMS is recommended to address long term solutions to contaminant migration from SWMU 17. Since the active operations represent a continuing source of contamination to the soils and groundwater, corrective measures should be developed which can mitigate contaminant releases while minimizing the impact to the active operations. Such corrective measures might include:

- Construction of a concrete pad with appropriate drainage controls for all burning operations;
- Construction of an impermeable cap to prevent infiltration of precipitation and reduce contaminant flushing; and
- Excavation of the shallow fill materials and installation of an impermeable liner to abate future contaminant migration.

The objective of the CMS is to identify and develop proposed corrective measures and alternatives by screening available technologies, assessing site conditions, and examining financial, institutional, and health impacts. A CMS would justify the recommended corrective actions on a technical, environmental and human health basis, including applicable cleanup levels. The CMS would provide complete information on the status of remediation activities and establish a system for regular reporting, record keeping, and compliance requirements. Finally, the CMS would provide sufficient information so that remedial design and implementation could proceed.

13.2 SWMU 31 (COAL ASH SETTLING LAGOONS)

13.2.1 Recommendations

1) Recommendation: Collect Additional RFI Data

The human health risk assessment indicates a risk based on the hypothetical future site worker groundwater usage scenario. However, migration of metals from the coal ash lagoon sediments to the groundwater and eventually to the New River appears to be occurring. Since the lagoon sediments were only sampled for TCLP waste disposal characterization during the RFI, they could not be considered in the human health risk assessment. Although the previous investigation included sediment sampling data, this information could not be fully assessed for human health risks. Additionally, the compositing procedure used in the previous investigation to collect the samples may not have been appropriate to characterize the sediments. Therefore, additional sampling is recommended to define the nature and extent of contamination at SWMU 31.

Based on the available sampling data, a "No Further Action" recommendation would be inappropriate. However, sampling of the sediments, coupled with the additional sampling of the New River, would allow for risk assessment of the sediment pathway and may provide sufficient information to support a "No Further Action" recommendation. The sediments should be sampled for TAL metals; a minimum of two additional New River sediment and surface water samples should be collected along the area of likely groundwater discharge from SWMU 31.

Should the supplemental data demonstrate a significant release of contaminants to the groundwater and the New River, the following action alternatives should be considered:

- Elimination of the discharge of filter backwash and drinking water overflow to the lagoons. The discharge to the lagoons is a flushing mechanism which facilitates the migration of metals from the sediments to the groundwater; and

- Closure of SWMU 31 through excavation of sediments and backfilling of the lagoons.

13.3 SWMU 48 (OILY WASTEWATER DISPOSAL AREA)

13.3.1 Recommendations

1) Recommendation: Perform Dye Tracing Study

Better definition of the groundwater flow at the SWMU 48 area and identification of specific discharge points are necessary to fully evaluate site conditions in this vicinity. Therefore, a dye tracing study is recommended for the SWMU 48 area. Although this study would not necessarily identify the source of VOCs found in the SWMU 48 and SWMU 13 groundwater, it would help to quantify risk analysis by defining the pathways of contaminant migration. The study would also provide useful groundwater characterization information for SWMUs 13, 16, 27, 28, 29, 30, 50, 51, 52, 53, and 59.

2) Recommendation: Access Restriction/Surface Water Runoff Drainage Control

Human health risk analysis suggests the potential for carcinogenic adverse human health effects for ingestion and dermal contact with surface soils (the most significant surface soil contamination appears to be from the upper disposal mound). However, the risk analysis determined that the inhalation of particulates pathway is not a concern. Therefore, restriction of access by installing a fence around the upper oily waste disposal mound at this SWMU is recommended to minimize contact with surface soils. Construction of surface water drainage controls will minimize the potential for contaminant migration through runoff.

13.4 SWMU 54 (PROPELLANT ASH DISPOSAL AREA)

13.4.1 Recommendations

1) Recommendation: Conduct Corrective Measures Study (CMS)

Risk analysis indicates the potential for noncarcinogenic and carcinogenic adverse human health effects for dermal and ingestion exposure scenarios for subsurface soils and groundwater. 2,4,6-TNT and other chemicals of concern identified for SWMU 54 were also found in New River sediments indicating contaminant migration. One of the waste ash composite samples exceeded the TCLP regulatory limit for lead; the ash is at the surface in places and SWMU 54 is prone to flooding which may transport contaminants to downstream receptors. Additionally, this area is not within the facility security fence and is accessible from the New River. Therefore, a CMS is recommended to define methods of source remediation.

The objective of the CMS is to identify and develop proposed corrective measures and alternatives by screening available technologies, assessing site conditions, and examining financial, institutional, and health impacts. A CMS would justify the recommended corrective actions on a technical, environmental and human health basis, including applicable cleanup levels. The CMS would provide complete information on the status of remediation activities and establish a system for regular reporting, record keeping, and compliance requirements. Finally, the CMS would provide sufficient information so that remedial design and implementation could proceed.

13.5 STROUBLES CREEK

13.5.1 Recommendations

1) Recommendation: Additional Sampling

Risk analysis suggests a low potential for carcinogenic adverse human health effects for dermal and ingestion exposure scenarios for sediments and for dermal exposure scenarios for surface water. However, since contaminants were found in the sample taken upstream of RAAP, and since only two samples were collected, additional work is required to fully characterize the creek. All potential sources contributing to the quality of Stroubles Creek have not been investigated. Additional sampling may indicate contaminant sources unrelated to activities at RAAP. Complete characterization of the creek should include a detailed analysis of the effects of dilution on the contaminants.

13.6 NEW RIVER

13.6.1 Recommendations

1) Recommendation: Additional Sampling

Risk analysis suggests the potential for carcinogenic adverse human health effects for dermal and ingestion exposure scenarios for sediments and for dermal exposure scenarios for surface water. However, since sample locations were chosen to correspond to the likely discharge point of the four SWMUs investigated for this report, the possible impacts of other SWMUs or permitted outfall discharges to the river have not been fully explored. Therefore, additional work is necessary to completely characterize the river. Additional sampling of the river may provide essential information for quantifying pathways at specific SWMUs as the basis of further action. The sampling may also indicate contaminant sources unrelated to activities at RAAP. Complete characterization of the river should include a detailed analysis of the effects of dilution on the contaminants.

TABLE 13.1
SUMMARY OF RFI RECOMMENDATIONS
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

SWMU or Area of Concern	HUMAN HEALTH RISK CONCERNS[1]									RECEPTORS			Risk Driver Compounds[3]	Recommendation
	Ingestion			Dermal Contact			Inhalation			Site Worker	Const. Worker	Rec. Users[2]		
	GW	SW/SE	Soil	GW	SW/SE	Soil	GW	SW	Soil					
SWMU 17/40: Contaminated Waste Burning Areas and Sanitary Landfill	✓		✓	✓		✓				Soil (I) Soil (D) GW (I) GW (D)	Soil (I) Soil (D)	H-Soil (I) H-Soil (D)	Antimony and Beryllium (GW); Arsenic and Beryllium (Surface Soil); Antimony and Arsenic (Subsurface Soil)	Conduct Corrective Measures Study Interim Measures
SWMU 31: Coal Ash Settling Lagoons	✓			✓						GW (I) GW (D)			Antimony and Beryllium (GW)	Collect Additional RFI Data
SWMU 48: Oily Wastewater Disposal Area	✓		✓	✓		✓	✓			Soil (I) Soil (D) GW (I) GW (D) GW (IH)	Soil (I) Soil (D)	H-Soil (I) H-Soil (D)	Beryllium and Carbon Tetrachloride (GW); Arsenic and Beryllium (Surface Soil)	Perform Dye Tracing Study Access Restriction/Surface Water Runoff Drainage Control
SWMU 54: Propellant Ash Disposal Area	✓		✓	✓		✓				GW (I) GW (D)	Soil (I) Soil (D)		Antimony, Arsenic and Beryllium (GW); Mercury and 2,4,6-Trinitrotoluene (Subsurface Soil)	Conduct Corrective Measures Study
Stroubles Creek		✓			✓					SE (I) SE (D)		F-SW (D)	Beryllium (SW); Arsenic and Beryllium (SE)	Additional Sampling
New River		✓			✓					SE (I) SE (D)		F-SW (D)	Beryllium (SW); Beryllium (SE)	Additional Sampling

1 - For compounds with hazard indices >1 or cancer risks > 1 x 10^{-6}

2 - F = fisherman, H = hunter, R = recreational surface water user.

3 - Risk driver compounds are discussed in the risk assessment subsections of Sections 7 - 12 of this report.

(I) - Ingestion
(D) - Dermal
(IH) - Inhalation
(SE) - Sediment
(SW) - Surface Water
(GW) - Groundwater

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SECTION 14

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