N62269.AR.000092
NAWC WARMINSTER
5090.3a

Focused Feasibility Study Report

for

Operable Unit 1
Naval Air Warfare Center
(NAWC)

Warminster, Pennsylvania

Northern Division
Naval Facilities Engineering Command

Contract Number N62472-90-D-1298

Contract Task Order 0022

April 1993

HALLIBURTON NUS
Environmental Corporation

CL
46

Halliburton NUS
CORPORATION

993 Old Eagle School Road, Suite 415
Wayne, PA 19087-1710

(215) 971-0900
FAX: (215) 971-9715

HNPH/51-4-3-153

April 21, 1993

Project Number 3933

Mr. Lonnie Monaco
Naval Facilities Engineering Command (NAVFACENGCOM)
Northern Division, Mailstop No. 82
Environmental Contracts Branch
10 Industrial Highway
Lester, Pennsylvania 19113

Reference: CLEAN Contract No. N62472-90-D-1298

Subject: Transmittal of Final Focused Feasibility Study (FFS) Report for Operable Unit 1 (OU-1)
Naval Air Warfare Center (NAWC), Warminster, Pennsylvania
Contract Task Order No. 22

Dear Mr. Monaco:

Halliburton NUS Corporation is pleased to submit the enclosed Final FFS Report for OU-1 at NAWC Warminster in response to the referenced statement of work. Two copies of this report are being provided.

This report focuses on interim remedial alternatives for groundwater contamination in the overburden and shallow bedrock aquifers at Sites 1, 2, and 3 (referred to as Area A) and Sites 5, 6, and 7 (Area B). These areas involve a portion of OU-1, which has been defined as all contaminated groundwater attributable to the facility in overburden and shallow bedrock aquifers. An operable unit is a discrete portion of a facility or a discrete action representing an incremental step in the investigation and remediation of hazardous substances at a facility. NAWC Warminster is being divided into OUs to help expedite the selection and implementation of actions necessary to protect human health and the environment.

The following members of the Technical Review Committee are being provided with the indicated number of copies of this report.

Technical Review Committee Member	No. of Copies
Mr. Eugene McGough, Jr., Manager Warminster Township	1 copy
Mr. Joseph Butch, Chairman Warminster Township Water and Sewer Authority	1 copy

Technical Review Committee Member	No. of Copies
Mr. Peter F. Palestina, Chairman Northampton Township Board of Supervisors	1 copy
Mr. Richard Lander, Executive Director Northampton Township Water and Sewer Authority	1 copy
Mr. Norman Kelly, Mayor Ivyland Borough	1 copy
Mr. Robert M. Pellegrino, Township Manager Upper Southampton Township Board of Supervisors	1 copy
Mr. Henry Cole, Director Upper Southampton Township Water Authority	1 copy
Mr. Albert W. Wills, Chief of Environmental Engineering Bucks County Department of Health	1 copy
Mr. Darius Ostrauskas, Remedial Project Manager United States Environmental Protection Agency (EPA)	1 copy
Mr. Dave Kennedy Pennsylvania Department of Environmental Resources (PA DER), Bureau of Waste Management	1 copy

One copy of the Final FFS Report for OU-1 has also been sent to Michael Hunter, Environmental Program Manager, NAWC Warminster.

Please contact me if you have any questions or comments.

Sincerely,

Neil Teamerson

Neil Teamerson
Project Manager

NT/dew

Enclosures

cc: David Rule (NAVFACENGCOM)
Roger Boucher (NAVFACENGCOM)
Raymond Mannella (NAVFACENGCOM)
John Trepanowski (Halliburton NUS)
Michael Turco (Halliburton NUS)
Eugene McGough (Warminster Township)(with attachment)
Joseph Butch (Warminster Township Water and Sewer Authority)(with attachment)
Peter Palestina (Northampton Township)(with attachment)
Richard Lander (Northampton Township)(with attachment)
Norman Kelly (Ivyland Borough)(with attachment)
Robert Pellegrino (Upper Southampton Township Board of Supervisors)(with attachment)
Henry Cole (Upper Southampton Township Water Authority)(with attachment)
Albert Wills (Bucks County Department of Health)(with attachment)
Darius Ostrauskas (EPA)(with attachment)
Dave Kennedy (PA DER)(with attachment)
Michael Hunter (NAWC Warminster)(with attachment)

R-49-12-92-3

FOCUSED FEASIBILITY STUDY REPORT
FOR
OPERABLE UNIT 1
NAVAL AIR WARFARE CENTER (NAWC)
WARMINSTER, PENNSYLVANIA

COMPREHENSIVE LONG-TERM
ENVIRONMENTAL ACTION NAVY (CLEAN) CONTRACT

Submitted to:
Northern Division
Environmental Branch, Code 18
Naval Facilities Engineering Command
10 Industrial Highway, Mail Stop #82
Lester, Pennsylvania 19113-2090

Submitted by:
Halliburton NUS Corporation
993 Old Eagle School Road, Suite 415
Wayne, Pennsylvania 19087-1710

Contract Number N62472-90-D-1298
Contract Task Order 0022

APRIL 21, 1993

SUBMITTED BY:

Neil Teamerson

NEIL TEAMERSON
PROJECT MANAGER
HALLIBURTON NUS CORPORATION
WAYNE, PENNSYLVANIA

APPROVED FOR SUBMISSION BY:

John Trepanowski

JOHN J. TREPANOWSKI, P.E.
PROGRAM MANAGER
HALLIBURTON NUS CORPORATION
WAYNE, PENNSYLVANIA

TABLE OF CONTENTS

SECTION		PAGE
EXECUTIVE SUMMARY		**ES-1**
1.0	**INTRODUCTION**	**1-1**
1.1	PURPOSE OF REPORT	1-1
1.2	ORGANIZATION OF REPORT	1-2
2.0	**IDENTIFICATION AND SCREENING OF TECHNOLOGIES**	**2-1**
2.1	INTRODUCTION	2-1
2.2	REMEDIAL ACTION OBJECTIVES	2-1
2.2.1	Applicable or Relevant and Appropriate Requirements (ARARs)	2-2
2.2.1.1	Contaminant-Specific ARARs and TBCs	2-9
2.2.1.2	Location-Specific ARARs and TBCs	2-20
2.2.1.3	Action-Specific ARARs and TBCs	2-26
2.2.2	Remedial Action Levels	2-31
2.3	GENERAL RESPONSE ACTIONS	2-31
2.4	IDENTIFICATION AND SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS	2-32
2.4.1	Initial Identification and Screening of Technologies and Options	2-32
2.4.2	Screening of Technologies and Process Options Which Passed Initial Screening	2-32
2.4.2.1	No Action	2-38
2.4.2.2	Institutional Controls	2-38
2.4.2.3	Removal Technologies	2-40
2.4.2.4	Containment	2-42
2.4.2.5	Disposal Technologies	2-42
2.4.2.6	In-Situ Treatment Technologies	2-46
2.4.2.7	Treatment Technologies	2-47
2.4.3	Summary of Final Screening of Technologies and Process Options	2-57
3.0	**DEVELOPMENT AND SCREENING OF REMEDIAL ALTERNATIVES**	**3-1**
3.1	DEVELOPMENT OF REMEDIAL TECHNOLOGIES	3-1
3.1.1	No Action with Groundwater Monitoring	3-1
3.1.2	Groundwater Extraction, Onsite Treatment, and Discharge to Surface Water	3-1
3.1.3	Groundwater Extraction, Onsite Pretreatment, and Discharge to NAWC Warminster Wastewater Treatment Plant or Publicly Owned Treatment Works	3-10
3.2	SCREENING OF REMEDIAL ALTERNATIVES	3-11
4.0	**DETAILED ANALYSIS OF ALTERNATIVES**	**4-1**
4.1	ALTERNATIVE 1: NO ACTION WITH GROUNDWATER MONITORING	4-4
4.1.1	Description	4-4
4.1.2	Overall Protection of Human Health and the Environment	4-4
4.1.3	Compliance with ARARs	4-4
4.1.4	Long-Term Effectiveness and Permanence	4-4
4.1.5	Reduction of Toxicity, Mobility, or Volume through Treatment	4-4
4.1.6	Short-Term Effectiveness	4-5

TABLE OF CONTENTS (CONTINUED)

SECTION		PAGE
4.1.7	Implementability	4-5
4.1.8	Cost	4-5
4.2	ALTERNATIVE 2: GROUNDWATER EXTRACTION, ONSITE TREATMENT, AND DISCHARGE TO SURFACE WATER	4-5
4.2.1	Description	4-5
4.2.2	Overall Protection of Human Health and the Environment	4-6
4.2.3	Compliance with ARARs	4-6
4.2.4	Long-Term Effectiveness and Permanence	4-7
4.2.5	Reduction of Toxicity, Mobility, or Volume through Treatment	4-7
4.2.6	Short-Term Effectiveness	4-7
4.2.7	Implementability	4-8
4.2.8	Cost	4-8
4.3	ALTERNATIVE 3: GROUNDWATER EXTRACTION, ONSITE PRETREATMENT, AND DISCHARGE TO THE NAWC WARMINSTER WASTEWATER TREATMENT PLANT OR PUBLICLY OWNED TREATMENT WORKS	4-9
4.3.1	Description	4-9
4.3.2	Overall Protection of Human Health and the Environment	4-10
4.3.3	Compliance with ARARs	4-10
4.3.4	Long-Term Effectiveness and Permanence	4-11
4.3.5	Reduction of Toxicity, Mobility, or Volume through Treatment	4-11
4.3.6	Short-Term Effectiveness	4-11
4.3.7	Implementability	4-11
4.3.8	Cost	4-12
4.4	SUMMARY OF DETAILED ANALYSIS OF ALTERNATIVES	4-12
5.0	**COMPARATIVE ANALYSIS OF ALTERNATIVES**	**5-1**
5.1	OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT	5-1
5.2	COMPLIANCE WITH ARARs	5-1
5.3	LONG-TERM EFFECTIVENESS AND PERMANENCE	5-1
5.4	REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT	5-2
5.5	SHORT-TERM EFFECTIVENESS	5-2
5.6	IMPLEMENTABILITY	5-2
5.7	COSTS	5-3
REFERENCES		**R-1**
APPENDICES		
A	**CONCEPTUAL DESIGN CALCULATIONS**	
B	**DETAILED COST ESTIMATES**	

TABLES

NUMBER		PAGE
2-1	Potential Federal ARARs	2-3
2-2	Potential State ARARs	2-6
2-3	Federal Regulatory Requirements and Dose Response Parameters for Chemicals of Concern	2-10
2-4	Clean Air Act - National Ambient Air Quality Standards	2-18
2-5	Pennsylvania Water Quality Standards and Ambient Water Quality Criteria	2-21
2-6	Pennsylvania Ambient Air Quality Standards	2-23
2-7	Initial Screening of Remedial Technologies and Process Options	2-33
2-8	Final Screening of Remedial Technologies and Process Options	2-58
3-1	Assumed Influent and Effluent Concentrations for Metals Discharge to Surface Water Alternative	3-7
3-2	Assumed Influent and Effluent Limits for Organics Discharge to Surface Water Alternative	3-8
4-1	Summary of Detailed Analysis of Alternaltives	4-13

FIGURES

NUMBER		PAGE
3-1	Conceptual Extraction Well Layout - Sites 1, 2, and 3 (Area A)	3-3
3-2	Conceptual Extraction Well Layout - Sites 5, 6, and 7 (Area B)	3-4
3-3	Process Flow Diagram Alternative 2: Discharge to Surface Water	3-5

EXECUTIVE SUMMARY

This Focused Feasibility Study (FFS) for Operable Unit 1 (OU-1) at Naval Air Warfare Center (NAWC) Warminster has been prepared for the Northern Division, Naval Facilities Engineering Command as authorized under Contract Task Order No. 22 under Contract N62472-90-D-1298. This work is part of the Navy's Installation Restoration Program (IRP), which is designed to identify contamination of Navy and Marine Corps facilities resulting from past operations and to institute corrective measures, as needed.

PURPOSE

The purpose of this FFS is to present remedial alternatives for OU-1, which is defined as any groundwater in overburden and shallow bedrock that has been contaminated due to hazardous substance releases by NAWC Warminster. The Phase II Remedial Investigation (RI) report for OU-1 at NAWC Warminster identifies the known nature and extent of contaminated groundwater in overburden and shallow bedrock aquifers and an unacceptable risk to human health associated with this groundwater. Based on information in the Phase II RI report, it has further been determined that a remedial alternative for OU-1 can be selected at this time. This FFS has been prepared as part of the remedy selection process for OU-1.

Feasibility studies for other media affected by the facility (including groundwater in deeper bedrock aquifers) will be performed upon completion of additional RI work. These feasibility studies will be performed to facilitate the selection of additional remedial actions necessary to protect human health and the environment.

REMEDIAL ACTION OBJECTIVES

Contaminated groundwater in overburden and shallow bedrock aquifers, identified as OU-1, presents an unacceptable risk to human health (see baseline Risk Assessment discussion within the Phase II RI report). The general objective of the remedy for OU-1 is to mitigate this risk.

Based on information in the Phase II RI report, there is uncertainty regarding the full nature and extent of contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster and, as a result, uncertainty regarding the ability of any remedy to fully restore the groundwater of concern

to drinking water quality or other beneficial uses. However, available RI information provides an adequate basis for selecting a remedial alternative to minimize the migration of NAWC Warminster-related contaminants in the overburden and shallow bedrock aquifers while additional investigations are conducted to fully identify the nature and extent of the contamination in these aquifers and to identify a final remedy.

The remedial objectives for OU-1 are therefore summarized as follows:

- Minimize migration of all contaminated groundwater attributable to NAWC Warminster in overburden and shallow bedrock aquifers.

- Conduct additional investigations to fully identify the nature and extent of contaminated groundwater attributable to NAWC Warminster in overburden and shallow bedrock aquifers both on and off current NAWC Warminster property and generate the data necessary to select a final remedy for groundwater.

A remedy with these objectives is considered an interim remedy. Alternatives for this interim remedy are developed in this FFS. A final remedy for OU-1 will be selected in the future with the benefit of information generated during the implementation of the selected interim remedy.

REMEDIAL ALTERNATIVES DEVELOPMENT

The FFS was prepared based on data obtained during previous investigations at NAWC Warminster, using EPA Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (October 1988), the revised National Oil and Hazardous Substances Pollution Contingency Plan (NCP of 1990), EPA Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites (December 1988), and the Navy/Marine Corps Installation Restoration Program (February 1992).

Based on the site problems and the remedial response objectives, general response actions and the associated technologies and process options were identified. These general response actions and technologies/process options are summarized in Section 2.3 and Table 2-7, respectively.

The technologies and process options were screened for effectiveness, implementability, and relative cost in Section 2.4. Remedial alternatives were assembled using the technologies and process options that passed the screening. In addition, CERCLA requires that the "No Action" alternative be evaluated at every

site to establish a baseline for comparison with action alternatives. The alternatives that were assembled are briefly described below:

- **Alternative 1: No Action with Groundwater Monitoring**. Under this alternative, no remedial action would be undertaken to address contaminated groundwater attributable to NAWC Warminster in overburden and shallow bedrock aquifers. Instead, additional studies necessary to identify the full nature and extent of contaminated groundwater in overburden and shallow bedrock aquifers would be conducted as part of continuing RIs addressing the facility. In addition to these studies, monitoring of groundwater in overburden and shallow bedrock aquifers would be conducted for 30 years.

- **Alternative 2: Groundwater Extraction, Onsite Treatment, and Discharge to Surface Water**. Under this alternative, contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster would be extracted using a series of extraction wells. The extraction wells would be located as necessary to maximize the effectiveness of the system. The extracted groundwater would be pumped to an onsite treatment system constructed specifically to treat groundwater. Treatment would include air stripping to remove volatile organics and carbon adsorption to remove semivolatile organics. Emissions from the air stripper would be treated by vapor-phase carbon adsorption unless an exemption from air treatment requirements is obtained. Metals would be treated by precipitation and filtration (and ion exchange, or other means, if necessary). Upon meeting effluent limits consistent with National Pollutant Discharge Elimination System (NPDES) requirements, the treated water would be discharged to an unnamed tributary of Little Neshaminy Creek or an unnamed tributary of Southampton Creek. Treatability studies would be performed to confirm effluent levels meet NPDES requirements.

  Concurrent with the design, construction, and operation of the initial extraction well network and treatment system, investigations would be conducted both on and off current NAWC Warminster property as necessary to fully identify the nature and extent of contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster. If additional contamination of concern attributable to NAWC Warminster is identified, the extraction well network and treatment system would be modified as necessary to minimize migration of contaminants and to maximize the effectiveness of the extraction well network.

- **Alternative 3: Groundwater Extraction, Onsite Pretreatment, and Discharge to the NAWC Warminster Wastewater Treatment Plant or Publicly Owned Treatment Works.** Under this alternative, contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster would be extracted using a series of extraction wells. The extraction wells would be located as necessary to maximize the effectiveness of the extraction system. The extracted groundwater would be pumped to an onsite treatment system constructed specifically to pretreat groundwater prior to discharge to the NAWC Warminster wastewater treatment plant (WWTP). In the event that the NAWC Warminster WWTP ceases operation as part of base realignment and closure, the pretreated groundwater would then be discharged to a publicly owned treatment works (POTW) such as the Warminster Municipal Authority (WMA) WWTP. Pretreatment would be performed as necessary to meet the influent requirements of the receiving WWTP. Pretreatment may include air stripping to remove volatile organics, precipitation/filtration (and ion exchange or other means, if necessary) to remove metals, and/or carbon adsorption to treat semivolatile organics. If necessary, emissions from the air stripper would be treated by vapor-phase carbon adsorption. After pretreatment, the groundwater would be discharged to the POTW WWTP or NAWC Warminster WWTP. Treatability studies would be conducted as necessary to confirm that the pretreatment meets the requirements of the receiving WWTP and that the WWTP meets NPDES requirements.

  Concurrent with the design, construction, and operation of the initial extraction well network and pretreatment system, investigations would be conducted both on and off current NAWC Warminster property as necessary to fully identify the nature and extent of contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster. If additional contamination of concern attributable to NAWC Warminster is identified, the extraction well network and pretreatment system would be modified as necessary during the interim action for OU-1 to minimize migration of contaminants and to maximize the effectiveness of the extraction well network.

EVALUATION OF REMEDIAL ALTERNATIVES

The three remedial alternatives were evaluated using seven of the nine criteria specified in the NCP and EPA guidance document previously identified. These criteria include overall protection of human health and the environment; compliance with ARARs; long-term effectiveness and permanence; reduction of

toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost. The remaining two criteria, state acceptance and community acceptance, will be evaluated following comment on the RI/FFS reports and Proposed Plan for OU-1 and will be addressed in the Record of Decision (ROD) once an interim action decision has been made.

The comparative analysis summarizing the evaluation of these criteria is included in Section 5.0.

The cost estimates for the remedial alternatives are as follows:

Alternative	Capital Cost	Annual Cost	Present Worth
1	$72,000	$182,000	$2,871,000
2	$3,515,000	$628,000	$13,172,000
3	$3,515,000	$628,000	$13,172,000

1.0 INTRODUCTION

1.1 PURPOSE OF REPORT

In response to Contract Task Order No. 22 under Contract N62472-90-D-1298, Halliburton NUS Corporation is submitting this Focused Feasibility Study (FFS) report for the Naval Air Warfare Center (NAWC) (formerly the Naval Air Development Center), Warminster, Pennsylvania. This work is part of the Navy's Installation Restoration Program (IRP), which is designed to identify contamination of Navy and Marine Corps facilities resulting from past operations and to institute corrective measures, as needed.

IRP activities are typically performed in four distinct phases. The first phase consists of a Preliminary Assessment (PA) followed by the second phase which is a Site Inspection (SI). The third phase is a Remedial Investigation/Feasibility Study (RI/FS), which is intended to characterize physical and chemical parameters and risks associated with the facility. The fourth phase consists of Remedial Action designed to control and mitigate contamination. This report is prepared under Phase III IRP activities.

The purpose of this FFS is to present remedial alternatives for OU-1, which is defined as any groundwater in overburden and shallow bedrock aquifers that has been contaminated due to hazardous substance releases by NAWC Warminster. The Phase II Remedial Investigation (RI) report for OU-1 at NAWC Warminster identifies the known nature and extent of contaminated groundwater in overburden and shallow bedrock aquifers and an unacceptable risk to human health associated with this groundwater. Based on information in the Phase II RI report, it has further been determined that a remedial alternative for OU-1 can be selected at this time. This FFS has been prepared as part of the remedy selection process for OU-1.

Feasibility studies for other media affected by the facility (including groundwater in deeper bedrock aquifers) will be performed upon completion of additional RI work. These feasibility studies will be performed to facilitate the selection of additional remedial actions necessary to protect human health and the environment.

1.2 ORGANIZATION OF REPORT

This report presents the remedial alternatives for all groundwater contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster, including known contamination in the vicinity of Areas A (Sites 1, 2, and 3) and B (Sites 5, 6, and 7).

- Section 2.0 discusses remedial action objectives, Applicable or Relevant and Appropriate Requirements (ARARs) pertaining to groundwater at Areas A and B, and the identification and screening of technologies and process options.

- Section 3.0 presents the development of remedial alternatives.

- Section 4.0 presents the detailed analysis of each remedial alternative.

- Section 5.0 presents a comparative analysis of the remedial alternatives.

- Appendix A contains conceptual design calculations for remedial alternatives.

- Appendix B contains detailed cost estimates for remedial alternatives.

The Phase II RI report for OU-1 contains a description of the facility, regional and local hydrogeology, groundwater use, the known nature and extent of overburden and shallow bedrock groundwater contamination, and a risk assessment for this groundwater. The elements are part of the Phase II RI report and are not repeated here.

This FFS was prepared using EPA Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (OSWER Directive 9355.3-01, October 1988), the revised National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR 300, March 1990), EPA Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites (OSWER Directive 9283.1-2, December 1988), and the Navy/Marine Corps Installation Restoration Manual (February 1992).

2.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

2.1 INTRODUCTION

In this section, the following four actions of the Focused Feasibility Study (FFS) procedure are performed:

- Establish remedial action objectives (Section 2.2).
- Identify general response actions to meet remedial objectives, including no action (Section 2.3).
- Identify remedial technologies and process options under each general response action with emphasis on permanent solutions (Section 2.4).
- Screen remedial technologies and process options based on effectiveness and implementability considerations (Section 2.4).

2.2 REMEDIAL ACTION OBJECTIVES

Contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster, identified as OU-1, presents an unacceptable risk to human health (see baseline Risk Assessment discussion within the Phase II RI report). The general objective of the remedy for OU-1 is to mitigate this risk.

Based on information in the Phase II RI report, there is uncertainty regarding the full nature and extent of contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster and, as a result, uncertainty regarding the ability of any remedy to fully restore the groundwater of concern to drinking water quality or other beneficial uses. However, available RI information provides an adequate basis for selecting a remedial alternative to minimize the migration of NAWC Warminster-related contaminants in the overburden and shallow bedrock aquifers within the facility boundary while additional investigations are conducted to fully identify the nature and extent of the contamination in these aquifers and to identify a final remedy.

The remedial objectives for OU-1 are therefore summarized as follows:

- Minimize migration of all contaminated groundwater attributable to NAWC Warminster in overburden and shallow bedrock aquifers.

- Conduct additional investigations to fully identify the nature and extent of contaminated groundwater attributable to NAWC Warminster in overburden and shallow bedrock aquifers both on and off current NAWC Warminster property and generate the data necessary to select a final remedy for groundwater.

A remedy with these objectives is considered an interim remedy. Alternatives for this interim remedy are developed in this FFS. A final remedy for OU-1 will be selected in the future with the benefit of information generated during the implementation of the selected interim remedy.

2.2.1 Applicable or Relevant and Appropriate Requirements (ARARs)

Tables 2-1 and 2-2 present a summary of potential Federal and state ARARs for any remedial actions undertaken for OU-1 at NAWC Warminster.

The definition of ARARs is as follows:

- Any standard, requirement, criterion, or limitation under federal environmental law.

- Any promulgated standard, requirement, criterion, or limitation under a state environmental or facility-siting law that is more stringent than the associated federal standard, requirement, criterion, or limitation.

TABLE 2-1

POTENTIAL FEDERAL ARARs
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA

Contaminant-Specific Requirements	Rationale
Safe Drinking Water Act (42 USC 300) MCLs, SMCLs (40 CFR Part 143) and MCLGs (40 CFR Part 141)	Remedial actions may include groundwater cleanup to MCLs, MCLGs, and/or SMCLs
Clean Water Act (33 USC 1251-1376) Federal Ambient Water Quality Criteria (AWQCs) (40 CFR 131)	Remedial actions may result in surface water discharges that could impact aquatic life
Clean Air Act (42 USC 7401)	
National Ambient Air Quality Standards (NAAQS) (40 CFR Part 50)	Remedial alternatives may result in emissions to the atmosphere
National Emission Standards for Hazardous Air Pollutants (NESHAPs) (40 CFR 61.60-61.71)	Remedial alternatives may result in hazardous chemical emissions
New Source Performance Standards (NSPS) (40 CFR Part 60)	Remedial alternatives may result in emissions to the atmosphere
Air Emissions for Non-attainment Areas (OSWER Directive 9355.0-28)	Remedial alternatives may result in air emissions
Reference Doses (RfDs), EPA Office of Research and Development Cancer Slope Factors, EPA Environmental Criteria and Assessment Office, EPA Carcinogen Assessment Group Health Advisories, EPA Office of Drinking Water Health Effects Assessments	Considered in the human health risk assessment
Threshold Limit Values, American Conference of Governmental Industrial Hygienists	May be applicable to air concentrations during remedial activities
Identification and Listing of Hazardous Wastes (40 CFR Part 261)	Remedial alternatives may result in the generation of hazardous wastes

TABLE 2-1
POTENTIAL FEDERAL ARARs
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE TWO

Location-Specific Requirements	Rationale
Federal Protection of Wetlands Executive Order (E.O. 11990)	Wetland or floodplain resources may be affected by remedial action
Endangered Species Act of 1978 (16 USC 1531) (40 CFR 502)	Considered in the environmental assessment
Fish and Wildlife Coordination Act of 1980 (16 USC 661) Fish and Wildlife Conservation Act (16 USC 2901) Fish and Wildlife Improvement Act of 1978 (16 USC 742a)	Remedial alternatives may affect fish and wildlife habitat
Groundwater Protection Strategy (EPA, 1984)	Remedial alternatives may be determined by specific category
Executive Order on Floodplain Management (E.O. 11988)	Floodplain resources may be affected by remedial action

Action-Specific Requirements	Rationale
Hazardous Waste Generator Requirements (40 CFR Part 262)	Standards applicable to generators of hazardous wastes that may be generated during remedial action
Hazardous Waste Transportation Requirements (40 CFR Part 263)	Remedial alternatives may require transportation of hazardous materials off site for treatment/disposal
Standards for Owners and Operators of Hazardous Waste Treatment, Storage, or Disposal (TSD) Facilities (40 CFR Part 264) Interim Status Standards for Owners and Operators of Hazardous Waste or TSD Facilities (40 CFR Part 264)	Remedial alternatives may involve hazardous waste treatment, storage, and disposal facilities
Land Disposal Restrictions (40 CFR Part 268)	Standards for the land disposal of hazardous wastes
Criteria for Classification of Solid Waste Disposal Facilities and Practices (40 CFR Part 257)	Establishes criteria for use in determining which solid waste disposal facilities and practices pose a reasonable probability of adverse effects on health and thereby constitute prohibited open dumps.

TABLE 2-1
POTENTIAL FEDERAL ARARs
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE THREE

Action-Specific Requirements	Rationale
Department of Transportation (DOT) Rules for Hazard Materials Transport (49 CFR) Parts 107, 171-179)	Remedial alternatives may include transport of waste for offsite treatment and disposal
National Environmental Policy Act	Requires consideration of environmental effects due to Federal actions
Clean Water Act (40 CFR Part 122) National Pollutant Discharge Elimination System (NPDES)	Remedial actions may involve discharge to surface waters
Clean Air Act (42 USC 7401) NAAQS (40 CFR Parts 50 and 53), NESHAPs (40 CFR Part 61), and NSPS (40 CFR Part 60)	Treatment technologies for emissions to air (incineration, surface impoundments, waste piles, landfills, and sources of fugitive emissions)
Occupational Safety and Health Act (29 USC 651-678)	Regulates worker health and safety
Revised Procedures for Planning and Implementing Offsite Actions (OSWER Directive 9834.11)	Establishes procedures for offsite response actions

TABLE 2-2

POTENTIAL STATE ARARs
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA

Contaminant-Specific Requirements	Rationale
State Water Quality Standards (25 PA Code, Chapter 93)	Remedial actions may include discharge to surface waters
State Air Pollution Regulations (25 PA Code, Chapters 121-143)	Remedial actions may include technologies with atmospheric emissions
State Water Quality Toxics Management Strategy (25 PA Code, Chapter 16)	Remedial actions may include discharge to surface waters
State Safe Drinking Water Regulations (25 PA Code, Chapter 109)	State MCLs and treatment technologies
PADER Groundwater Protection Strategy (February 1992)	Remedial actions may need to address nondegradation of groundwater quality

Location-Specific Requirements	Rationale
State Water Quality Standards (25 PA Code, Chapter 93.9)	Specific water uses that are protective of particular streams

Action-Specific Requirements	Rationale
State Hazardous Waste Management (25 PA Code, Article VII)	Remedial actions may include treating, storing, and disposing of hazardous wastes
State Solid Waste Disposal Regulations (25 PA Code, Chapter 75)	Remedial actions may include treating, storing, and disposing of solid wastes
State Pollutant Discharge Elimination System (NPDES) Rules 25 PA Code, Chapter 92)	Remedial actions may include discharge to surface waters
State Wastewater Treatment Requirements (25 PA Code, Chapter 95)	Remedial actions may include treatment and discharge to surface waters
State Industrial Waste Management Regulations (25 PA Code, Chapter 97)	Remedial actions may include treatment and discharge to surface waters

TABLE 2-2
POTENTIAL STATE ARARs
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE TWO

Action-Specific Requirements	Rationale
State Special Water Pollution Regulations (25 PA Code, Chapter 101)	Applicable for permitted solid waste disposal facilities
State Erosion Control Regulations (25 PA Code, Chapter 102)	Soil disturbance during proposed remedial actions may require erosion and sedimentation control measures
State Hazardous Substances Transportation Regulations PA Code Title 13 (Flammable Liquids and Flammable Solids) and Title 15 (Oxidizing Materials, Poisons, and Corrosive Liquids)	Applicable to wastes generated during a remedial action that would be shipped off site for analysis, treatment, or disposal
State General Provisions (25 PA Code, Chapter 91)	Standards for the reinjection of treated groundwater
State Construction, Modification, Reactivation and Operation of Sources Regulations (25 PA Code, Chapter 127)	Standards for the operation of air pollution controls at a potential source
State Stormwater Management Act (Act No. 167)	Requires measures to control stormwater runoff during remedial alternatives or development of land
State Hazardous Waste Regulations (25 PA Code, Chapter 264)	Establishes procedures to measure the background groundwater quality

One of the primary concerns during the development of remedial action alternatives for hazardous waste sites under CERCLA is the degree of human health and environmental protection afforded by a given remedy. Section 121 of CERCLA requires that primary consideration be given to remedial alternatives that attain or exceed ARARs. The purpose of this requirement is to make CERCLA response actions consistent with other pertinent Federal and state environmental requirements.

Definitions of the two types of ARARs, as well as other "to be considered" (TBC) criteria, are given below:

- Applicable Requirements means those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or state law that directly and fully address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site.

- Relevant and Appropriate Requirements means those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or state law, while not "applicable," address problems or situations sufficiently similar (relevant) to those encountered at the CERCLA site, that their use is well suited (appropriate) to the particular site.

- "To Be Considered" (TBC) Criteria are non-promulgated, non-enforceable guidelines or criteria that may be useful for developing remedial action, or necessary for determining what is protective to human health and/or the environment. Examples of TBC criteria include EPA Drinking Water Health Advisories, Carcinogenic Potency Factors, and Reference Doses.

Section 121(d)(4) of CERCLA allows the selection of a remedial alternative that will not attain all ARARs if any of six conditions for a waiver of ARARs exist. These conditions are as follows: (1) the remedial action is an interim measure whereby the final remedy will attain the ARAR upon completion; (2) compliance will result in greater risk to human health and the environment than other options; (3) compliance is technically impracticable; (4) an alternative remedial action will attain the equivalent of the ARAR; (5) for state requirements, the state has not consistently applied the requirement in similar circumstances; or (6) compliance with the ARAR will not provide a balance between protecting public health, welfare, and the environment at the facility with the availability of Fund money for response at other

facilities (fund balancing). Condition (1) above applies to remedial alternatives developed in the FFS, since the objective is to implement an interim action.

ARARs fall into three categories, based on the manner in which they are applied.

- Contaminant Specific: Health-/risk-based numerical values or methodologies that establish concentration or discharge limits for particular contaminants. Examples of contaminant-specific ARARs include Maximum Contaminant Levels (MCLs) and Clean Water Act (CWA) water quality criteria. Contaminant-specific ARARs govern the extent of site cleanup.

- Location Specific: Restrictions based on the concentration of hazardous substances or the conduct of activities in specific locations. These may restrict or preclude certain remedial actions or may apply only to certain portions of site. Examples of location-specific ARARs include RCRA location requirements and floodplain management requirements. Location-specific ARARs pertain to special site features.

- Action Specific: Technology- or activity-based controls or restrictions on activities related to management of hazardous waste. Action-specific ARARs pertain to implementing a given remedy.

2.2.1.1 Contaminant-Specific ARARs and TBCs

This section presents a summary of Federal and state contaminant-specific ARARs and TBC criteria of potential concern in the case of OU-1. All ARARs and TBC criteria provide some medium-specific guidance on "acceptable" or "permissible" concentrations of contaminants. Table 2-3 contains regulatory requirements and dose response parameters for contaminants of concern at NAWC Warminster.

The Safe Drinking Water Act (SDWA) promulgated National Primary Drinking Water Standard Maximum Contaminant Levels (MCLs) (40 CFR Part 141). MCLs are enforceable standards for contaminants in public drinking water supply systems. They consider not only health factors but also the economic and technical feasibility of removing a contaminant

TABLE 2-3

FEDERAL REGULATORY REQUIREMENTS AND DOSE RESPONSE PARAMETERS FOR CHEMICALS OF CONCERN
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA

Chemical	Safe Drinking Water Act[1][2][10] (mg/L)		Health Advisory[3] (mg/L)	Reference Dose[4][6][11] (mg/kg/day)		Cancer Slope Factor[4][5][11] $(mg/kg/day)^{-1}$		Weight of Evidence[4][11]	Ambient Water Quality Criteria[6] (mg/L)	
	MCL	MCLG		Oral	Inhalation	Oral	Inhalation		Water & Fish	Fish Only
Benzene	0.005	0	1-Day/Child: 0.2 10-Day/Child: 0.2	2×10^{-1}	NA	2.9×10^{-2}	2.9×10^{-2}	A	0.0012	0.071
Tetrachloroethene	0.005	0	1-Day/Child: 2.0 10-Day/Child: 2.0 Longer-Term/Child: 1.0 Longer-Term/Adult: 5.0	1×10^{-2}	NA	5.1×10^{-2}	1.8×10^{-3}	B2	0.0008	0.00885
1,1,1-Trichloroethane	0.2	0.2	1-Day/Child: 100 10-Day/Child: 40 Longer-Term/Child: 40 Longer-Term/Adult: 10 Lifetime: 0.2	3.5×10^{-2}	3×10^{-1}	NA	NA	D	NA	NA
Carbon tetrachloride	0.005	0	1-Day/Child: 4.0 10-Day/Child: 0.2 Longer-Term Child: 0.07 Longer-Term Adult: 0.3	7×10^{-4}	NA	1.3×10^{-1}	1.3×10^{-1}	B2	0.00025	0.0044
1,2-Dichloropropane	0.005	0	10-Day/Child: 0.09	NA	1.14×10^{-3}	6.8×10^{-2}	NA	B2	0.00052	0.039
1,1-Dichloroethane	NA	NA	NA	1×10^{-1}	1.43×10^{-1}	NA	NA	C	NA	NA
Chloroform (Trihalomethanes)	0.1	NA	1-Day/Child: 4.0 10-Day/Child: 4.0 Longer-Term/Child: 0.1 Longer-Term/Adult: 0.4	1×10^{-2}	NA	6.1×10^{-3}	8.05×10^{-2}	B2	0.0057	0.470
1,2-Dichloroethane	0.005	0	1-Day/Child: 0.7 10-Day/Child: 0.7 Longer-Term/Child: 0.7 Longer-Term/Adult: 2.6	NA	NA	9.1×10^{-2}	9.1×10^{-2}	B2	0.00038	0.099

TABLE 2-3
FEDERAL REGULATORY REQUIREMENTS AND DOSE RESPONSE PARAMETERS FOR CHEMICALS OF CONCERN
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE TWO

Chemical	Safe Drinking Water Act[1][2][10] (mg/L)		Health Advisory[3] (mg/L)	Reference Dose[4][6][11] (mg/kg/day)		Cancer Slope Factor[4][5][11] $(mg/kg/day)^{-1}$		Weight of Evidence[4][11]	Ambient Water Quality Criteria[6] (mg/L)	
	MCL	MCLG		Oral	Inhalation	Oral	Inhalation		Water & Fish	Fish Only
Trichloroethene	0.005	0	NA	NA	NA	1.7×10^{-3}	6.0×10^{-3}	B2	0.0027	0.081
cis-1,2-Dichloroethene	0.07	0.07	1-Day/Child: 4.0 10-Day/Child: 3.0 Longer-Term/Child: 3.0 Longer-Term/Adult:1.0 Lifetime: 0.07	9×10^{-3}	NA	NA	NA	NA	NA	NA
trans-1,2-Dichloroethene	0.1	0.1	1-Day/Child: 20.0 10-Day/Child: 2.0 Longer-Term/Child2.0 Longer-Term/Adult6.0 Lifetime: 0.1	9×10^{-3}	NA	NA	NA	NA	0.7	140
1,1-Dichloroethene	0.007	0.007	1-Day/Child: 2.0 10-Day/Child: 1.0 Longer-Term/Child:1.0 Longer-Term/Adult:4.0 Lifetime: 0.007	9×10^{-3}	NA	6×10^{-1}	1.2×10^{0}	C	5.7×10^{-5}	0.0032
2-Butanone	NA	NA	1-Day/Child: 80.0 10-Day/Child: 8.0 Longer-Term/Child3.0 Longer-Term/Adult9.0 Lifetime: 0.2	5×10^{-2}	8.6×10^{-2}	NA	NA	D	NA	NA
Chloromethane	NA	NA	1-Day/Child: 9.0 10-Day/Child: 0.4 Longer-Term/Child0.4 Longer-Term/Adult:1.0 Lifetime: 0.003	NA	NA	1.3×10^{-2}	6.3×10^{-3}	C	NA	NA
1,2-Dichlorobenzene	0.6	0.6	NA	9×10^{-2}	5.71×10^{-2}	NA	NA	D	2.7	17

TABLE 2-3
FEDERAL REGULATORY REQUIREMENTS AND DOSE RESPONSE PARAMETERS FOR CHEMICALS OF CONCERN
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE THREE

Chemical	Safe Drinking Water Act[1][2][10] (mg/L)		Health Advisory[3] (mg/L)	Reference Dose[4][6][11] (mg/kg/day)		Cancer Slope Factor[4][5][11] $(mg/kg/day)^{-1}$		Weight of Evidence[4][11]	Ambient Water Quality Criteria[6] (mg/L)	
	MCL	MCLG		Oral	Inhalation	Oral	Inhalation		Water & Fish	Fish Only
Ethylbenzene	0.7	0.7	1-Day/Child: 30.0 10-Day/Child: 3.0 Longer-Term/Child: 1.0 Longer-Term/Adult: 3.0 Lifetime: 0.7	1×10^{-1}	3×10^{-1}	NA	NA	D	3.1	29
Toluene	1.0	1.0	1-Day/Child: 20.0 10-Day/Child: 2.0 Longer-Term/Child: 2.0 Longer-Term/Adult: 7.0 Lifetime: 1.0	2×10^{-1}	1×10^{-1}	NA	NA	D	4.8	200
Trichlorofluoromethane	NA	NA	1-Day/Child: 7.0 10-Day/Child: 7.0 Longer-Term/Child: 3.0 Longer-Term/Adult: 0.0 Lifetime: 2.0	3×10^{-1}	2×10^{-1}	NA	NA	NA	5.67×10^{-3}	0.47
Vinyl Chloride	0.002	0	1-Day/Child: 3.0 10-Day/Child: 3.0 Longer-Term/Child: 0.01 Longer-Term/Adult: 0.05	NA	NA	1.9	3×10^{-1}	A	0.002	0.525
Xylenes	10	10	1-Day/Child: 40.0 10-Day/Child: 40.0 Longer-Term/Child: 10.0 Longer-Term/Adult: 10.0 Lifetime: 10.0	2.0	NA	NA	NA	D	NA	NA
Benzo(a)anthracene	0.0001*	0	NA	NA	NA	7.3[12]	6.1[12]	B2	4.4×10^{-6}	4.9×10^{-5}
Benzo(a)pyrene	0.0002	0	NA	NA	NA	7.3	6.1	B2	4.4×10^{-6}	4.9×10^{-5}

TABLE 2-3
FEDERAL REGULATORY REQUIREMENTS AND DOSE RESPONSE PARAMETERS FOR CHEMICALS OF CONCERN
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE FOUR

Chemical	Safe Drinking Water Act[1][2][10] (mg/L)		Health Advisory[3] (mg/L)	Reference Dose[4][6][11] (mg/kg/day)		Cancer Slope Factor[4][5][11] $(mg/kg/day)^{-1}$		Weight of Evidence[4][11]	Ambient Water Quality Criteria[6] (mg/L)	
	MCL	MCLG		Oral	Inhalation	Oral	Inhalation		Water & Fish	Fish Only
Benzo(b)fluoranthene	0.0002*	0	NA	NA	NA	7.3[12]	6.1[12]	B2	4.4×10^{-6}	4.9×10^{-5}
Benzo(g,h,i)perylene	NA	NA	NA	NA	NA	NA	1.29×10^{-1}	D	4.4×10^{-6}	4.9×10^{-5}
Butylbenzylphthalate	0.1*	0	NA	2.0×10^{1}	NA	NA	NA	C	3	5.2
Chrysene	0.0002*	0	NA	NA	NA	7.3[12]	6.1[12]	B2	4.4×10^{-6}	4.9×10^{-5}
Dibenz(a,h)anthracene	0.0003*	0	NA	NA	NA	7.3[12]	6.1[12]	B2	4.4×10^{-6}	4.9×10^{-5}
Diethylphthalate	NA	NA	Lifetime: 5.0	8×10^{-1}	NA	NA	NA	D	23	120
Di-n-octylphthalate	NA	NA	NA	2×10^{-2}	NA	NA	NA	NA	NA	NA
Fluoranthene	NA	NA	NA	4×10^{-2}	NA	NA	NA	D	0.042	0.054
Indeno(1,2,3-cd)pyrene	0.0004*	0	NA	NA	NA	7.3[12]	6.1[12]	B2	4.4×10^{-6}	4.9×10^{-5}
Phenanthrene	NA	NA	NA	NA	NA	NA	NA	D	NA	NA
Pyrene	NA	NA	NA	3×10^{-2}	NA	NA	NA	D	0.96	11
Arsenic	0.05	NA	NA	3×10^{-4}	NA	1.75×10^{0}	5.0×10^{1}	A	0.000018	0.00014
Cadmium	0.005	0.005	1-Day/Child: 0.04 10-Day/Child: 0.04 Longer-Term/Child: 0.005 Longer-Term/Adult0.02 Lifetime: 0.005	5×10^{-4}	NA	NA	6.1×10^{0}	B1	NA	NA
Chromium (total)	0.1	0.1	1-Day/Child: 1.0 10-Day/Child: 1.0 Longer-Term/Child0.2 LongerpTerm/Adult: 0.8 Lifetime: 0.1	1×10^{-0}(tri) 5×10^{-3}(hex)	5.7×10^{-7} (hex)	NA	4×10^{1} (hex)	D (tri) A (hex, inhalation)	NA	NA

TABLE 2-3
FEDERAL REGULATORY REQUIREMENTS AND DOSE RESPONSE PARAMETERS FOR CHEMICALS OF CONCERN
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE FIVE

Chemical	Safe Drinking Water Act[1][2][10] (mg/L)		Health Advisory[3] (mg/L)	Reference Dose[4][6][11] (mg/kg/day)		Cancer Slope Factor[4][5][11] $(mg/kg/day)^{-1}$		Weight of Evidence[4][11]	Ambient Water Quality Criteria[6] (mg/L)	
	MCL	MCLG		Oral	Inhalation	Oral	Inhalation		Water & Fish	Fish Only
Cobalt	NA	NA	NA	6.0×10^{-2}	NA	NA	NA	NA	NA	NA
Lead	0.015[8]	0	NA	NA	NA	NA	NA	NA	NA	NA
Manganese	NA	NA	NA	1×10^{-1}	1.1×10^{-4}	NA	NA	NA	NA	NA
Nickel	0.1	0.1	1-Day/Child: 1.0 10-Day/Child: 1.0 Longer-Term/Child 0.5 Longer-Term/Adult 1.7 Lifetime: 0.1	2×10^{-2}	NA	NA	8.4×10^{-1} (refinery dust)	A	0.61	4.6
Thallium	0.002	0.0005	1-Day/Child: 0.007 10-Day/Child: 0.007 Longer-Term/Child 0.007 Longer-Term/Adult 0.02 Lifetime: 0.0004	7.0×10^{-5}	NA	NA	NA	NA	0.0017	0.0063
Aluminum	0.05-0.2[13]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Barium	2.0	2.0	Lifetime: 2.0	7×10^{-2}	1.4×10^{-4}	NA	NA	NA	NA	NA
Copper	1.3	1.3	NA	3.7×10^{-2}	NA	NA	NA	D	1.3	NA
Mercury	0.002	0.002	Longer-Term/Adult 0.002 Lifetime: 0.002	3×10^{-4}	8.6×10^{-5}	NA	NA	D	1.4×10^{-4}	1.5×10^{-5}
Silver	0.05[13]	NA	1-Day/Child: 0.2 10-Day/Child: 0.2 Longer-Term/Child 0.2 Longer-Term/Adult 0.2 Lifetime: 0.1	5×10^{-3}	NA	NA	NA	D	NA	NA

TABLE 2-3
FEDERAL REGULATORY REQUIREMENTS AND DOSE RESPONSE PARAMETERS FOR CHEMICALS OF CONCERN
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE SIX

Chemical	Safe Drinking Water Act[1][2][10] (mg/L)		Health Advisory[3] (mg/L)	Reference Dose[4][6][11] (mg/kg/day)		Cancer Slope Factor[4][5][11] $(mg/kg/day)^{-1}$		Weight of Evidence[4][11]	Ambient Water Quality Criteria[6] (mg/L)	
	MCL	MCLG		Oral	Inhalation	Oral	Inhalation		Water & Fish	Fish Only
Vanadium	NA	NA	1-Day/Child: 0.08 10-Day/Child: 0.08 Longer-Term/Child 0.03 Longer-Term/Adult 0.11 Lifetime: 0.02	7×10^{-3}	NA	NA	NA	NA	NA	NA
Zinc	5.0[13]	NA	Lifetime: 2.1	2×10^{-1}	NA	NA	NA	D	NA	NA

NA Not Available
(1) Safe Drinking Water Act, 40 CFR 141/142/143.
(2) EPA, 1990a.
(3) EPA, 1992a.
(4) IRIS February, 1993.
(5) EPA, 1992b
(6) EPA, 1990b. Based on protection of human health.
(7) Calculated from LD_{LO}.
(8) Action level, EPA, 1991b.
(9) RfD has been revoked pending review of carcinogenicity.
(10) EPA, 1991a.
(11) Heast, 1992 Annual
(12) Memorandum on Carcinogenicity of Benzo(a)pyrene and PAHs, Pei-Fing Hurst, March 22, 1991
(13) Secondary MCL
* Proposed

from a water supply system. Secondary MCLs (SMCLs) (40 CFR Part 143) are not enforceable but are intended as guidelines for contaminants that may adversely affect the aesthetic quality of drinking water, such as taste, odor, color, and appearance, and may deter public acceptance of drinking water provided by public water systems.

The SDWA also established Maximum Contaminant Level Goals (MCLGs) for several organic and inorganic compounds in drinking water. MCLGs are set at levels of no known or anticipated adverse health effects, with an adequate margin of safety. The NCP [40 CFR Part 300.430(e)(2)(i)] states that MCLGs that are set at levels above zero shall be attained by remedial actions for groundwaters or surface waters that are current or potential sources of drinking water (where the MCLGs are relevant and appropriate under the circumstances of the release based on the factors in Section 300.400(g)(2) of the NCP). If an MCLG is found not to be relevant and appropriate, the corresponding MCL shall be achieved where relevant and appropriate to the circumstances of the release. For MCLGs that are set at zero, the MCL promulgated for that contaminant under the SDWA shall be attained by the remedial actions. In cases involving multiple contaminants or pathways where attainment of chemical-specific ARARs will result in a cumulative cancer risk in excess of 10^{-4}, criteria in paragraph (e)(2)(i)(A) of Section 300.430 (i.e., risk-based criteria) may be considered when determining the cleanup level to be attained. The NCP explains that cleanup levels set at zero (generally the case for carcinogens) are not appropriate because CERCLA does not require complete elimination of risk and because "true zero" cannot be detected.

SDWA requirements may be relevant and appropriate to remedial actions involving groundwater. Table 2-3 contains available Federal SDWA standards for the contaminants of concern identified during the previous studies conducted at NAWC Warminster.

EPA Health Advisories are nonenforceable guidelines (TBCs) developed by the EPA Office of Drinking Water for chemicals that may be intermittently encountered in public water supply systems. Health advisories are available for short-term, longer-term, and lifetime exposures for a 10-kg child and/or a 70-kg adult. Health advisories may be pertinent for remedial actions involving groundwater, especially for contaminants that are not regulated under the SDWA.

The Clean Water Act (CWA) sets EPA Ambient Water Quality Criteria (AWQCs) that are non-enforceable guidelines developed for pollutants in surface waters pursuant to Section 304(a)(1) of the Clean Water Act. Although AWQCs are not legally enforceable, they have been used by many states to develop enforceable water quality standards; they should be considered as potential ARARs, as specified by CERCLA. AWQCs

are available for the protection of human health from exposure to contaminants in drinking water as well as from ingestion of aquatic biota and for the protection of freshwater and saltwater aquatic life. AWQCs may be considered for actions that involve groundwater treatment and/or discharge to nearby surface waters.

Reference Dose (RfD), as defined in the EPA Integrated Risk Information System (IRIS), is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. RfDs are developed for chronic and/or subchronic human exposure to hazardous chemicals and are based on the assumption that thresholds exist for certain toxic effects. The RfD is usually expressed as an acceptable dose (mg) per unit body weight (kg) per unit time (day). The RfD is derived by dividing the no-observed-adverse effect level (NOAEL) or the lowest-observed-adverse effect level (LOAEL) by an uncertainty factor (UF) times a modifying factor (MF). The use of uncertainty factors and modifying factors is discussed in the EPA, Office of Research and Development (ORD) Health Effects Assessment Summary Tables, Fourth Quarter FY1989 [October 1989-ORD(RD-689)] (EPA, 1989a). RfDs are TBCs for NAWC Warminster.

Cancer Slope Factors (CSFs) are used for estimating the lifetime probability (assumed 70-year lifespan) of human receptors contracting cancer as a result of exposure to known or suspected carcinogens. These factors are generally reported in units of kg-day/mg and are derived through an assumed low dosage linear relationship and an extrapolation from high to low dose responses determined from human or animal studies. Cancer risk and CSFs are most commonly estimated through the use of a linearized multistage mathematical extrapolation model applied to animal bioassay results. The value used in reporting the slope factor is the upper 95 percent confidence limit. CSFs are TBCs for NAWC Warminster.

The Clean Air Act (CAA) (42 USC 7401) consists of three programs or requirements that may be ARARs: National Ambient Air Quality Standards (NAAQS) (40 CFR Part 50), National Emission Standards for Hazardous Air Pollutants (NESHAPs) (40 CFR Part 61), and New Source Performance Standards (NSPS) (40 CFR Part 60). NESHAPs, which are emission standards for source types (i.e., industrial categories) that emit hazardous air pollutants, are not likely to be applicable or relevant and appropriate for NAWC Warminster because they were developed for a specific source.

EPA requires the attainment and maintenance of primary and secondary NAAQS, shown in Table 2-4, to protect public health and public welfare, respectively. These standards are not source specific but rather

TABLE 2-4

CLEAN AIR ACT - NATIONAL AMBIENT AIR QUALITY STANDARDS
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA

Parameter	Primary Standard ($\mu g/m^3$)	Secondary Standard ($\mu g/m^3$)
Carbon monoxide	10,000 (8-hour)[1] 40,000 (1-hour)[1]	10,000 (8-hour)[1] 40,000 (1-hour)[1]
Lead	1.5 (90-day)[2]	1.5 (90-day)[2]
Nitrogen oxides	100 (1-year)[3]	100 (1-year)[3]
Ozone	235 (1-hour)[1]	235 (1-hour)[1]
Particulate matter (expressed as PM-10)	150 (24-hour)[1] 50 (1-year)[3]	150 (24-hour)[1] 50 (1-year)[3]
Sulfur Dioxide	365 (24-hour)[1] 80 (1-year)[3]	1,300 (3-hour)[1]

Primary: Protection of public health
Secondary: Protection of public welfare
(1) Maximum concentration not to be exceeded more than once per year
(2) Maximum arithmetic mean averaged over a calendar quarter
(3) Annual arithmetic mean

are national limitations on ambient air quality. States are responsible for assuring compliance with the NAAQS. Requirements in an EPA-approved State Implementation Plan (SIP) for the implementation, maintenance, and enforcement of NAAQS are potential ARARs.

NSPS are established for new sources of air emissions to ensure that the new stationary sources minimize emissions. These standards are for categories of stationary sources that cause or contribute to air pollution that may endanger public health or welfare. Standards are based upon the best demonstrated technology (BDT). NSPS are generally not applicable to CERCLA remedial actions but may be relevant and appropriate to NAWC Warminster if the pollutant(s) emitted (e.g., from an air stripping tower) and the technology employed during the cleanup action are sufficiently similar to the pollutant and source category regulated by an NSPS and are well suited to the circumstances at the site.

Hazardous Waste Identification and Listing Regulations (40 CFR Part 261) defines those solid wastes which are subject to regulation as hazardous waste under 40 CFR Parts 262 to 265 and Parts 124, 270, and 271.

OSWER Directive 9355.0-28 is a TBC that guides the control of air emissions from air strippers at Superfund groundwater remediation sites. For sites located in areas that are not attaining the NAAQS for ozone, add-on emission controls are required for an air stripper with an actual emission rate in excess of 3 pounds per hour or 15 pounds per day, or a potential (i.e., calculated) rate of 10 tons per year of total volatile organic compounds. This TBC may be relevant and appropriate in meeting risk management guidelines because NAWC Warminster is located in an area that is not attaining the NAAQS for ozone.

Pennsylvania Safe Drinking Water Regulations (PA Code, Title, 25 Chapter 109) sets forth drinking water quality standards at least as stringent as the National Primary Drinking Water Regulations. MCLs that are promulgated by the EPA are automatically incorporated into the Pennsylvania SDWA. If an MCL does not exist for a contaminant, the Pennsylvania SDWA require the maximum allowable concentration to be determined in the following order: (1) the concentration that EPA has proposed to set or is considering setting as a primary MCL for the contaminant; (2) the concentration associated with a lifetime cancer risk of 10^{-6} for carcinogenic contaminants or the lifetime drinking water health advisory concentration for noncarcinogenic contaminants, provided that this concentration is equal to or greater than the practical quantitation level and the level achievable through the use of available treatment technology; or (3) the lowest concentration achievable considering the practical quantitation level and available treatment technology.

Pennsylvania Water Quality Toxics Management Strategy (PA Code, Title 25, Chapter 16) is the water quality toxics management strategy and contains water quality criteria for toxics. Values for toxics of concern are shown in Table 2-5.

Pennsylvania Water Quality Standards (PA Code, Title 25, Chapter 93) set forth state water quality standards. The standards are based upon water uses that are to be protected and will be considered by the Pennsylvania Department of Environmental Resources (PADER) in its regulation of discharges to surface water. The standards may be applicable for actions involving the discharge of pollutants to surface water.

Table 2-5 provides state Water Quality Standards applicable to surface waters near NAWC Warminster (Southampton Creek, Little Neshaminy Creek, and their unnamed tributaries).

Pennsylvania Air Pollution Control Regulations (PA Code, Title 25, Chapters 121 through 143) govern air emissions from remedial actions. The regulations provide for the control and prevention of air pollutants and guidance for the design and operation of air pollution sources. Potential sources of air pollution at the site may include onsite remedial actions that involve air stripping. Pennsylvania has adopted the NAAQS presented in Table 2-4 and has air quality standards for five additional constituents as shown in Table 2-6.

PADER Groundwater Protection Strategy is a guideline (TBC) for achieving nondegradation of groundwater quality through use of best demonstrated control technologies.

2.2.1.2 Location-Specific ARARs and TBCs

Federal Protection of Wetlands Executive Order (E.O. 11990) requires Federal agencies, in carrying out their responsibilities, to take action to minimize the destruction, loss, or degradation of wetlands and to preserve

TABLE 2-5

PENNSYLVANIA WATER QUALITY STANDARDS AND AMBIENT WATER QUALITY CRITERIA
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA

Parameter	Water Quality Standard[1]	Ambient Water Quality Criteria for Protection of Aquatic Life[2] (µg/L)		Ambient Water Quality Criteria for Protection of Human Health[2](µg/L)
		Continuous Concentration	Maximum Concentration	
Aluminum	0.1 of the 96-hour LC_{50}	NP	NP	NP
Arsenic	NP	190	360	50
Barium	NP	NP	NP	NP
Cadmium	NP	1.3[3]	4.6[3]	10
Chromium (Total)	NP	243[3]	1,963[3]	170,050
Cobalt	NP	NP	NP	NP
Copper	NP	13[3]	20[3]	1,000
Iron	1.5 mg/L (total); 0.3 mg/L (diss.)	NP	NP	NP
Lead	NP	3.8[3]	99[3]	50
Manganese	1.0 mg/L	NP	NP	NP
Mercury	NP	0.012	2.4	0.144
Nickel	NP	177[3]	1,596[3]	632
Silver	NP	0.2	5.2[3]	50
Thallium	NP	18	90	13
Vanadium	NP	NP	NP	NP
Zinc	NP	119[3]	132[3]	5,000
Benzene	NP	128	640	1
Tetrachloroethene	NP	139	695	0.7
Trichlorethene	NP	450	2,250	3
cis-1,2-Dichloroethene	NP	NP	NP	NP
trans-1,2-Dichloroethene	NP	1,350	6,750	350
1,1-Dichloroethene	NP	1,492	7,460	NP
1,1,1-Trichlorethane	NP	605	3,025	1,000
2-Butanone	NP	NP	NP	NP
Carbon tetrachloride	NP	556	2,780	0.3
Chloroform	NP	389	1,945	0.2
1,2-Dichloropropane	NP	2,165	10,825	NP
1,1-Dichloroethane	NP	NP	NP	NP

TABLE 2-5
PENNSYLVANIA WATER QUALITY STANDARDS AND AMBIENT WATER QUALITY CRITERIA
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE TWO

Parameter	Water Quality Standard[1]	Ambient Water Quality Criteria for Protection of Aquatic Life[2] (µg/L)		Ambient Water Quality Criteria for Protection of Human Health[2](µg/L)
		Continuous Concentration	Maximum Concentration	
Chloromethane	NP	5,500	27,500	0.2[4]
1,2-Dichlorobenzene	NP	164	820	400[5]
1,2-Dichloroethane	NP	3,088	15,440	0.4
Ethylbenzene	NP	580	2,900	1,400
Toluene	NP	330	1,650	14,300
Trichlorfluoromethane	NP	NP	NP	NP
Vinyl chloride	NP	NP	NP	0.02
Xylenes	NP	NP	NP	NP
Benzo(a)anthracene	NP	0.1	0.5	0.003
Benzo(a)pyrene	NP	NP	NP	0.003
Benzo(b)fluoranthene	NP	NP	NP	0.003
Benzo(ghi)perylene	NP	NP	NP	0.003
Butylbenzylphthalate	NP	35	140	NP
Chrysene	NP	NP	NP	0.003
Dibenz(ah)anthracene	NP	NP	NP	0.003
Diethylphthalate	NP	800	4,000	350,000
Di-n-octylphthalate	NP	NP	NP	NP
Fluoranthene	NP	40	200	42
Indeno(1,2,3-cd)pyrene	NP	NP	NP	0.003
Phenanthrene	NP	1	5	0.003
Pyrene	NP	NP	NP	0.003

(1) 25 PA Code, Chapter 93.
(2) 25 PA Code Chapter 16
(3) Based on assumed hardness of 115 mg/L.
(4) Total halomethanes
(5) Total dichlorobenzenes
NP Not promulgated.

TABLE 2-6

PENNSYLVANIA AMBIENT AIR QUALITY STANDARDS
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA

Parameter	Standard
Settled particulate	0.8 $mg/cm^2/mo$ (1-year average) 1.5 $mg/cm^2/mo$ (30-day average)
Beryllium	0.01 $\mu g/m^3$ (30-day average)
Sulfates (as H_2SO_4)	10 $\mu g/m^3$ (30-day average) 30 $\mu g/m^3$ (24-hour average)
Fluorides (total soluble as HF)	5 $\mu g/m^3$ (24-hour average)
Hydrogen sulfide	0.005 ppm (24-hour average) 0.1 ppm (1-hour average)

Source Code: PA Code Title 25, Chapter 131

and enhance the natural and beneficial values of wetlands. According to the published definition of national wetlands, Federal Register 40 CFR Appendix C, several small areas of palustrine forested wetlands are present along intermittent tributaries to Little Neshaminy Creek or Southampton Creek. This ARAR has been retained in the event that wetland areas may be affected.

The Endangered Species Act of 1978 (16 USC 1531) (40 CFR Part 502) provides for consideration of the impacts on endangered and threatened species and their critical habitats. This act requires federal agencies, in consultation with the Secretary of the Interior, to ensure that any action authorized, funded, or carried out by the agency is not likely to jeopardize the continued existence of any endangered or threatened species or adversely affect its critical habitat. A review of the available information indicates that no state or Federally listed endangered or threatened species are known to permanently or seasonally reside in the vicinity of NAWC Warminster. For this reason, the Endangered Species Act of 1978 is not applicable or relevant and appropriate to actions taken at the site.

The Fish and Wildlife Coordination Act (16 USC 661) provides for consideration of the impacts on wetlands and protected habitats. The act requires that federal agencies, before issuing a permit or undertaking Federal action for the modification of any body of water, consult with the appropriate state agency exercising jurisdiction over wildlife resources to conserve those resources. Consultation with the United States Fish and Wildlife Service is also required.

The Fish and Wildlife Improvement Act of 1978 (16 USC 742a) and The Fish and Wildlife Conservation Act of 1980 (16 USC 2901) provide for consideration of the impacts on wetlands and protected habitats.

EPA's Groundwater Protection Strategy (EPA, 1984) policy is to protect groundwater for its highest present or potential beneficial use. This policy (TBC) will be incorporated into future regulatory amendments. The strategy designates three categories of groundwater:

- Class I - Special Groundwaters: Waters that are highly vulnerable to contamination and are either irreplaceable or ecologically vital sources of drinking water.

- Class II - Current and Potential Sources of Drinking Water and Waters Having Other Beneficial Uses: Waters that are currently used or that are potentially available.

- Class III - Groundwater Not a Potential Source of Drinking Water and of Limited Beneficial Use. Class III groundwater units are further subdivided into two subclasses.

  - Subclass IIIA includes groundwater units that are highly to intermediately interconnected to adjacent groundwater units of a higher class and/or surface waters. They may, as a result, be contributing to the degradation of the adjacent waters. They may be managed at a similar level as Class II groundwaters, depending upon the potential for producing adverse effects on the quality of adjacent waters.

  - Subclass IIIB is restricted to groundwater characterized by a low degree of interconnection to adjacent surface waters or other groundwater units of a higher class within the Classification Review Area. These groundwaters are naturally isolated from sources of drinking waters in such a way that there is little potential for producing adverse effects on quality. They have low resource values outside of mining or waste disposal.

Groundwater beneath and adjacent to NAWC Warminster is designated as a Class II aquifer.

Federal Floodplain Management Executive Order (E.O. 11988) requires Federal agencies to evaluate the potential effects of actions they may take in a floodplain to avoid, to the extent possible, the adverse impacts associated with direct and indirect development of a floodplain.

Pennsylvania Water Quality Standards (25 PA Code 93.9) contains specific water uses that are protective of particular streams.

2.2.1.3 Action-Specific ARARs and TBCs

RCRA Subtitle C regulates the treatment, storage, and disposal of hazardous waste from its generation until its ultimate disposal. In general, RCRA Subtitle C requirements for the treatment, storage, or disposal of hazardous waste will be applicable if

- The waste is a listed or characteristic waste under RCRA.
- The waste was treated, stored, or disposed (as defined in 40 CFR 260.10) after the effective date of the RCRA requirements under consideration.
- The activity at the CERCLA site constitutes current treatment, storage, or disposal as defined by RCRA.

RCRA Subtitle C requirements may be relevant and appropriate when the waste is sufficiently similar to a hazardous waste and/or the onsite remedial action constitutes treatment, storage, or disposal, and the particular RCRA requirement is well suited to the circumstances of the contaminant release and site. RCRA Subtitle C requirements may also be relevant and appropriate when the remedial action constitutes generation of a hazardous waste. Onsite activities, mandated by a Federally ordered Superfund cleanup, must comply with the substantiative requirements of RCRA Subtitle C but not with the administrative requirements (i.e., permits) of RCRA. All RCRA Subtitle C requirements must be met if the cleanup is not under Federal order and/or when the hazardous waste moves off site.

The following requirements included in the RCRA Subtitle C regulations may pertain to the NAWC Warminster:

- Hazardous waste generator requirements (40 CFR Part 262).
- Transportation requirements (40 CFR Part 263).
- Standards for owners and operators of hazardous waste treatment, storage, and disposal (TSD) facilities (40 CFR Part 264).

- Interim status standards for owners and operators of hazardous waste TSD facilities (40 CFR Part 265).

- Land Disposal Restrictions (40 CFR Part 268)

A generator that treats, stores, or disposes of hazardous waste on site must comply with RCRA Standards Applicable to Generators of Hazardous Waste (40 CFR Part 262). These standards include manifest, pre-transport (i.e., packaging, labeling, placarding), recordkeeping, and reporting requirements. The standards are applicable to actions taken at NAWC Warminster that constitute generation of a hazardous waste (e.g., generation of groundwater treatment residues that may be hazardous).

Standards Applicable to Transporters of Hazardous Waste (40 CFR Part 263) are applicable to offsite transportation of hazardous waste from NAWC Warminster. These regulations include requirements for compliance with the manifest and recordkeeping systems and requirements for immediate action and cleanup of hazardous waste discharges (spills) during transportation. Transporters must also have a Pennsylvania transporter permit.

Standards for Owners and Operators of Hazardous Waste TSD Facilities (40 CFR Part 264) are applicable to remedial actions taken at NAWC Warminster and to offsite facilities receiving hazardous waste from the site for treatment and/or disposal and have a RCRA Part B permit. Onsite facilities must also have a RCRA Part B permit if the site is not a Federally ordered CERCLA cleanup. Standards for TSDFs include requirements for preparedness and prevention, releases from solid waste management units (i.e., corrective action requirements), closure and post-closure care, use and management of containers, and design and operating standards for tank systems, surface impoundments, waste piles, landfills, and incinerators.

RCRA Land Disposal Restrictions (LDR) Requirements (40 CFR Part 268) restrict certain wastes from being placed or disposed on the land unless they meet specific Best Demonstrated Available Technology (BDAT) treatment standards (expressed as concentrations, total or in the TCLP extract, or as specified technologies).

Placement of hazardous waste into underground injection wells constitutes "land disposal" under the LDRs. Furthermore, RCRA Section 3020(a) bans hazardous waste disposal by underground injection into or above an underground source of drinking water. RCRA Section 3020(b), however, exempts from the ban all

reinjections of treated contaminated groundwater into such formations undertaken as part of a CERCLA Section 104 or 106 response action, or a RCRA corrective action, if the following conditions are met:

- The contaminated groundwater is treated to substantially reduce hazardous constituents prior to such injection.

- The response action or corrective action is sufficient to protect human health and the environment upon completion.

Therefore, the LDR requirements may not be applicable or relevant and appropriate to reinjection of treated groundwater at NAWC Warminster.

RCRA Criteria for Classification of Solid Waste Disposal Facilities and Practices (40 CFR Part 257) establishes criteria for use in determining which solid waste disposal facilities and practices pose a reasonable probability of adverse effects on health and thereby constitute prohibited open dumps.

DOT Rules for Hazardous Materials Transport (49 CFR Parts 107 and 171-179) regulate the transport of hazardous materials, including packaging, shipping equipment, and placarding. These rules are considered applicable to wastes shipped off site for laboratory analysis, treatment, or disposal.

The Clean Water Act (CWA), as amended, governs point-source discharges through the National Pollutant Discharge Elimination System (NPDES), discharge or dredge or fill material, and oil and hazardous waste spills to United States waters. NPDES requirements (40 CFR Part 122) will be applicable if the direct discharge of pollutants into surface waters is part of the remedial action.

The Occupational Health and Safety Act (29 USC, Sections 651 through 678) regulates worker health and safety during implementation of remedial actions.

OSWER Directive 9834.11 establishes procedures for planning and implementing offsite response actions.

Pennsylvania Stormwater Management Act (Act No. 167) requires measures to control stormwater runoff during remedial alternatives or development of land.

Pennsylvania Special Water Pollution Regulations (PA Code, Title 25, Chapter 101) establish a procedure for mandatory notification of downstream users in the case of an accident in which a toxic substance enters surface waters. These regulations also specify bonding requirements for solid waste facilities that would ensure closure of a permitted site in a manner that would abate or prevent water pollution. The regulations may be applicable for remedial actions that include onsite treatment of solid waste.

Pennsylvania Hazardous Substances Transportation Regulations (PA Code, Title 13 and Title 15) govern the transport of flammable liquids and solids, oxidizing materials, poisons, and corrosive liquids. These regulations may be applicable to certain wastes that are shipped off site for laboratory analysis, treatment, or disposal. These regulations are generally equivalent to Federal DOT regulations.

Pennsylvania Hazardous Waste Management Regulations (PA Code, Title 25, Article VII) essentially parallel RCRA Subtitle C hazardous waste management regulations. Similar to RCRA Subtitle C regulations, Pennsylvania regulations include requirements for the following:

- Generators of hazardous waste (Chapter 262).
- Transporters of hazardous waste (Chapter 263).
- New and existing hazardous waste management facilities applying for a permit (Chapter 264).
- Interim status hazardous waste management facilities applying for a permit (Chapter 265).

The above regulations may be relevant and appropriate to onsite remedial actions and applicable to the transport of hazardous waste off site.

The corrective action program requirements of Chapter 264 (Section 264.100) require contaminated groundwater to be remediated to background levels. This regulation also establishes procedures to measure background groundwater quality. As stated in the regulation, groundwater remedial actions may be terminated when it can be demonstrated that concentration levels of hazardous constituents in the monitoring wells have remained at background levels for a period of three consecutive years.

Pennsylvania NPDES Rules (PA Code, Title 25, Chapter 92) govern point-source discharges to Pennsylvania waters. The rules include requirements for permits, permit applications, permit conditions, and monitoring. These rules may be applicable for remedial actions involving a discharge to surface water. To the extent that Pennsylvania water quality criteria and standards, waste-water treatment requirements,

industrial waste treatment, and special water pollution control regulations (PA Code, Title 25, Chapters 16, 93, 95, 97, and 101) pertain to a discharge for which an NPDES permit is required, the provisions of these chapters govern if their application produces a more stringent effluent limitation than would be produced by application of Federal standards. The Pennsylvania NPDES rules are generally equivalent to the federal standards.

Pennsylvania General Provisions (PA Code, Title 25, Chapter 91) are general provisions that are applicable if treated groundwater reinjection is a component of the remediation. If reinjection is done off site, it will be necessary to obtain a water quality management permit (Section 91.21). If the reinjection is done on site, then the substantive requirements of Chapter 91 must be met, but a permit would not be required.

Pennsylvania Wastewater Treatment Regulations (PA Code, Title 25, Chapter 95) are regulations that are required to maintain water quality and include treatment requirements, effluent limitations based on best practical control technologies, and waste-load allocations for pollutants for which minimum treatment requirements have not been established. These regulations will be applicable for remedial actions that include a discharge to surface water.

Pennsylvania Construction, Modification, Reactivation, and Operation of Sources Regulations (PA Code, Title 25, Chapter 127) regulate the construction, modification, or reactivation of an air contaminant source as well as the installation of an air cleaning device on an air contamination source. Remedial actions used to remove volatile contaminants from the groundwater at NAWC Warminster are subject to plan approval review under Chapter 127. The various air quality permitting criteria are site specific. Depending on site conditions, air pollution controls may be required for an air stripper at NAWC Warminster.

Pennsylvania Solid Waste Disposal Regulations (PA Code 25, Chapter 75) regulate the disposal of solid wastes including municipal and industrial materials. The regulations set operating and permitting standards for disposal areas and characterize waste materials to achieve proper disposal. Any remedial actions resulting in the generation of waste material for onsite or offsite disposal are governed by these regulations.

Pennsylvania Industrial Waste Management Regulations (PA Code 25, Chapter 97) regulate the disposal of industrial waste materials. The regulation characterizes wastes and sets permitting and disposal standards. Remedial activities resulting in the generation of industrial waste such as wastewater treatment plant sludges are regulated under this statute.

Pennsylvania Erosion Control Regulations (PA Code 25, Chapter 102) regulate earthwork and construction that may result in the erosion of soils and sedimentation and pollution of surface wastes. Remedial activities on site that may include soil excavation for remediation or construction are subject to these regulations.

2.2.2 Remedial Action Levels

Since remedial alternatives being evaluated for OU-1 at this time are for an interim remedy, certain ARARs may be waived per the discussion in Section 2.2.1. Because the primary objective of the interim remedy for OU-1 is to minimize the migration of contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster, the requirement to attain contaminant-specific ARARs for restoring these aquifers may be waived temporarily until a final remedy for OU-1 is selected.

2.3 GENERAL RESPONSE ACTIONS

Using the general response actions developed for NAWC Warminster, future sections will identify the types of technologies (e.g., physical treatments) and process options (e.g., activated carbon adsorption, ambient-temperature air stripping, high-temperature steam stripping) associated with these technologies. These will be screened for technical implementability, and a representative process option will be selected for applicable and implementable technologies. The selected process options will then be assembled into remedial alternatives. Listed below are the six general response actions that were identified for OU-1.

- No Action
- Institutional Controls
- Removal
- Containment
- In-situ Treatment
- Treatment

2.4 IDENTIFICATION AND SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS

This stage of the FFS consists of the following steps:

- Identifying remedial technologies and process options based on remedial action objectives and general response actions.
- Screening technologies for technical implementability and effectiveness.
- Evaluating process options considered to be implementable.

2.4.1 Initial Identification and Screening of Technologies and Options.

In this step, potentially applicable technology types and process options are identified based on the remedial action objectives and the general response actions. This list of technologies and process options is reduced by evaluating the options with respect to technical implementability. This is accomplished by using available information from the RI site characterization on contaminant types and concentrations and onsite characteristics to screen out technologies and process options that cannot be effectively implemented at the site.

A summary of the initial screening of technologies and process options is presented in Table 2-7.

2.4.2 Screening of Technologies and Process Options Which Passed Initial Screening

Further screening of the technologies and process options that passed the initial screening can be applied in accordance with EPA guidance for feasibility studies. Three criteria are used to eliminate from further consideration any technologies and process options that are undesirable regarding effectiveness, implementability, and cost. These criteria are defined as follows:

- Effectiveness
  - Protection of human health and environment; reduction in toxicity, mobility, and volume, and permanence of solution.
  - Ability of the technology to handle the estimated areas or volumes of contaminated medium.

TABLE 2-7

INITIAL SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA

General Response Action Component	Remedial Technology	Process Option	Description	Screening Comments
No Action	None	Not applicable	No remedial actions taken	Required as a baseline consideration by NCP
Institutional Controls	Access restrictions	Deed restrictions	Groundwater use in the area of groundwater contamination would involve restrictions on wells	Potentially applicable
	Monitoring	Groundwater monitoring	Periodic monitoring of offsite wells and onsite monitoring wells in the areas of groundwater contamination	Potentially applicable
Removal	Extraction	Extraction wells	A series of pumping wells to extract contaminated groundwater	Potentially applicable
	Subsurface drains	Interceptor trenches	Perforated pipe in trenches backfilled with porous media to collect groundwater	Potentially applicable for overburden aquifer; however, not applicable for fractured bedrock of shallow bedrock aquifer
Containment	Capping	Capping of soil surface with impervious material	Surface soil to be capped with impervious material to prevent infiltration and leaching of soil contaminants to groundwater	Not applicable; does not meet objective of minimizing migration of contaminated overburden and shallow bedrock groundwater
	Vertical barriers	Slurry wall/grout curtain	Soil/bentonite or cement grout mixture injected into trenches/borings to create curtain impervious to groundwater flow	Potentially applicable for overburden aquifer; not applicable for fractured bedrock of shallow bedrock aquifer

TABLE 2-7
INITIAL SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE TWO

General Response Action Component	Remedial Technology	Process Option	Description	Screening Comments
Disposal	Surface water discharge	Direct discharge of water to local stream or river	Collected/treated groundwater discharged to tributary of Little Neshaminy or Southhampton Creek	Potentially applicable
	Discharge to existing wastewater treatment plant	Indirect discharge of water through existing wastewater treatment plant	Collected/treated groundwater discharged to existing wastewater treatment plant	Potentially applicable
	Subsurface discharge (re-injection)	Injection wells	Collected/treated groundwater injected into ground through a series of wells	Potentially applicable
	Spray irrigation	Discharge to surface soil for infiltration	Collected/treated groundwater sprayed to surface for evaporation/infiltration	Potentially applicable
	Water Reuse	Reuse for drinking water or industrial purposes	Collected/treated groundwater used to supplement NAWC Warminster water supply	Not applicable; NAWC Warminster has an adequate supply of water for drinking and industrial purposes
In Situ Treatment	Biological	Aerobic	Degradation of organics using microorganisms in an aerobic environment	Potentially applicable for organic contaminants
	Air sparging	Aeration	Air forced under pressure through soils below the water table	Not applicable for depth and nature of contamination identified to date

TABLE 2-7
INITIAL SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE THREE

General Response Action Component	Remedial Technology	Process Option	Description	Screening Comments
Treatment	Biological	Aerobic	Aerobic degradation of organics using microorganisms, nutrients, and an oxygen source	Potentially applicable to organic contaminants; not applicable to inorganics
		Anaerobic	Anaerobic degradation of organics using microorganisms	Not applicable to primary organic contaminants. Degradation product of PCE and TCE is vinyl chloride. Not applicable to inorganics.
	Chemical/physical	Coagulation - flocculation/ precipitation	Removal of heavy metals by adding agents to reduce solubility and encourage precipitation of contaminants	Potentially applicable to inorganic contaminants; not applicable to primary organic contaminants
		Oxidation - reduction	Manipulation of oxidation or reduction state of a compound to alter its characteristics	Not applicable to site-related contaminants
		Chlorination	Disinfection of water using chlorine compounds	Not applicable; combining organics and chlorine may produce trihalomethane
		Neutralization	Addition of acidic or basic compounds to alter the pH of a solution	Potentially applicable; may be required for all discharge technologies
		Air stripping	Mixing groundwater with large volumes of air in a packed column to promote the transfer of VOCs to the air	Potentially applicable; Not applicable for inorganic contaminants

TABLE 2-7
INITIAL SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE FOUR

General Response Action Component	Remedial Technology	Process Option	Description	Screening Comments
Treatment	Chemical/physical	Steam stripping	Mixing groundwater with large volumes of steam in a packed column to promote transfer of VOCs to steam for condensation	Not applicable for organic components at concentrations detected; will not be applicable for inorganic contaminants
		Carbon adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column	Potentially applicable for organic contaminants; may not be effective for inorganic contaminants
		Reverse osmosis	Use of high pressure to force water through a membrane, leaving contaminants behind	Not applicable to primary organic contaminants. Potentially applicable for inorganic contaminants.
		Ion exchange	Contaminated water is passed through a resin bed where ions are exchanged between resin and water	Not applicable to primary organic contaminants. Potentially applicable for inorganic contaminants.
		UV/ozonation/ hydrogen peroxide	The enhanced oxidation of a compound to carbon dioxide and water	Potentially applicable for organic contaminants; not applicable to inorganic contaminants
		Solvent extraction	Extracting organic contaminants using a characteristic solvent	Not applicable to site contaminants
		Filtration	Removal of suspended solids using a granular bed or other means	Potentially applicable for pretreatment or removal of particulates

- Ability of the technology to meet the remediation goals identified in the remedial action objectives.

- Technical reliability (innovative versus well proven) with respect to contaminants and site conditions.

- Implementability
  - Overall technical feasibility at the site
  - Availability of vendors, mobile units, storage and disposal services, etc.
  - Administrative feasibility
  - Special long-term maintenance and operation requirements

- Cost
  - Capital cost
  - Operation and maintenance (O&M) costs

All of the items listed under each criterion may not apply directly to each technology; therefore, each item will only be addressed where appropriate.

The initial screening evaluation generally focuses on effectiveness and implementability with less effort directed at cost evaluations. Technologies whose use would be precluded by waste characteristics are screened and eliminated from further consideration. At this stage, no technologies will be eliminated based on cost. A process option within a technology category, however, may not be carried through if an equally effective process option under that technology is available at a lower cost. Each technology presented in this section is not intended to necessarily stand alone because it may be subsequently combined with other processes into remedial action alternatives.

For each technology, at least one representative process is selected to more effectively facilitate the subsequent development and evaluation of alternatives without limiting flexibility during the development of remedial alternatives. The remainder of this section presents the technologies and process options that were considered.

2.4.2.1 No Action

The no-action scenario is considered to provide a baseline level to which other remedial technologies and alternatives can be compared. Under this scenario, no removal or treatment of contaminants in the groundwater would occur.

Effectiveness. The no-action option would not achieve the remedial action objectives for interim measures. Over time, the degree of contamination in the groundwater may decrease through natural attenuation and dilution provided that the sources of contamination are eliminated. The rate of decrease in contaminant levels is difficult to predict at NAWC Warminster due to fractured bedrock. Long-term, periodic groundwater monitoring would be required to assess the ability of the aquifer to naturally lower contaminant levels through flushing.

The no-action option would not minimize plume migration. The no-action scenario would not provide any protection of uncontaminated groundwater because the plume would continue to migrate into downgradient areas.

Implementability. There are no implementability considerations associated with the no-action scenario.

Cost. Because no action would be taken at the site, there would be no capital or annual O&M costs.

Conclusion. Retain no action as a baseline as required by CERCLA.

2.4.2.2 Institutional Controls

Access Restrictions

Institutional controls may include access restrictions for preventing access to groundwater such as regulatory prohibitions, zoning regulations, and local ordinances.

Effectiveness. Access restrictions would not reduce the toxicity, mobility, or volume of contaminants in the groundwater. Access restrictions would also not provide any additional protection of the environment because the plume may continue to spread into uncontaminated or lesser contaminated areas. Access

restrictions would, however, reduce the potential risk to human health associated with ingestion/inhalation of contaminated groundwater.

Implementability. Land-use restrictions are already in place at NAWC Warminster. These restrictions would not apply if the NAWC Warminster property was sold and no longer a government-owned facility.

At present, the overburden and shallow bedrock aquifers are not currently used for potable water supply at NAWC Warminster.

Cost. Because only administrative actions would be taken, capital and O&M costs would be low.

Conclusion. Because land-use restrictions are already in place at NAWC Warminster, this option will be eliminated from further consideration. However, future uses of the facility may include residential development. Access restrictions in the form of limitations on future well development may be appropriate if new water supply sources are to be created at the facility.

Groundwater Monitoring

Periodic groundwater monitoring throughout the area of potential groundwater contamination would be used to evaluate migration of contaminants and the potential for contamination of the onsite drinking water supply and nearby residential, municipal, and commercial wells.

Effectiveness. Groundwater monitoring would not reduce the toxicity, mobility, or volume of contaminants in the groundwater. Also, monitoring would not provide any additional protection of the environment because the plume may continue to spread into uncontaminated or lesser contaminated areas. Monitoring would allow establishment of a trend in contaminant levels to evaluate whether contaminant levels are increasing, decreasing, or stable. Monitoring will also be helpful in measuring and evaluating the effectiveness of groundwater remediation.

Implementability. A groundwater monitoring program could be readily implemented at NAWC Warminster.

Cost. Because only groundwater monitoring would be conducted, capital and O&M costs would be low.

Conclusion. Retain monitoring for further consideration.

2.4.2.3 Removal Technologies

The treatment technologies discussed require that the groundwater be brought to the surface for treatment or disposal. Two process options are potentially applicable for this purpose: extraction using a pumping well system and subsurface drains using interceptor or collection trenches.

Extraction Wells

The extraction option uses a pumping well system, composed of a series of wells completed in overburden deposits and shallow bedrock, that can be used to capture contaminated groundwater for treatment. The wells used in the capture system would be designed and located to provide optimum efficiency in capturing contaminated groundwater while minimizing the collection of uncontaminated groundwater.

Effectiveness. The effectiveness of a pumping well system depends largely on the extent of contamination and the geology and hydrogeology at the site. The effectiveness of a pumping well system will depend on the ability of individual wells to intersect fractures and joint planes within the bedrock and effectively capture groundwater flow through the overburden in selected areas requiring treatment.

A capture system for groundwater at NAWC Warminster would decrease the migration of onsite contaminated groundwater from the source into downgradient areas of the overburden and shallow bedrock aquifers. This could in turn lessen the extent of contaminant migration to the deeper bedrock aquifers underlying OU-1.

Implementability. Groundwater extraction through a pumping well system can be readily implemented at NAWC Warminster. The technology uses readily available equipment and techniques and has been proven effective in similar situations. Implementation of this technology would require long-term operation and maintenance. Maintenance may require periodic replacement of mechanical components and well flushing to remove fine-grained material that may clog extraction wells.

Cost. Capital and O&M costs are relatively low.

Conclusion. Retain groundwater extraction for further evaluation.

Subsurface Drains

Subsurface drains (e.g., french drains) can be used as preventive measures (leachate collection) and/or as abatement measures (interceptor trenches). Construction of subsurface drains involves digging a trench or system of trenches below the water table. The excavated trench is then backfilled with permeable material such as gravel or crushed rock. Collection pipes and pumps are used for water removal. Subsurface drains or trenches function similarly to an infinite line of extraction wells; that is, they create a continuous zone of depression that runs the length of the drainage trench.

Effectiveness. Subsurface drains can control further contamination by reducing contact between groundwater and contaminated soils. This technology can also control migration of the contaminated plume, although to a much lesser degree than extraction wells. The use of collection trenches for the extraction of groundwater has been most effective in low-permeability media where wells are not effective. Collection trenches could be partially effective in capturing some of the groundwater in overburden deposits but would not be effective in capturing contaminated groundwater that extends into the underlying bedrock aquifers. At NAWC Warminster, where the overburden and shallow bedrock are hydraulically connected and transmit water, a pumping well system may be more efficient in capturing and extracting contaminated groundwater than collection trenches, although some combination of collection trenches and extraction wells could potentially be used.

Implementability. The amount of excavation required for implementation of collection trenches is dependent on the area of remediation and the depth to groundwater, which varies throughout the site. Trenches for groundwater collection would require extensive excavation as well as disposal of any contaminated soil from the trench. French drains are normally not constructed much deeper than 40 feet below the ground surface and are not effective in extracting groundwater contaminants below 60 feet. Since the depth of groundwater contamination extends to at least 75 feet in the shallow bedrock aquifer, the construction of such trenches would not be feasible.

Cost. Capital cost for subsurface drains would be moderate. O&M costs would be low.

Conclusion. Because of implementability concerns, subsurface drains are eliminated from further consideration for collection of groundwater.

2.4.2.4 Containment

Slurry Wall/Grout Curtain

The placement of a vertical barrier to groundwater migration can be effective in limiting the inflow of uncontaminated groundwater into a contaminant source and in controlling the spread of contaminated groundwater. A slurry wall consists of a mixture of soil, bentonite clay, and water that is placed into an excavated trench or bored holes. A grout wall is similar, utilizing a grout or cement component instead of bentonite clay.

Effectiveness. Both a slurry wall and a grout curtain can be effective at limiting the flow of groundwater in a particular area. The technologies do not allow for the reduction in existing contamination. The shallow nature of the overburden soils at NAWC Warminster limits the effectiveness of this technology to the overburden aquifer. This technology does not address the vertical component of groundwater migration and would not be effective in limiting migration between the overburden, shallow bedrock, and deeper bedrock aquifers underlying OU-1.

Implementability. The construction of a slurry wall/grout curtain could be readily implemented in the overburden soils at NAWC Warminster by excavating trenches or conducting a series of adjacent soil borings. Implementation of this technology into the shallow bedrock beneath the soil overburden may prove difficult, particularly in areas where the interface between the shallow bedrock and deeper bedrock aquifers is deep. In addition, no effective confining layer exists to separate these aquifers.

Cost. The capital and O&M costs for this technology in the overburden aquifer are expected to be low. Extending this technology into the underlying bedrock would increase costs significantly.

Conclusions. This technology will not be retained for further consideration. The utility of this technology at greater depths is limited because of construction difficulties. Additionally, this technology would only be effective if implemented in areas where vertical migration of groundwater was not a concern.

2.4.2.5 Disposal Technologies

Extracted groundwater must eventually be disposed when brought to the surface. The available disposal options include discharge to offsite surface water, discharge to the existing NAWC Warminster wastewater

treatment plant, discharge to an existing POTW such as the Warminster Municipal Authority (WMA) wastewater treatment plant, discharge to groundwater, and spray irrigation.

Discharge to Offsite Surface Water and Wastewater Treatment Plant

The discharge of treated and/or untreated groundwater to surface water bodies at NAWC Warminster is applicable for the disposal of extracted groundwater. Intermittent tributaries of Little Neshaminy Creek are located north of the facility; an intermittent tributary to Southampton Creek is located to the south. Direct discharge to these tributaries would require an NPDES permit, which would set limits of contaminant concentration and flow rates of the discharged water.

The wastewater treatment plant (WWTP) at NAWC Warminster discharges to a tributary of Little Neshaminy Creek under an NPDES permit. Indirect discharge of groundwater through an existing POTW such as the WMA WWTP or the NAWC Warminster WWTP following pretreatment, as required, are potential disposal methods for extracted groundwater. Influent flow rate and contaminant concentration are the potential limiting factors for this disposal option.

Effectiveness. Direct discharge to Little Neshaminy or Southampton Creeks (or its tributaries) is a potentially effective means of disposing of the volumes of water generated by the groundwater extraction systems. The treatment capacity of the NAWC Warminster WWTP would not limit the flow rate at which groundwater can be disposed. The treatment plant is currently discharging about 80,000 gallons per day, and the NPDES permit allows a discharge of 250,000 gallons per day. Thus, disposal to the NAWC Warminster WWTP will effectively handle the necessary volumes of water generated by any groundwater extraction. Note that NAWC Warminster is currently considering upgrading the WWTP to meet nitrogen and ammonia requirements. If the WWTP is not upgraded, the base may tie in to the WMA WWTP. Indirect discharge to the WMA WWTP would, therefore, also be an effective means to dispose of pretreated groundwater.

Implementability. Direct discharge to surface water, which would require installation of underground piping from the groundwater treatment system to surface water, is implementable. Disposal to the WMA or NAWC Warminster WWTP, which would require installation of underground piping from the treatment system to the nearest acceptable sewer line, is also implementable.

Cost. Capital costs for the direct disposal of groundwater to surface water or the WMA or NAWC Warminster WWTP are expected to be low, as are the O&M costs.

Conclusion. Retain discharge to surface water and discharge to the WMA and NAWC Warminster WWTP for further consideration.

Discharge to Groundwater

Subsurface discharge involves the use of injection wells to reinject treated groundwater into the aquifers or infiltration basins to allow gravity drainage of treated groundwater into the aquifer. Underground injection wells can be coupled with extraction wells to create a closed system in which pumping and injection rates balance one another.

Effectiveness. Subsurface discharge is an effective means of disposing of the volumes of water generated by the groundwater pumping/treatment system. Injection wells offer the advantage of decreasing groundwater remediation time by increasing the groundwater flow rate through the aquifer. Infiltration basins would not be effective during the winter months due to freezing problems.

Implementability. Installation of a well system for underground injection is implementable; however, achieving a closed system within the fractured bedrock at the site may be difficult. Reinjected water that is not captured by the extraction wells could potentially force contaminated groundwater into lesser contaminated areas. Periodic groundwater monitoring would help to assess whether or not this condition is occurring. Infiltration basins would be implementable providing there is sufficient uncontaminated land available that has the proper drainage characteristics. Subsurface discharge would require that groundwater be treated to either action or background levels prior to reinjection.

Underground injection of water may require a state permit, depending on whether it occurs on site or off site. The permit would set limitations on contaminant concentrations, and possibly flow rates, of disposed water.

Cost. The capital and O&M costs for subsurface discharge are high compared with those for surface water discharge.

Conclusion. Because the costs for subsurface discharge are high compared to other disposal options, and because implementation of this option is questionable due to fractured bedrock, subsurface discharge (reinjection and infiltration basins) will be eliminated from further consideration.

Spray Irrigation

Spray irrigation involves the discharge of treated/untreated groundwater to the soil surface after spraying into the air. This technology allows for the volatilization of VOCs and promotes recharge of the aquifer.

Effectiveness. Spray irrigation is suitable for the volatilization of some VOCs. It is not effective for the removal of less volatile VOCs or inorganic compounds such as heavy metals. The technology allows for the recharge of an aquifer and can be used to encourage flow into a groundwater extraction system.

Implementability. Spray irrigation would be partially effective for the disposal of treated groundwater for the facility. Treatment before disposal may be required to reduce the discharge of contaminants. Parameters involved in implementing this technology include flow rate, contaminant concentration, and available sorptive capacity of site soils. The soils at the facility must have the ability to infiltrate the sprayed groundwater so that surface water runoff is not generated. Soil characteristics at the facility may not allow sufficient discharge volume, potentially making other disposal techniques, such as surface water discharge, more applicable.

Cost. The capital and O&M costs for this technology are expected to be low. Piping must be constructed to route water from the source wells to the spray area. If the system is coupled with a treatment system, capital O&M costs are expected to be moderate.

Conclusion. Because spray irrigation offers no significant advantages over the other disposal options, it will be eliminated from further consideration.

2.4.2.6 In-Situ Treatment Technologies

Contaminated groundwater may be treated in situ (i.e., in place). The in-situ treatment processes that passed initial screening include aerobic biodegradation and air sparging.

Aerobic Biodegradation

In-situ biodegradation is a relatively new technology that has been primarily used to treat petroleum hydrocarbons. In-situ biodegradation treatment involves the stimulation of indigenous microbial populations and/or the inoculation of the subsurface with cultured species possessing specialized metabolic capabilities for the particular waste. The objective of this technology is to accelerate the biodegradation process by optimizing the organisms' environment. This typically involves setting up a flow pattern using a number of pumping wells and reinjection points to disperse microorganisms, oxygen, and nutrients throughout the hydrogeologic formation.

A conventional biological treatment technology, such as activated sludge, is often incorporated into the circulation system, which provides additional treatment as well as a microbe-rich, nutrient-rich solution. The solution is recharged into the subsurface to enhance microbial growth.

Quantifiable characteristics needed to assess the in-situ biodegradability of a particular waste include

- Microorganisms present at the site
- Aquifer properties (dissolved oxygen content, pH, temperature, etc.)
- Biodegradation products (particularly hazardous ones)
- Biodegradability of the waste (half-life, rate constants)

Effectiveness. Halogenated solvents such as PCE and TCE are very persistent under aerobic conditions (Wilson et al., 1986). Some laboratory studies suggest that biodegradation of halogenated compounds such as PCE and TCE does not occur under aerobic conditions (Bouwer et al., 1981), recent laboratory work indicates that TCE can be completely mineralized to carbon dioxide and water in the presence of certain aromatic compounds (e.g., benzene, toluene, phenol) (Litchfield, 1989).

In-situ biodegradation would not be effective for inorganic contaminants.

Implementability. Implementation of this technology is possible but would be complex and would require highly skilled personnel due to the need to maintain proper environmental conditions. Injection of toxic aromatic compounds into the aquifer, however, in order to facilitate in-situ biodegradation, may be feasible but may not be acceptable, and in-situ biodegradation technology using other compounds, such as methane, has not been developed. A number of vendors offer biological treatment technology, although none to date have demonstrated a full-scale system for biodegradation of all halogenated contaminants in groundwater (Bonk, 1992). Aerobic biodegradation may require increasing the oxygen content in the groundwater. In addition, the acclimation time of the microbial culture to the waste must be estimated because long periods of acclimation to subsurface pollutants may be required before biodegradation can occur. Because no full-scale systems have been demonstrated, scale-up problems, environmental impacts, and long-term equipment operation and maintenance requirements cannot be fully assessed at this time.

Cost. The capital and O&M costs for in-situ aerobic treatment are low compared to the other treatment technologies.

Conclusion. Because full-scale systems for biodegradation of PCE, TCE, and other site contaminants are not commercially available at this time, in-situ aerobic treatment will be eliminated from further consideration. In addition, the process is not effective for inorganics.

2.4.2.7 Treatment Technologies

In this section, only primary treatment technologies for the removal of the contaminants will be discussed. Discussion of secondary treatment technologies that may be required for water conditioning before or after primary treatment, such as filtration or sedimentation for the removal of suspended solids, will be included as part of the primary technology sections.

Aerobic Biodegradation

Biological treatment uses microorganisms, primarily bacteria, actinomycetes, and fungi, to break down hazardous organic compounds into nontoxic or less toxic forms. Aerobically, microorganisms have the potential to completely oxidize organic substances into carbon dioxide and water. The fundamentals of biological treatment involve the following:

- Demonstrated biodegradability of the waste using either acclimated, indigenous (native) microorganisms or exogenous cultured species.
- Maintenance of optimal environmental conditions such as temperature and pH.
- Maintenance of essential nutrients such as phosphorus and nitrogen.

Although a wide variety of organic substances have been efficiently biodegraded with existing technologies, certain classes of organic compounds show resistance to microbial attack and are biodegraded very slowly or only partially. Halogenated solvents such as PCE and TCE are very persistent in oxygenated waters (Wilson et al., 1986). Although some laboratory studies suggest that biodegradation of halogenated compounds such as PCE and TCE does not occur under aerobic conditions (Bouwer et al., 1981), recent laboratory work has indicated that microorganisms that oxidize methane and propane can co-oxidize TCE and a variety of other halogenated organic compounds (Fogel et al., 1986; Strand and Shippert, 1986; and Henry and Grbic-Galic, 1986). In addition, recent laboratory work indicates that TCE can be completely mineralized to carbon dioxide and water in the presence of certain aromatic compounds (e.g., benzene, toluene, phenol) (Litchfield, 1989).

Typical aerobic biological treatment systems include activated sludge processes and various forms of fixed-film bioreactors. In activated sludge processes, a suspended aerobic microbial culture is used to treat the incoming contaminated water. The aerobic environment is produced through the use of diffused or mechanical aeration. At the end of the reaction period, the resulting flocculent slurry of microorganisms is removed from the aeration tank, usually by sedimentation, and a portion of the mass is recycled and the remaining mass (sludge) wasted. The four basic activated sludge process configurations are nominal plug flow, continuous flow, complete mix, and sequential batch reactor.

In fixed-film bioreactors, organisms grow as a film on an immobile support such as rock or plastic media. Organisms are continuously sloughed off by the fluid stream and must be removed by a final settler. Common types of fixed-film reactors include packed towers and rotating-disc reactors as well as various modifications of these two configurations.

In addition to these fixed-film reactors, a third type of biological treatment, Biological Activated Carbon (BAC), is currently being investigated. BAC involves growing microorganisms on a packed carbon bed or a fluidized carbon bed (Voice, 1990). This type of system provides the benefit of contaminant removal through both biodegradation and adsorption. Research at this time is currently focused on the removal of

petroleum hydrocarbons from groundwater; petroleum hydrocarbons are relatively easily biodegraded compared to chlorinated solvents such as PCE and TCE (Voice, 1990).

Effectiveness. Although researchers have demonstrated the biodegradation of TCE in aerobic systems exposed to methane, propane, and certain aromatic compounds in the laboratory, TCE biological treatment systems in the field have not been demonstrated. The co-metabolism process works moderately well for TCE but does not appear to be effective for PCE (Wilson, 1992). Currently, there are a number of pilot-scale studies and one full-scale study under way, but no results have been published to date (Litchfield, 1989; and Nack, 1989). Due to the innovative nature of this technology, bench- and pilot-scale studies would be needed to determine the effectiveness of aerobic biodegradation for the groundwater contaminants at NAWC Warminster.

Implementation. Aerobic biodegradation processes could be implemented on site. A number of vendors offer biological treatment technology, although none have demonstrated a full-scale system for biodegradation of NAWC Warminster contaminants at this time (Bonk, 1992). Implementation considerations include the disposal of biomass sludge produced and the potential release of organics into the air. Because no full-scale systems have been demonstrated, however, scale-up problems and long-term equipment operation and maintenance requirements cannot be fully assessed.

Cost. The capital and O&M costs for aerobic treatment are low to moderate compared to the other treatment technologies.

Conclusion. Because full-scale systems for biodegradation of the primary groundwater contaminants (i.e., PCE and TCE) are not commercially available at this time, aerobic treatment will be eliminated for further consideration.

Air Stripping

Air stripping is a proven technology well suited for the removal of VOCs from contaminated water. This aeration process promotes mass transfer of VOCs from the aqueous phase to the gas phase as defined by Henry's Law. In general, air stripping is used for volatile compounds with a Henry's Law constant greater or equal to 3.0 atm-L/mole (Camp, Dresser and McKee Incorporated, 1985). Removal efficiencies of VOCs typically range from 50 percent to more than 99 percent depending on the operating parameters (i.e., air-to-water ratio), as well as the physical properties of the organic compound(s).

The countercurrent packed tower is the most commonly used air stripping configuration. Water is distributed over the top of the unit while air is forced upward through the bottom. Loosely fitted packing material serves to increase the air/water interface area to provide maximum mass transfer. Key factors that influence process performance include air-to-water ratio, type of packing material, operating temperature, surface hydraulic loading, and contact time.

Effectiveness. Air stripping is a well-proven, reliable technology that would be effective for removing the primary VOCs from groundwater at NAWC Warminster. Theoretically, removal efficiencies greater than 99.99 percent could be achieved for these contaminants. It would not be effective for semivolatile organics or inorganics. Since air stripping only removes the contaminants from the water and concentrates them in the off-gas, the off-gas may have to be subsequently treated by other means, such as granular activated carbon adsorption, catalytic oxidation, or thermal destruction.

Implementability. Air stripping would be readily implementable at the site. There are a sufficient number of vendors that provide air-stripping technology. Control of off-gas emissions would be required. An exemption from air treatment requirements may be obtained, depending on the VOC concentrations in the off-gas and air flow rate. One of the maintenance considerations for air stripping is channeling of the flow resulting from clogging of the packing material. Common causes of clogging include oils, suspended solids, high iron concentrations, and slightly soluble salts such as calcium carbonate. High levels of any of these substances would require pretreatment. At NAWC Warminster, provisions may be needed for chemical precipitation of iron and manganese and removal of suspended solids.

Cost. Capital costs are low, and O&M costs range from low to moderate, depending on influent contaminant concentrations and the degree of removal required.

Conclusion. Retain air stripping as a representative process option for physical/chemical treatment.

Activated Carbon Adsorption

Activated carbon adsorption is a frequently applied technology for the removal of organic compounds from contaminated water. Activated carbon will adsorb many organic compounds to some extent but is most effective for the less polar and less soluble organic compounds. Removal efficiency of more than 99 percent can be achieved depending on the type of organic solute and system operating parameters, such as retention time and carbon replacement frequency. The fundamental principle behind activated

carbon treatment involves the physical attraction of organic solute molecules to exchange sites on the internal pore surface areas of the specially treated (activated) carbon grains. As water is filtered through the adsorbent, the organic molecules eventually occupy all of the surface sites on the carbon grains. The exhausted carbon must then be either regenerated or disposed according to Federal (RCRA) and state regulations.

Typical activated carbon adsorption treatment systems include gravity flow or pressure flow columns in series and/or parallel configurations with backwashing capability. Granular activated carbon is generally used in these systems. Common flow rates range from 0.5 to 5.0 gpm/feet^2. Factors such as pH and temperature of the influent, empty bed contact time, surface area/volume ratio of the activated carbon, and solubility of the organic compound will affect the carbon adsorption process.

Effectiveness. Carbon adsorption is a well-proven, reliable technology that would be effective for removing most of the organics from groundwater at NAWC Warminster. Removal efficiencies as high as 99 percent could potentially be achieved for most of these contaminants. Carbon adsorption would not be as effective for removal of compounds with properties such as vinyl chloride, however, because removal efficiencies are expected to be significantly lower for these compounds. As activated carbon only concentrates the contaminants, the spent carbon would have to be subsequently disposed in a hazardous waste landfill or regenerated.

Implementation. Carbon adsorption would be readily implementable at NAWC Warminster. There are a sufficient number of vendors that provide carbon adsorption units. Implementation factors include planning for disposal or regeneration (on site or off site) of the exhausted carbon. Thermal, steam, and solvent treatments are the most common types of regeneration technologies. Furthermore, pretreatment (e.g., filtration, precipitation) may be required if the influent has a total solids concentrations greater than 50 mg/L, oil and grease concentrations greater than 10 mg/L, or calcium or magnesium concentrations greater than 500 mg/L to prevent clogging and high pressure drops (Berkowitz et al., 1978; and EPA, 1986). At NAWC Warminster, filtration may be needed ahead of the activated carbon adsorbers to ensure maximum carbon life cycle.

Cost. Capital costs are low, and O&M costs range from low to moderate, depending on the carbon usage rate, which is a function of influent contaminant concentrations.

Conclusion. Retain carbon adsorption for further consideration.

Ion Exchange

Ion exchange resins are insoluble solids containing fixed cations or anions capable of reversible exchange with mobile ions of the same charge in solutions with which they are brought into contact. The ion exchange resins will eventually be exhausted and must be regenerated. The regeneration waste will contain the ions removed at much higher concentrations than in the influent and must be further treated and/or disposed of.

Effectiveness. Ion exchange is effective for the removal of soluble metals and anions such as halides, sulfates, and nitrates. At NAWC Warminster, it would effectively remove metals to very low concentrations, if required to meet discharge limits.

Implementability. Ion exchange would be readily implementable at NAWC Warminster. There are many vendors that provide ion exchange units. The upper influent concentration limit for exchangeable ions for efficient operations is approximately 2,500 mg/L. Influent suspended solids must be very low, otherwise the resin bed could be fouled or plugged. Some organics, especially aromatics, can be irreversibly adsorbed by the resin, resulting in decreased capacity.

Cost. Capital costs are low to moderate and O&M costs range from low to moderate, depending on the frequency of regeneration required, which is a function of influent contaminant concentrations.

Conclusion. Ion exchange is retained for further evaluation as a polishing step if effluent limits for metals are low. The technology can be used to reduce metals to very low concentrations and for removal of dissolved solids, if required.

Reverse Osmosis

Reverse osmosis uses a semi-permeable barrier that will pass only certain components of a solution. The membrane is permeable to water but impermeable to most dissolved substances, both organic and inorganic. The driving force is an applied pressure gradient. Reverse osmosis produces a concentrated solution (for further treatment or disposal) and a dilute stream of purified water.

Effectiveness. Reverse osmosis may be used to concentrate dilute solutions of many inorganic and organic solutes. Reverse osmosis reduces excess dissolved solids, reduces or removes many organics and metals, and produces almost turbidity-free water.

Implementability. Reverse osmosis would be readily implementable. Pretreatment may be required to optimize pH and filter out suspended solids.

Cost. Capital and O&M costs are moderate.

Conclusion. Reverse osmosis is retained for further evaluation as a polishing step if effluent limits for metals are low. The technology can be used to reduce metals to very low concentrations and for removal of dissolved solids, if required.

Ozone/Ultraviolet Light Radiation (Ozone/UV)/Hydrogen Peroxide

Ozone/UV/hydrogen peroxide processes use a controlled combination of either ozone or hydrogen peroxide and ultraviolet light to induce photochemical oxidation of organic compounds. Ozone has been used extensively in Europe for purification, disinfection, and odor control of drinking water. Ozone alone has the ability to break down some organics but has generally proven to be an ineffective oxidant of halogenated organics under conditions normally used for drinking water treatment or for disinfecting wastewaters (i.e., 1 to 10 mg/L concentration levels and 5- to 10-minute contact times) (Brenton et al., 1986; and Arienti et al., 1986). Oxidation of organic species to carbon dioxide, water, etc., however, is possible if the ozone dosage and contact times are sufficiently high (EPA, 1987).

Ultraviolet (UV) radiation is electromagnetic energy whose wavelengths fall between those of visible light and X-ray radiation on the electromagnetic spectrum. UV energy is capable of breaking down or rearranging a molecular structure, depending on the dissociation energies of the chemical bonds within the structure (EPA, 1987). The combination of ultraviolet radiation with ozone or hydrogen peroxide treatment results in the oxidation of organic contaminants at a rate many times faster than that obtained from applying UV light alone (McShea et al., 1987).

A typical continuous-flow hydrogen peroxide/ozone/UV system consists of an oxygen or air source, an ozone generator or hydrogen peroxide feed system, a UV/oxidation reactor, and an ozone decomposer. Flow patterns and configurations are designed to maximize exposure of the wastewater to the UV radiation,

which is supplied by an arrangement of UV lamps. Typical reactor designs range from mechanically agitated reactors to spray, packed, and tray-type towers. Reactor gases are passed through a catalytic ozone decomposer, which converts remaining ozone to oxygen and destroys any volatiles. The gases are then discharged or recycled.

Effectiveness. Hydrogen peroxide/ozone/UV technology has effectively oxidized halogenated organics, benzene derivatives, and various aliphatics (McShea et al., 1987). PCE and TCE have been reduced from levels of 20 ppm to less than 5 ppb (McShea et al., 1987). This process is considered an innovative technology; only a few commercial systems have been installed and tested. Bench- and pilot-scale treatability studies would therefore need to be conducted to determine the actual effectiveness and cost of applying this process to the contaminants in the groundwater at NAWC Warminster.

Implementation. Hydrogen peroxide/ozone/UV technology should be implementable. Only a few vendors, however, currently offer this technology. Implementation may involve pretreatment of influents containing high concentrations of suspended solids. With this treatment, no toxics are emitted to the atmosphere or adsorbed onto media that require further treatment or disposal.

Cost. Capital and O&M costs are moderate.

Conclusion. Air stripping and carbon adsorption were chosen as representative process options for treatment because these processes are more proven in the field than hydrogen peroxide/ozone/UV. However, hydrogen peroxide/ozone/UV will be retained for further consideration because this innovative technology could be considered during remedial design. The selection of treatment process options during the FS will depend on design contaminant concentrations and compliance with air regulations and standards.

Filtration

Filtration is a process using a porous medium to remove suspended solids from a liquid. It is valuable in wastewater treatment as a pre-treatment to remove suspended solids before other treatment processes and for the final cleaning or polishing of treated effluent. It is effective in removing organic and inorganic contaminants (particularly metals) that are bound to suspended solids in groundwater, often reducing the need for further treatment of these contaminants.

Liquid filtration may be accomplished by numerous methods including screens, fibrous fabrics (paper or cloth), or beds of granular material. Flow through a filter can be encouraged by pressure on the inlet side or by drawing a vacuum on the filter outlet.

Effectiveness. This technology is widely used for the removal of suspended materials from liquids. Filtering systems can be staged to progressively remove smaller materials; many system variations have been designed to reduce clogging and provide easy maintenance.

Filtration is especially useful in reducing contaminant levels of metals and organic compounds that are bound to suspended solid materials. These compounds may not easily be removed by other treatment methods such as aeration or carbon filtration, making filtration an advisable pre-treatment step for these technologies. It should be noted, however, that conventional filtration is not effective in removing dissolved contaminants but is readily applicable to suspended solids.

Implementation. Filtration systems are commercially available from a wide variety of manufacturers and can be readily ordered to almost any specification. For groundwater treatment, the primary use of a filtration system will be for the removal of suspended material before further treatment and possibly as a final treatment before discharge from a treatment system. Filter media will occasionally have to be replaced or regenerated, potentially resulting in the generation of sludges requiring specialized disposal because of contaminant content.

Cost. Capital costs for filtration are low, as are O&M costs. O&M costs may elevate slightly if frequent turbidity in the pumped groundwater requires additional filter maintenance.

Conclusion. Filtration will be retained as a process option for groundwater treatment.

Coagulation-Flocculation/Precipitation

Coagulation-flocculation/precipitation are liquid treatment processes that involve the addition of compounds or chemical reagents that bind to suspended materials and to each other, and to form insoluble salts with the compounds to be removed from solution, encouraging the creation of particles that are too large to remain in suspension and resulting in the precipitation or settling of suspended material. The technology is useful as a pretreatment step for removing contaminants such as heavy metals or semivolatile organics that are be tightly bound to suspended materials.

Effectiveness. Coagulation-flocculation/precipitation is useful for the removal of suspended materials from a liquid. It is not effective in the removal of dissolved contaminants such as VOCs. As stated, the technology is especially useful as a pretreatment step for removing contaminants bound to suspended solids.

Implementation. This technology is widely used in liquid treatment and is readily available commercially. The use of such a system may require the construction of piping and tanks if a self-contained unit is not commercially available. As with filtration, excessive suspended solids in the raw water may require added maintenance and can result in the generation of sludges requiring specialized disposal because of contaminant content.

Cost. The capital costs and O&M costs are expected to be low. The presence of high amounts of suspended solids may necessitate additional system maintenance.

Conclusion. Coagulation-flocculation/precipitation will be retained as a process option for groundwater treatment.

Neutralization

Neutralization is a treatment process for altering the pH or acidity/alkalinity of a solution. When ionic salts are present in water, some water molecules break into ionic constituents H^+ and OH^-. Neutralization is a process by which the relative concentrations of H^+ and OH^- ions are balanced. This is generally accomplished by adding acidic compounds (H^+) to balance alkaline solutions (OH^-) or vice-versa.

Effectiveness. Neutralization is an easily accomplished means of balancing or changing the pH of a solution. The process is best performed in a well-mixed system. A thorough analysis of the waste to be treated is advisable to avoid the creation of compounds more toxic than the original compounds and to ensure that incompatible compounds are not introduced into the system. The technology is particularly useful as a pretreatment step for pH adjustment before other treatment steps that require altered pH levels for optimum efficiency. Neutralization is also frequently used as a finishing step prior to discharge of a treated liquid.

Implementation. Neutralization technology is easily implemented; it is widely used and commercially available. Limited construction is necessary to include neutralization equipment as a step in a treatment system.

Cost. The capital O&M costs for neutralization are expected to be low.

Conclusion. Neutralization will be retained as a process option for wastewater treatment.

2.4.3 Summary of Final Screening of Technologies and Process Options

The evaluations of technologies and process options, based on effectiveness, implementability, and cost, are summarized in Table 2-8. In this table, the technologies are organized according to the general response actions developed in Section 2.3. Where appropriate, the ability of the technology to achieve the remedial action objectives developed in Section 2.2 is summarized under the "Effectiveness" column in the table. Technologies and process options are retained or eliminated for further consideration in the "Conclusion" column of this table.

The technologies and process options to be further considered in this report are as follows:

- No Action
- Groundwater Monitoring
- Extraction wells
- Discharge to surface water
- Discharge to existing WWTP
- Treatment Technologies
  - Air stripping
  - Activated carbon absorption
  - Ion exchange
  - Reverse osmosis
  - Photochemical oxidation (ozone/UV/hydrogen peroxide)
  - Filtration
  - Coagulation/flocculation/precipitation
  - Neutralization

TABLE 2-8

FINAL SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA

General Response Action Component	Remedial Technology	Process Option	Effectiveness	Implementability	Cost	Conclusion
No action	None	Not applicable	Does not provide any additional reduction in the toxicity, mobility, or volume of contaminants	Readily implemented.	No capital and O&M costs.	Retain as a baseline.
Institutional Controls	Access to groundwater restrictions	Zoning regulations, local ordinances, etc.	Does not provide any additional reduction in the toxicity, mobility, or volume of contaminants.	Already implemented at NAWC Warminster. May need to add restrictions based on future use(s) of property.	Negligible capital and O&M costs. Administrative costs only.	Eliminate from further consideration
	Monitoring	Groundwater Monitoring	Does not provide any additional reduction in the toxicity, mobility, or volume of contaminants.	Readily implemented.	Low capital and O&M costs.	Retain for further consideration
Removal	Extraction	Extraction Wells	Effective for the collection of groundwater in overburden and bedrock.	Readily implemented.	Low capital and O&M costs.	Retain for further consideration
	Subsurface Drains	Interceptor Trenches	Effective for the collection of groundwater in overburden.	Readily implemented for overburden groundwater collection only.	Moderate capital and low O&M costs.	Eliminate from further consideration
Containment	Slurry wall/grout curtain	Impermeable Vertical barrier	Does not provide reduction of existing contamination levels. Partially effective for overburden aquifer only.	Readily implemented for shallow depths only.	Low capital and O&M costs for shallow depths. Significantly higher for deeper depths.	Eliminate from further consideration

TABLE 2-8
FINAL SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE TWO

General Response Action Component	Remedial Technology	Process Option	Effectiveness	Implementability	Cost	Conclusion
Disposal	Surface water discharge	Direct discharge to intermediate tributaries of Little Neshaminy Creek north of the facility.	Effective means of disposal.	Implementable. May require pretreatment.	Moderate capital and O&M costs.	Retain for further consideration
		Direct discharge to intermediate tributaries of Southampton Creek south of the facility.	Effective means of disposal.	Implementable. May require pretreatment.	Moderate capital and O&M costs.	Retain for further consideration
	Discharge to WWTP	Discharge to WMA or NAWC Warminster wastewater treatment plant.	Effective means of disposal.	Readily Implementable. May require pretreatment plant.	Low to Moderate capital and O&M costs.	Retain for further consideration
	Subsurface discharge	Reinjection Wells.	Effective means of disposal. May reduce remediation time.	Implementable for overburden. Pretreatment required.	Capital and O&M costs higher than surface discharge.	Eliminate from further consideration
	Spray irrigation	Spray irrigation jets.	Effective means of disposal with verification of pumping rate and soil permeability.	Readily Implementable. May require pretreatment.	Low capital and O&M costs.	Eliminate from further consideration
In-situ Treatment	Biological	Aerobic	Potentially partially effective. Not effective for inorganics.	Not adequately demonstrated pilot- or full-scale for contaminants of concern.	Low capital and O&M costs.	Eliminate from further consideration

TABLE 2-8
FINAL SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS
NAWC WARMINSTER
BUCKS COUNTY, PENNSYLVANIA
PAGE THREE

General Response Action Component	Remedial Technology	Process Option	Effectiveness	Implementability	Cost	Conclusion
Treatment	Biological	Aerobic	Potentially partially effective.	Not adequately demonstrated pilot- or full-scale for contaminants of concern.	Low to moderate capital and O&M costs.	Eliminate from further consideration
	Chemical/physical	Air Stripping	Effective for primary organic contaminants.	Readily implemented, off gas treatment may be required.	Low capital cost. Low to moderate O&M costs.	Retain for further consideration.
		Activated Carbon Adsorption	Effective for organic contaminants.	Readily implementable.	Low capital cost. Low to moderate O&M costs.	Retain for further consideration.
		Ion Exchange	Effective for inorganics.	Readily implementable.	Low to moderate capital and O&M costs.	Retain for further consideration.
		Reverse Osmosis	Effective for inorganics and some organics.	Readily implementable.	Moderate capital and O&M costs.	Retain for further consideration.
		Photochemical Oxidation (UV/Ozonation/ Hydrogen peroxide)	Effective for primary organic contaminants.	Implementable. Few vendors and commercial installations.	Moderate capital and O&M costs.	Retain for further consideration as innovative technology.
		Filtration	Effective for removal of suspended solids.	Readily implementable.	Low capital and O&M costs.	Retain for further consideration
		Coagulation/ Flocculation/ Precipitation	Effective for removal of suspended solids.	Readily implementable.	Low capital and O&M costs.	Retain for further consideration
		Neutralization	Effective pH adjustment for pre- or post-treatment.	Readily implementable.	Low capital and O&M costs.	Retain for further consideration

3.0 DEVELOPMENT AND SCREENING OF REMEDIAL ALTERNATIVES

3.1 DEVELOPMENT OF REMEDIAL ALTERNATIVES

The purpose of this section is to develop and screen groundwater treatment and discharge alternatives based on technologies and process options that passed the final screening in Section 2.4. The alternatives developed in this section include the following:

- No Action with Groundwater Monitoring
- Groundwater Extraction, Onsite Treatment, and Discharge to Surface Water
- Groundwater Extraction, Onsite Pretreatment, and Discharge to NAWC Warminster Wastewater Treatment Plant or Publicly Owned Treatment Works

3.1.1 No Action with Groundwater Monitoring

Under this alternative, no remedial action would be undertaken to address contaminated groundwater attributable to NAWC Warminster in overburden and shallow bedrock aquifers. Instead, additional studies necessary to identify the full nature and extent of contaminated groundwater in overburden and shallow bedrock aquifers would be conducted as part of continuing RIs addressing the facility. In addition to these studies, monitoring of groundwater in overburden and shallow bedrock aquifers would be conducted for 30 years.

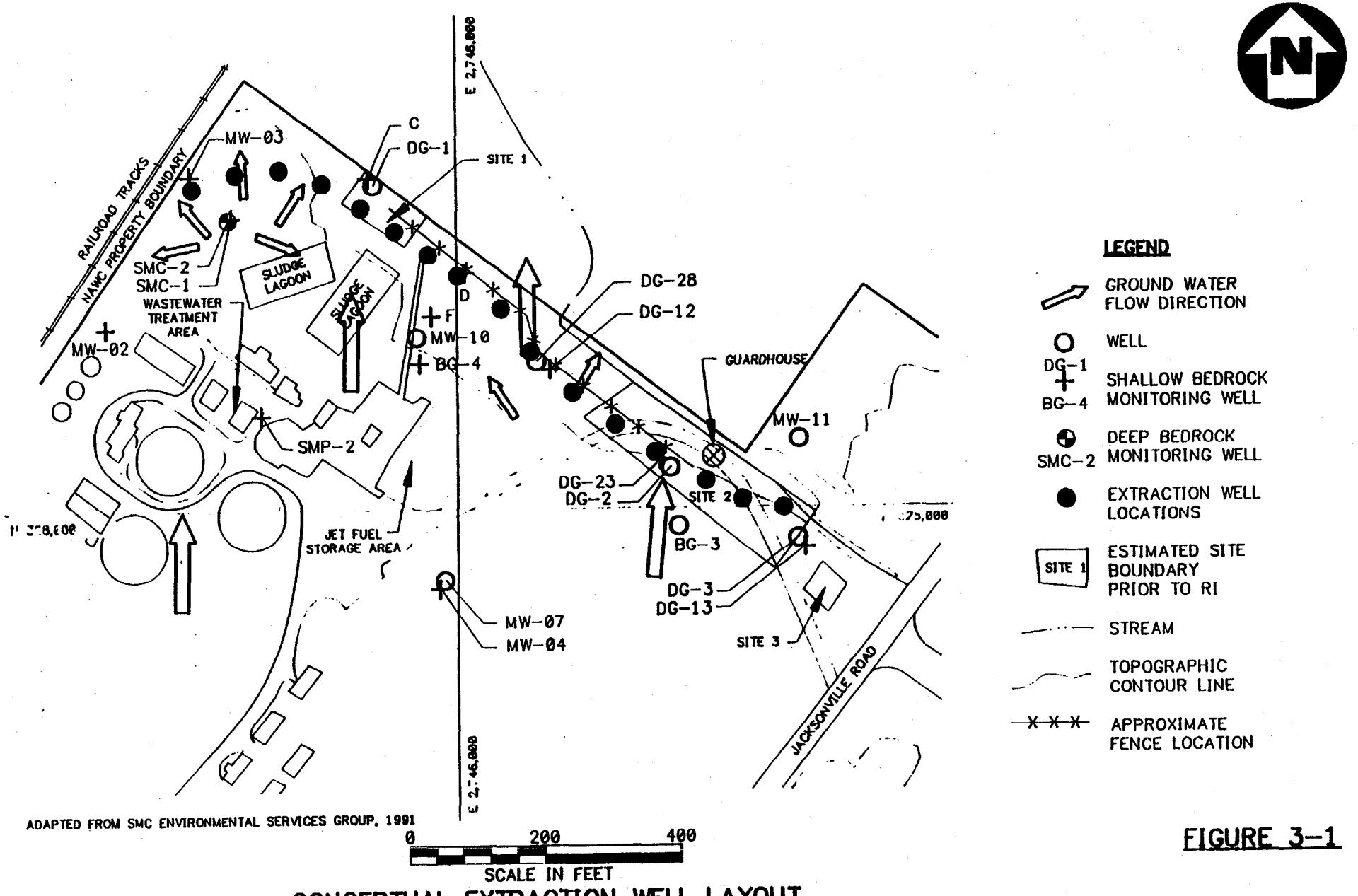
3.1.2 Groundwater Extraction, Onsite Treatment, and Discharge to Surface Water

Under this alternative, contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster would be extracted using a series of extraction wells. The conceptual extraction well systems were developed to contain contaminated groundwater in the overburden and shallow bedrock aquifers in the vicinity of Areas A and B. The conceptual system designs are intended to prevent contaminant migration. The extraction wells would be located as necessary to maximize the effectiveness of the system.

The extracted groundwater from both areas would be pumped to a treatment plant that would be constructed near Area A. Treatment would consist of precipitation and filtration to remove metals and air stripping and carbon adsorption to remove organics. If necessary, emissions from the air stripper would be treated by vapor-phase carbon adsorption. It is assumed that vapor-phase carbon adsorption would not be required because of the low maximum emission rate (0.016 lb/hr). Calculations are provided in Appendix A. The discharge limits would be imposed by the Pennsylvania Department of Environmental Resources (PADER) in an NPDES Permit. Ion exchange or reverse osmosis may be required as a polishing step to meet the assumed discharge limits for metals; however, it was not included in the cost estimate. Treatability studies would be required during the design phase to determine the achievable effluent limits, once final discharge limits have been established. Treated water would be discharged to an unnamed tributary of Little Neshaminy Creek. This alternative would attempt to prevent further migration of groundwater contaminants in the overburden and shallow bedrock aquifers from the vicinity of Areas A and B.

Based on aquifer characteristics and contaminant distribution, initial conceptual extraction systems were designed. One system would serve Area A and the other would serve Area B. Calculations are provided in Appendix A. Based on the initial conceptual designs, the total flow rate from the pumping wells near Area A would be approximately 36 gallons per minute (gpm). The total flow from Area B would be approximately 20 gpm. The total flow rate for treatment would be 56 gpm. It is assumed that the extraction wells would be installed in shallow bedrock only. The hydraulic connection between the overburden and shallow bedrock is such that groundwater withdrawal from shallow bedrock will also capture/contain contaminated groundwater from the overburden. The extraction wells would be approximately 87 feet deep near Area A and approximately 77 feet deep near Area B. Based on the conceptual design, 16 extraction wells, pumping at 2.3 gpm each, would be spaced approximately 62 feet apart near Area A. Nine extraction wells, also pumping at 2.3 gpm each, would be spaced approximately 67 feet apart near Area B. Approximate well locations are presented in Figures 3-1 and 3-2.

Groundwater would have to be raised from depths up to 87 feet. A header piping system would collect the water removed from the ground and convey it to the treatment plant. A booster pump station would also be needed to convey the groundwater from the Area B extraction system to the treatment plant. Figure 3-3 shows a schematic flow diagram of the proposed treatment system. The treatment plant was designed to meet assumed effluent limitations derived in accordance with the requirements of the Pennsylvania Water Quality Toxics Management Strategy, Discharge Elimination System Rules, and Wastewater Treatment Regulations (25 PA Code Chapters 16, 92, and 95, respectively). Effluent limits are usually based on the

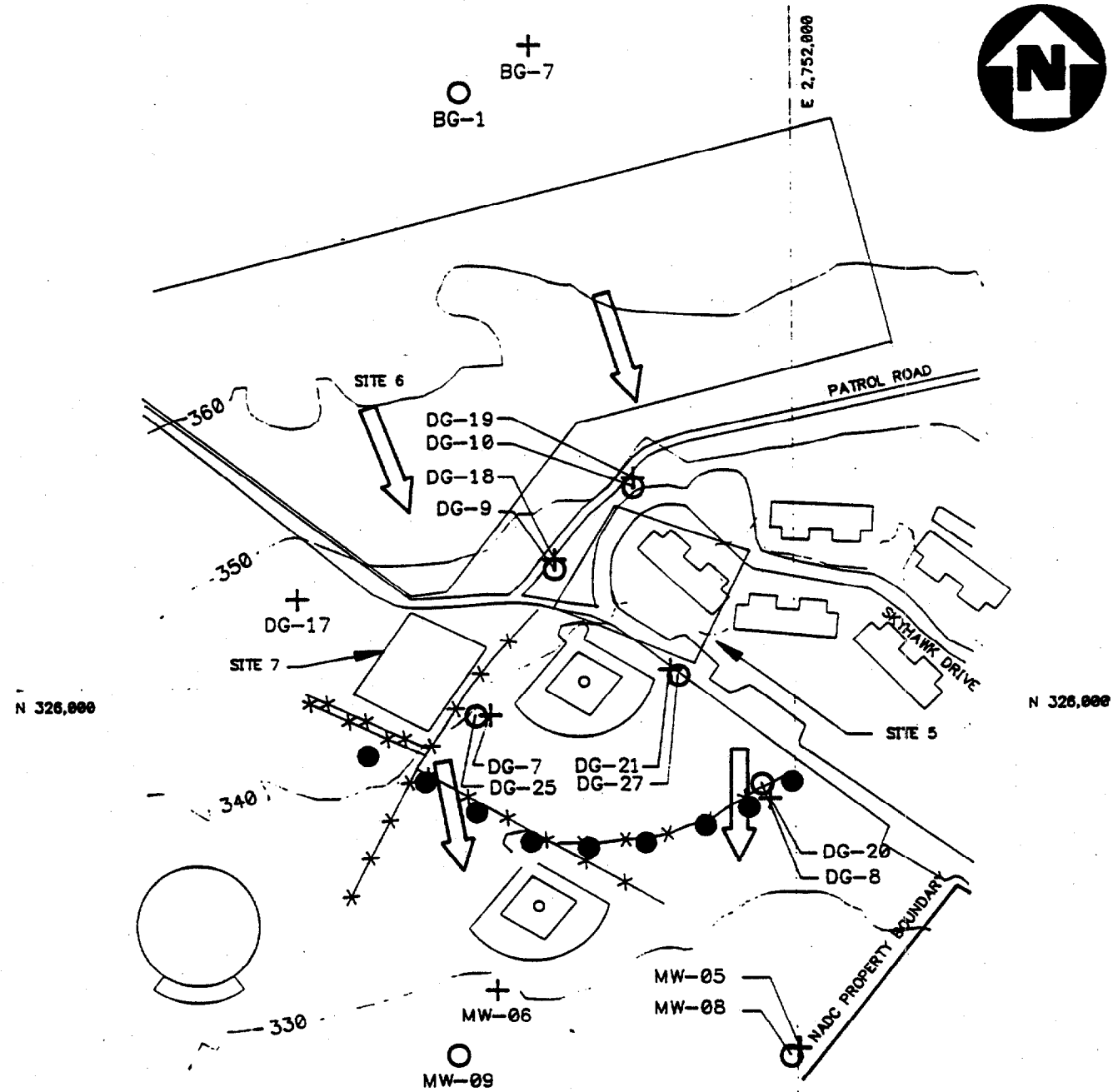


ADAPTED FROM SMC ENVIRONMENTAL SERVICES GROUP, 1991

FIGURE 3-1

CONCEPTUAL EXTRACTION WELL LAYOUT
SITES 1, 2, AND 3 (AREA A)
NAWC, WARMINSTER, PA

HALLIBURTON NUS
Environmental Corporation



LEGEND

GROUND WATER FLOW DIRECTION

WELL

DG-7 SHALLOW BEDROCK MONITORING WELL

DG-25

EXTRACTION WELL LOCATIONS

SITE 5 ESTIMATED SITE BOUNDARY PRIOR TO RI

TOPOGRAPHIC CONTOUR LINE

APPROXIMATE FENCE LOCATION

E 2,752,000

ADAPTED FROM SMC ENVIRONMENTAL SERVICES GROUP, 1991

0 200 400

SCALE IN FEET

FIGURE 3-2

CONCEPTUAL EXTRACTION WELL LAYOUT
SITES 5, 6, AND 7 (AREA B)
NAWC, WARMINSTER, PA

HALLIBURTON NUS
Environmental Corporatio

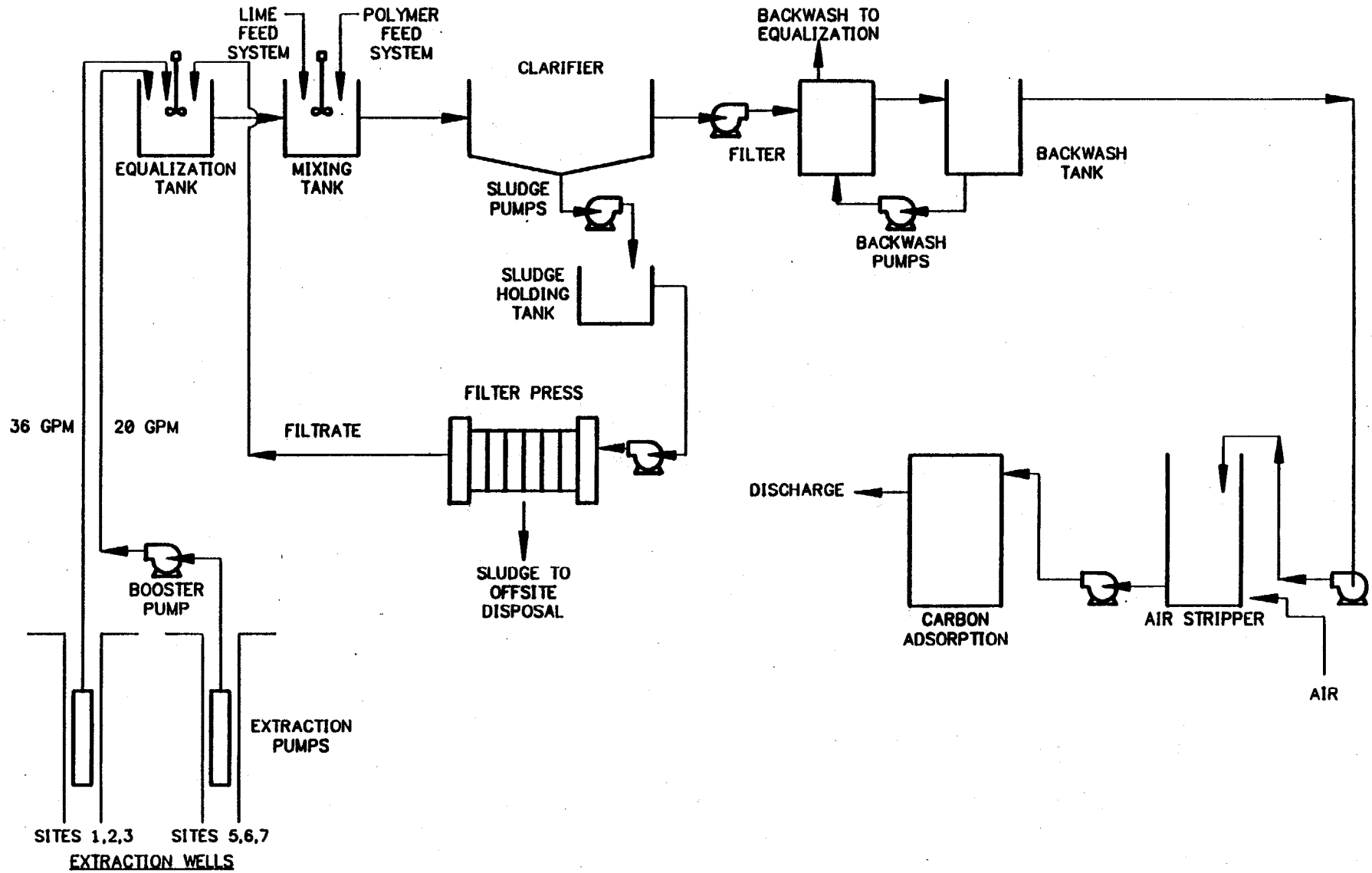


FIGURE 3-3

PROCESS FLOW DIAGRAM
ALTERNATIVE 2. DISCHARGE TO SURFACE WATER
NAWC, WARMINSTER, PA

NOT TO SCALE

HALLIBURTON NUS
Environmental Corporation

specific contaminant; the 7-day, 10-year low flow of the receiving stream; and the pumping rate. Since the 7-day, 10-year low flow of the receiving stream is zero (intermittent stream), the effluent limits were assumed to be Pennsylvania Water Quality Standards (25 PA Code Chapters 16 and 93) since no dilution would be provided by the receiving stream under low-flow conditions.

Treatment plant influent concentrations were based on a flow-weighted average of the representative concentrations for each contaminant at each of the two areas where groundwater is to be extracted. The representative concentration is the 97.5 percent upper confidence limit of the arithmetic average based on data collected at the area to date. Tables 3-1 and 3-2 contain a summary of the assumed initial influent and effluent concentrations for inorganics and organics, respectively.

Based on the estimated initial influent concentrations, the assumed effluent concentrations, and the projected flow rate, unit processes were combined to remove both organic and inorganic contaminants. Precipitation and filtration were selected to remove inorganics (metals). It may also be necessary to add ion exchange or reverse osmosis as a polishing step for metals removal where the assumed effluent limits are low. This would need to be verified during treatability studies. Air stripping and carbon adsorption were selected to remove volatile and semivolatile organics. Air stripping will be used to remove volatile organics prior to carbon adsorption to reduce carbon usage (volatile organic removal is not needed to meet assumed discharge requirements; see Table 3-2). Conceptual design calculations are provided in Appendix A. Treatability studies could be conducted during the design phase to determine whether ozone/UV/hydrogen peroxide could meet the effluent limits in a more cost-effective manner. It should be noted that the estimates of the location and depths of the extraction wells are developed conceptually in the FFS for cost estimation purposes.

Concurrent with the design, construction, and operation of the initial extraction well network and treatment system, investigations would be conducted both on and off current NAWC Warminster property as necessary to fully identify the nature and extent of contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster. If additional contamination of concern attributable to NAWC Warminster is identified, the extraction well network and treatment system would be modified during the interim action as necessary to minimize migration of contaminants and to maximize the effectiveness of the extraction well network.

TABLE 3-1

ASSUMED INFLUENT AND EFFLUENT CONCENTRATIONS FOR METALS DISCHARGE TO SURFACE WATER ALTERNATIVE NAWC WARMINSTER

Parameter	Influent	Assumed Effluent[1]	Treatment Required[4]
Aluminum	20,049	[2]	
Arsenic	8.0	50	No
Barium	700	---	
Cadmium	6.9	1.3 [3]	Yes
Calcium	55,716	---	
Chromium	39	243 [3]	No
Cobalt	23	---	
Copper	164	13 [3]	Yes
Iron	37,046	1,500	Yes
Lead	58	3.8 [3]	Yes
Magnesium	20,713	---	
Manganese	4,192	1,000	Yes
Mercury	0.14	0.012	Yes
Nickel	40	177 [3]	No
Potassium	4,863	---	
Silver	3.6	0.2	Yes
Sodium	27,069	---	
Thallium	1.16	13	No
Vanadium	22	---	
Zinc	339	119 [3]	Yes

All concentrations expressed in units of ug/L (ppb).

(1) 25 PA Code Chapters 16 or 93 (protection of aquatic life of human health, whichever is more stringent))
(2) 0.1 of the 96-hour LC_{50}
(3) Based on assumed hardness of 115 mg/L (criteria varies with hardness)
(4) Indication of whether contaminant removal is needed to meet assumed effluent limit.

TABLE 3-2

ASSUMED INFLUENT AND EFFLUENT LIMITS FOR ORGANICS DISCHARGE TO SURFACE WATER ALTERNATIVE NAWC WARMINSTER

Parameter	Influent	Assumed Effluent[1]	Treatment Required[2]
VOLATILES			
Benzene	1.3	1	YES
2-Butanone (MEK)	15	---	
Carbon tetrachloride	11	0.3	YES
Chloroform	9.4	0.2	YES
Chloromethane	0.7	0.2	YES
1,2-Dichlorobenzene	0.4	164	NO
1,1-Dichloroethane	5.1	---	
1,1-Dichloroethene	1.9	1,492	NO
1,2-Dichloroethane	2.3	0.4	YES
cis-1,2-Dichloroethene	90	---	
trans-1,2-Dichloroethene	1.3	350	NO
1,2-Dichloroethene (total) [3]	18.7	---	
1,2-Dichloropropane	0.6	2,165	NO
Ethylbenzene	0.1	580	NO
Tetrachloroethene	83	0.7	YES
Toluene	3.4	330	NO
1,1,1-Trichloroethane	6.8	605	NO
Trichloroethene	303	3	YES
Trichlorofluoromethane	19	---	
Vinyl chloride	1.0	0.02	YES
Xylenes	1.3	---	

TABLE 3-2
ASSUMED INFLUENT AND EFFLUENT LIMITS FOR ORGANICS
DISCHARGE TO SURFACE WATER ALTERNATIVE
NAWC WARMINSTER
PAGE TWO

Parameter	Influent	Assumed Effluent[1]	Treatment Required[2]
SEMIVOLATILES			
Benzo(a)anthracene	7.8	0.003	YES
Benzo(a)pyrene	12	0.003	YES
Benzo(b)fluoranthene	26	0.003	YES
Benzo(g,h,i)perylene	10	0.003	YES
Butylbenzylphthalate	0.3	35	NO
Chrysene	13	0.003	YES
Dibenz(a,h)anthracene	3.2	0.003	YES
Diethylphthalate	1.0	800	NO
Di-n-octylphthalate	2.3	---	
Fluoranthene	19	40	NO
Indeno(1,2,3-c,d)pyrene	10	0.003	YES
Phenanthrene	7.8	0.003	YES
Pyrene	15	0.003	YES

All concentrations expressed in units of ug/l (ppb).

(1) 25 PA Code Chapters 16 or 93 (protection of aquatic life or human health, whichever is more stringent).

(2) Indication of whether contaminant removal is needed to meet assumed effluent limit.

(3) The sum of cis-1,2-dichloroethene and trans-1,2-dichloroethene influent concentrations does not equal total 1,2-dichloroethene influent concentration because the analyses were conducted in two separate phases of the RI. All samples were not analyzed for the same parameters during the separate RI phases.

3.1.3 Groundwater Extraction, Onsite Pretreatment, and Discharge to NAWC Warminster Wastewater Treatment Plant or Publicly Owned Treatment Works

Under this alternative, contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster would be extracted using a series of extraction wells. The conceptual extraction systems are the same as for the discharge to surface water alternative discussed in Section 3.1.2.

The extracted groundwater would then be pretreated and discharged to the NAWC Warminster WWTP. In the event that the NAWC Warminster WWTP ceases operation as part of base realignment and closure, the pretreated groundwater would then be discharged to a POTW such as the Warminster Municipal Authority (WMA) WWTP. Pretreatment would be performed as necessary to meet the influent requirements of the receiving WWTP. Pretreatment may include air stripping to remove volatile organics, precipitation/filtration (and ion exchange, or other means, if necessary) to remove metals, and/or carbon adsorption to remove semivolatile organics. If necessary, emissions from the air stripper would be treated by vapor-phase carbon adsorption. It is assumed that vapor-phase carbon adsorption would not be required because of the low maximum emission rate (0.016 lb/hr). Calculations are provided in Appendix A. Treated water would be discharged to the POTW or the NAWC Warminster WWTP. The WWTP discharge limits are regulated by NPDES permit. This alternative would attempt to prevent further migration of groundwater contaminants in the overburden and shallow bedrock aquifers from the vicinity of Areas A and B.

The groundwater extraction systems are the same as for the discharge to surface water alternative. The initial conceptual extraction system for Area A consists of 16 wells pumping at approximately 2.3 gpm each. The wells would be approximately 87 feet deep, and the total flow rate of extracted groundwater would be approximately 36 gpm. The initial conceptual extraction system for Area B consists of 9 extractions wells pumping at approximately 2.3 gpm. The wells would be approximately 77 feet deep. Approximate initial well locations were shown in Figures 3-1 and 3-2. A schematic flow diagram of the proposed treatment system is shown in Figure 3-3. This is the same treatment system developed conceptually for the discharge to surface water alternative. The treatment plant was designed to meet the same effluent concentrations as the discharge to surface water alternative.

Discharges from the NAWC Warminster WWTP are regulated by an NPDES permit. Discharges from the pretreatment facility must not cause the NAWC Warminster WWTP to exceed the NPDES discharge limits.

The NAWC Warminster WWTP is scheduled to be closed when NAWC Warminster will connect to the township (WMA) sewage treatment plant in 1995 or 1996. Therefore, the NAWC Warminster WWTP may not be operational for industrial pretreatment use when the extraction and pretreatment system is operational. Groundwater would then need to be discharged to an existing POTW such as the WMA WWTP. Groundwater would need to be pretreated to meet limits imposed by the POTW.

Treatment plant influent concentrations would be the same as for the discharge to surface water alternative discussed previously. Based on the estimated influent concentrations, the assumed effluent concentrations, and the projected flow rate, unit processes were combined to remove both organic and inorganic contaminants. Treatability studies would be conducted as necessary to confirm that the pretreatment meets the requirements of the receiving WWTP and that the WWTP meets NPDES requirements. If treatability studies indicate that treatment to remove organics is unnecessary to meet WWTP limits, air stripping and/or carbon adsorption need not be included in the final design.

Concurrent with the design, construction, and operation of the initial extraction well network and pretreatment system, investigations would be conducted both on and off current NAWC Warminster property as necessary to fully identify the nature and extent of contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster. If additional contamination of concern attributable to NAWC Warminster is identified, the extraction well system and pretreatment system would be modified during the interim action as necessary to minimize migration of contaminants and to maximize the effectiveness of the extraction well network.

3.2 SCREENING OF REMEDIAL ALTERNATIVES

All technologies and process options that were combined into the remedial alternatives were found to be effective and implementable in Section 2.4.2. Therefore, further screening of alternatives, based on effectiveness, implementability, and cost, is not necessary to reduce the number of alternatives for detailed analysis. All of the alternatives previously developed in Section 3.1 will be retained for detailed analysis in Section 4.0. The alternatives are as follows:

- Alternative 1: No Action with Groundwater Monitoring
- Alternative 2: Groundwater Extraction, Onsite Treatment, and Discharge to Surface Water
- Alternative 3: Groundwater Extraction, Onsite Pretreatment, and Discharge to NAWC Warminster Wastewater Treatment Plant or Publicly Owned Treatment Works

4.0 DETAILED ANALYSIS OF ALTERNATIVES

Detailed analysis of alternatives will be conducted in accordance with the "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA" (EPA, 1988) and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), including the February 1990 revisions. In conformance with the NCP, seven of the following nine criteria will be used for the detailed analysis:

- Overall protection of human health and the environment
- Compliance with ARARs
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume
- Short-term effectiveness
- Implementability
- Cost
- State acceptance (not evaluated at this time)
- Community acceptance (not evaluated at this time)

State acceptance and community acceptance will be evaluated by addressing comments received after the FFS has been reviewed by the Pennsylvania Department of Environmental Resources, local townships and authorities, and the public.

Achievement of the groundwater remedial action objectives for OU-1 are evaluated for each alternative under the Overall Protection of Human Health and the Environment criterion.

Overall Protection of Human Health and the Environment: The primary requirement is that remedial actions are protective of human health and the environment. A remedy is protective if it adequately eliminates, reduces, or controls all current and potential site risks posed through each exposure pathway at the site. A site where, after the remedy is implemented, hazardous substances remain without engineering or institutional controls, must allow for unrestricted use and unlimited exposure for human and environmental receptors, Alternatively, adequate engineering controls, institutional controls, or some combination of the two must be implemented to control exposure and thereby ensure reliable protection

over time. In addition, implementation of a remedy cannot result in unacceptable short-term risks or cross-media impacts on human health and the environment.

Compliance with Applicable or Relevant and Appropriate Requirements (ARARs): Compliance with ARARs is one of the statutory requirements for remedy selection. However, CERCLA allows selection of a remedial alternative that will not attain ARARs if any of six conditions exist (see Section 2.2.2). One of these conditions is if the remedial action is an interim measure whereby the final remedy will attain the ARAR upon completion. Alternatives are developed and refined throughout the FFS process to ensure that they will meet all of the respective ARARs or that there is a good rationale for waiving an ARAR. During the detailed analysis, information on Federal and state action-specific ARARs will be assembled along with previously identified contaminant-specific and location-specific ARARs. Alternatives will be refined as necessary to ensure compliance with these requirements.

Long-term Effectiveness and Permanence: This criterion reflects CERCLA's emphasis on implementing remedies that will insure protection of human health and the environment in the future, as well as in the near term. In evaluating alternatives for their long-term effectiveness and the degree of permanence they afford, the analysis will focus on residual risks present at the site after the completion of the remedial action. The analysis will include consideration of the following:

- Degree or threat posed by the hazardous substances remaining at the site.
- Adequacy of any controls (e.g., engineering and institutional controls) used to manage the hazardous substances remaining at the site.
- Reliability of those controls.
- Potential impacts on human health and the environment, should the remedy fail, based on assumptions included in the reasonable maximum exposure scenario.

Reduction of Toxicity, Mobility, or Volume through Treatment: This criterion addresses the statutory preference for remedies that employ treatment as a principal element by ensuring that the relative performance of the treatment alternatives in reducing the toxicity, mobility, or volume will be assessed. Specifically, the analysis will examine the magnitude, significance, and irreversibility of reductions.

Short-term Effectiveness: This criterion examines the short-term impacts of the alternative (i.e., impacts during construction and implementation) on the neighboring community, workers, or surrounding environment. This includes potential threats to human health and the environment associated with the removal, treatment, and transportation of hazardous substances. The potential cross-media impacts of the remedy and the time to achieve protection of human health and the environment will also be analyzed.

Implementability: Implementability considerations include the technical and administrative feasibility of the alternatives, as well as the availability of goods and services (e.g., treatment, storage, or disposal capacity) on which the viability of the alternative depends. Implementability considerations often affect the timing of various remedial alternatives (e.g., limitations on the season in which the remedy can be implemented, the number and complexity of material handling steps, the need to obtain permits, and the need to secure technical services). Onsite activities must comply with the substantive portions of applicable permitting regulations.

Cost: Cost includes all capital costs and annual operation and maintenance (O&M) costs incurred over the life of the project. The focus during detailed analysis is on the present worth of these costs. Costs are used to select the most cost-effective alternative that will achieve the remedial action objectives.

State Acceptance: This criterion, which is an ongoing concern throughout the remedial process, reflects the statutory requirement to provide substantial and meaningful state involvement. State comments may be addressed during the development of the FFS, as appropriate, although formal state comments usually will not be received until after the state has reviewed the draft FFS and draft Proposed Plan prior to the public comment period. This criterion will not be used for detailed analysis of alternatives in the FFS.

Community Acceptance: This criterion refers to the community's comments on the remedial alternatives under consideration, where "community" is broadly defined to include all interested parties. These comments are taken into account throughout the FFS process. However, only preliminary assessment of community acceptance can be conducted during the development of the FFS, since formal public comment will not be received until after the public comment period for the FFS is held. This criterion will not be used for detailed analysis in the FFS.

4.1 ALTERNATIVE 1: NO ACTION WITH GROUNDWATER MONITORING

4.1.1 Description

Under this alternative, no remedial action would be undertaken to address contaminated groundwater attributable to NAWC Warminster in overburden and shallow bedrock aquifers. Instead, additional studies necessary to identify the full nature and extent of contaminated groundwater in overburden and shallow bedrock aquifers would be conducted as part of continuing RIs addressing the facility. In addition to these studies, monitoring of groundwater in overburden and shallow bedrock aquifers would be conducted for 30 years.

4.1.2 Overall Protection of Human Health and the Environment

This alternative would delay the implementation of actions necessary to meet the remedial action objectives in the case of OU-1. The selection of a remedy addressing contaminated groundwater would not be initiated until completion of the studies necessary to fully identify the nature and extent of contaminated groundwater attributable to NAWC Warminster.

4.1.3 Compliance with ARARs

Since no action would be taken under this alternative, there would be no ARARs.

4.1.4 Long-Term Effectiveness and Permanence

Delaying remedial action until the completion of additional investigations addressing groundwater would result in further contaminant migration while the studies continue and could possibly prolong the time required to restore contaminated groundwater in overburden and shallow bedrock aquifers.

4.1.5 Reduction of Toxicity, Mobility, or Volume through Treatment

This alternative does not employ treatment to reduce the toxicity, mobility, or volume of contaminated groundwater in overburden and shallow bedrock aquifers.

4.1.6 Short-Term Effectiveness

This alternative does not involve remedial action that would pose a risk to human health and the environment during implementation. Groundwater contaminants would continue to migrate and would present potential unacceptable risks to human health.

4.1.7 Implementability

Since no remedial action will be taken, this criterion is not applicable. Groundwater monitoring can be performed using existing monitoring wells. Additional wells, if needed, could be readily installed.

4.1.8 Cost

The estimated costs for this alternative are as follows:

- Estimated capital cost: $72,000
- Estimated annual cost: $182,000
- Estimated 30-year present worth: $2,871,000

The present-worth cost estimate of this alternative is based on a 30-year period of quarterly monitoring. Detailed costs are presented in Appendix B.

4.2 ALTERNATIVE 2: GROUNDWATER EXTRACTION, ONSITE TREATMENT, AND DISCHARGE TO SURFACE WATER

4.2.1 Description

Under this alternative, contaminated groundwater in overburden and shallow bedrock aquifers would be extracted using a series of extraction wells. The extraction wells would be located as necessary to maximize the effectiveness of the system. The extracted groundwater would be pumped to an onsite treatment system constructed specifically to treat groundwater. Treatment would include air stripping to remove volatile organics and carbon adsorption to remove semivolatile organics. Emissions from the air stripper would be treated by vapor-phase carbon adsorption unless an exemption from air treatment requirements is obtained. For cost estimation purposes, it was assumed that vapor-phase carbon

adsorption would not be required because of the low maximum volatile emission rate (0.016 lb/hr). Metals would be treated by precipitation and filtration (and ion exchange, or other means, if necessary). Upon meeting effluent limits consistent with NPDES requirements, the treated water would be discharged to an unnamed tributary of Little Neshaminy Creek or an unnamed tributary of Southampton Creek. Treatability studies would be performed to confirm effluent levels meet NPDES requirements.

Concurrent with the design, construction, and operation of the initial extraction well network and treatment system, investigations would be conducted both on and off current NAWC Warminster property as necessary to fully identify the nature and extent of contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster. If additional contamination of concern attributable to NAWC Warminster is identified, the extraction well network and treatment system would be modified as necessary to minimize migration of contaminants to maximize the effectiveness of the extraction well network.

This alternative would incorporate the sampling of existing onsite and offsite wells. Additional wells could be installed, if needed. For costing purposes, it was assumed a total of 20 wells would be sampled. Initially, sampling would be conducted on a quarterly basis until a trend in contaminant levels is established. Groundwater samples would be analyzed for metals, volatile organics, and semivolatile organics. Once a reliable trend is established, the frequency of monitoring would be reduced to a semi-annual basis and eventually to an annual basis. For costing purposes, it was assumed that sampling would be conducted on a quarterly basis for 30 years.

4.2.2 Overall Protection of Human Health and the Environment

This alternative would protect both human health and the environment by minimizing the migration of contaminated groundwater in the overburden and shallow bedrock aquifers. Additional studies to determine the full nature and extent of groundwater contamination attributable to NAWC Warminster would be conducted concurrently with the design, construction, and operation of the groundwater extraction and treatment system.

4.2.3 Compliance with ARARs

Under this alternative, all ARARs for discharge of treated water and air emissions would be met. Because the primary objective of the interim remedy for OU-1 is to minimize the migration of contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster, the

requirements to meet contaminant- and/or action-specific ARARs for groundwater (e.g., 25 PA Code Chapter 264 requirements) may be waived temporarily until a final remedy for OU-1 is selected.

Treatability studies would be necessary to confirm onsite treatment can meet NPDES requirements for the plant effluent.

4.2.4 Long-Term Effectiveness and Permanence

This alternative would initiate the process of minimizing the migration of contaminants in the overburden and shallow bedrock aquifers as soon as possible. Initiation of pumping and treatment of groundwater at this time may reduce the time necessary to restore the affected aquifers.

Long-term groundwater monitoring would be required to determine whether this alternative is effectively minimizing further contaminant migration. Operation and maintenance of the treatment plant and monitoring of the treated discharges would be required to insure that the treatment plant is effective in meeting the NPDES discharge limits.

4.2.5 Reduction of Toxicity, Mobility, or Volume through Treatment

The volume and toxicity of contaminated groundwater would be reduced by extraction and treatment. Further migration of groundwater in the overburden and shallow bedrock aquifers would be contained by the extraction systems.

The treatment system would generate residuals such as sludge and spent activated carbon that would require further treatment or disposal. It is assumed that dewatered sludge would be disposed of as a non-hazardous waste and that spent activated carbon would be regenerated by a vendor of the carbon.

4.2.6 Short-Term Effectiveness

There would be no additional risks to the general public or the environment during implementation of this alternative. Workers would be required to wear protective equipment during activities where they may be exposed to hazardous materials.

4.2.7 Implementability

The technologies and process options proposed for groundwater extraction and treatment are all demonstrated and commercially available. These systems are reliable if properly maintained. A treatability study would be needed to select and size the optimum treatment processes. The treatability study would also be required to ensure that the final NPDES discharge limits can be met.

The treatment plant discharge would be subject to monitoring requirements which would be imposed by the NPDES permit.

Investigations to determine the full nature and extent of contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster would be part of the Remedial Design/Remedial Action (RD/RA) for OU-1. If contaminated groundwater is found in overburden or shallow bedrock aquifers outside Areas A and B, additional extraction wells would be installed as part of the RD/RA for OU-1 to provide a remedy for additional contaminated groundwater of concern. The additional flow would be handled either by the initial treatment units, or additional treatment units may be installed.

4.2.8 Cost

The estimated costs for this alternative are as follows:

- Estimated capital costs: $3,515,000
- Estimated annual costs: $628,000
- Estimated 30-year present worth: $13,172,000

The present-worth cost estimate of this alternative is based on a 30-year operation period for the groundwater extraction and treatment system. Detailed costs are presented in Appendix B.

4.3 ALTERNATIVE 3: GROUNDWATER EXTRACTION, ONSITE PRETREATMENT, AND DISCHARGE TO THE NAWC WARMINSTER WASTEWATER TREATMENT PLANT OR PUBLICLY OWNED TREATMENT WORKS

4.3.1 Description

Under this alternative, contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster would be extracted using a series of extraction wells. The extraction wells would be located as necessary to maximize the effectiveness of the extraction system. The extracted groundwater would be pumped to an onsite treatment system constructed specifically to pretreat groundwater prior to discharge to the NAWC Warminster WWTP. In the event that the NAWC Warminster WWTP ceases operation as part of base realignment and closure, the pretreated groundwater would then be discharged to a POTW such as the WMA WWTP. Pretreatment would be performed as necessary to meet the influent requirements of the receiving WWTP. Pretreatment may include air stripping to remove volatile organics, precipitation/filtration (and ion exchange or other means, if necessary) to remove metals, and/or carbon adsorption to treat semivolatile organics. If necessary, emissions from the air stripper would be treated by vapor-phase carbon adsorption. After pretreatment, the groundwater would be discharged to the POTW WWTP or NAWC Warminster WWTP. Treatability studies would be conducted as necessary to confirm that the pretreatment meets the requirements of the receiving WWTP and that the WWTP meets NPDES requirements.Pretreatment would be performed as necessary to meet the influent requirements of the receiving WWTP. Pretreatment may include air stripping to remove volatile organics, precipitation/filtration (and ion exchange or other means, if necessary) to remove metals, and/or carbon adsorption to treat semivolatile organics. If necessary, emissions from the air stripper would be treated by vapor-phase carbon adsorption. For cost estimation purposes, it was assumed that vapor-phase carbon adsorption would not be required because of the low maximum volatile emission rate (0.016 lb/hr). After pretreatment, the groundwater would be discharged to the WMA WWTP or NAWC Warminster WWTP. Treatability studies would be conducted as necessary to confirm that the pretreatment meets the requirements of the receiving WWTP and that the WWTP meets NPDES requirements.

Concurrent with the design, construction, and operation of the initial extraction well network and pretreatment system, investigations would be conducted both on and off current NAWC Warminster property as necessary to fully identify the nature and extent of contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster. If additional contamination of concern attributable to NAWC Warminster is identified, the extraction well system and pretreatment system would be modified as

necessary to minimize migration of contaminants and to maximize the effectiveness of the extraction well network.

This alternative would incorporate the sampling of existing onsite and offsite wells. Additional wells could be installed, if needed. For costing purposes, it was assumed a total of 20 wells would be sampled. Initially, sampling would be conducted on a quarterly basis until a trend in contaminant levels is established. Groundwater samples would be analyzed for metals, volatile organics, and semivolatile organics. Once a reliable trend is established, the frequency of monitoring would be reduced to a semi-annual basis and eventually to an annual basis. For costing purposes, it was assumed that sampling would be conducted on a quarterly basis for 30 years.

4.3.2 Overall Protection of Human Health and the Environment

This alternative would protect both human health and the environment by minimizing the migration of contaminated groundwater in the overburden and shallow bedrock aquifers. Additional studies to determine the full nature and extent of groundwater contamination attributable to NAWC Warminster would be conducted concurrently with the design, construction, and operation of the groundwater extraction and treatment system.

4.3.3 Compliance with ARARs

Under this alternative, all ARARs for discharge of treated water and air emissions would be met. Because the primary objective of the interim remedy for OU-1 is to minimize the migration of contaminated groundwater in overburden and shallow bedrock aquifers attributable to NAWC Warminster, the requirements to meet contaminant- and/or action-specific ARARs for groundwater (e.g., 25 PA Code Chapter 264 requirements) may be waived temporarily until a final remedy for OU-1 is selected.

Prior to discharge to the WMA or NAWC Warminster WWTP, the effluent of the onsite treatment plant must meet the pretreatment requirements of the WWTP. Treatability studies must be conducted to confirm these requirements are met. The NPDES permit for the receiving facility would likely require modification, and treatability studies would be necessary to confirm the effluent of the WWTP meets the requirements of the modified NPDES permit. If treatability studies indicate that treatment to remove organics is unnecessary to meet WWTP limits, air stripping and/or carbon adsorption would not be included in the final design.

4.3.4 Long-Term Effectiveness and Permanence

This alternative would initiate the process of minimizing the migration of contaminants in the overburden and shallow bedrock aquifers as soon as possible. Initiation of pumping and treatment of groundwater at this time may reduce the time necessary to restore the affected aquifers.

Long-term groundwater monitoring would be required to determine whether this alternative is effectively minimizing further contaminant migration. Operation and maintenance of the pretreatment plant and monitoring of the treated discharges would be required to insure that the treatment provided is effective in meeting the influent limits for the WWTP.

4.3.5 Reduction of Toxicity, Mobility, or Volume through Treatment

The volume and toxicity of contaminated groundwater would be reduced by extraction and treatment. Further migration of groundwater in the overburden and shallow bedrock aquifers would be contained by the extraction systems.

The treatment system would generate residuals such as sludge and spent activated carbon that would require further treatment or disposal. It is assumed that dewatered sludge would be disposed of as a non-hazardous waste along with sludge that is currently generated by the WWTP and that spent activated carbon would be regenerated by a vendor of the carbon.

4.3.6 Short-Term Effectiveness

There would be no additional risks to the general public or the environment during implementation of this alternative. Workers would be required to wear protective equipment during activities where they may be exposed to hazardous materials.

4.3.7 Implementability

The technologies and process options proposed for groundwater extraction and treatment are all demonstrated and commercially available. These systems are reliable if properly maintained. A treatability study would be needed to select and size the optimum treatment processes. The treatability study would

also be required to assure onsite pretreatment meets the influent requirements of the WMA WWTP or NAWC Warminster WWTP and that the NPDES requirements of the receiving WWTP would be met.

The NPDES permit for the receiving WWTP would need to be amended to include the discharge of the extracted groundwater. The WWTP discharge would be subject to monitoring requirements which would be imposed by the amended NPDES permit.

Investigations to determine the full nature and extent of contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster would be part of the RD/RA for OU-1. If contaminated groundwater is found in overburden and shallow bedrock aquifers outside Areas A and B, additional extraction wells would be installed as part of the RD/RA for OU-1 to provide a remedy for additional contaminated groundwater of concern. The additional flow would be handled by the initial pretreatment units, or additional pretreatment units may be installed. The increase in additional flow would not be expected to present a problem with regard to exceeding the hydraulic capacity of the receiving WWTP.

4.3.8 Cost

The estimated costs for this alternative are as follows:

- Estimated capital cost: $3,515,000
- Estimated annual costs: $628,000
- Estimated 30-year present worth: $13,172,000

The present-worth cost estimate of this alternative is based on a 30-year operation period for the groundwater extraction and pretreatment system. Detailed costs are presented in Appendix B. The costs are the same as for Alternative 2. For cost estimation purposes, the potential cost of connecting to a POTW such as the WMA WWTP will already have been incurred.

4.4 SUMMARY OF DETAILED ANALYSIS OF ALTERNATIVES

A summary of the detailed analysis of the three remedial alternatives for Areas A and B is provided in Table 4-1.

TABLE 4-1

SUMMARY OF DETAILED ANALYSIS OF ALTERNATIVES
NAWC WARMINSTER

Criterion	Alternative 1: No Action with Groundwater Monitoring	Alternative 2: Groundwater Extraction, Onsite Treatment, and Discharge to Surface Water	Alternative 3: Groundwater Extraction, Onsite Pretreatment, and Discharge to NAWC Warminster WWTP or POTW
Overall Protection of Human Health and the Environment	Would delay implementation of action needed to meet remedial objectives. Would not meet primary objective of minimizing further contaminant migration.	Would minimize migration of contaminants in overburden and shallow bedrock aquifers.	Would minimize migration of contaminants in overburden and shallow bedrock aquifers.
Compliance with ARARs	No ARARs.	Since remedy is interim action, requirements to meet contaminant- and/or action-specific ARARs for groundwater could be waived until final remedy selected. Treatability studies needed to confirm onsite treatment could meet NPDES requirements. ARARs for discharge of treated water and air emissions would be met. No location-specific ARARs.	Since remedy is interim action, requirements to meet contaminant- and/or action-specific ARARs for groundwater could be waived until final remedy selected. Treatability studies needed to confirm that WWTP pretreatment requirements met. If such studies indicate that organics removal is not required, air stripping and/or carbon adsorption would not be included in final design. ARARs for discharge of treated water and air emissions would be met. No location-specific ARARs.
Long-Term Effectiveness and Permanence	Delaying remedial action would result in additional contaminant migration and could possibly prolong time required to restore aquifers of concern.	Would initiate process of minimizing contaminant migration in overburden and shallow bedrock aquifers as soon as possible. Initiation of pumping and treatment may reduce the time necessary to restore the affected aquifers. Long-term monitoring and O&M required.	Would initiate process of minimizing contaminant migration in overburden and shallow bedrock aquifers as soon as possible. Initiation of pumping and treatment may reduce the time necessary to restore the affected aquifers. Long-term monitoring and O&M required.
Reduction of Toxicity, Mobility, or Volume through Treatment	No treatment employed to reduce toxicity, mobility, or volume.	Volume and toxicity reduced by extraction and treatment. Treatment system would generate residuals that would require further treatment/ disposal.	Volume and toxicity reduced by extraction and treatment. Treatment system would generate residuals that would require further treatment/ disposal.

TABLE 4-1
SUMMARY OF DETAILED ANALYSIS OF ALTERNATIVES
NAWC WARMINSTER
PAGE TWO

Criterion	Alternative 1: No Action	Alternative 2: Groundwater Extraction, Onsite Treatment, and Discharge to Surface Water	Alternative 3: Groundwater Extraction, Onsite Pretreatment, and Discharge to NAWC Warminster WWTP or POTW
Short-Term Effectiveness	No remedial action that would pose a risk to human health or the environment.	No additional risks to general public or environment during implementation. Workers would need protective equipment if exposed to hazardous materials.	No additional risks to general public or environment during implementation. Workers would need protective equipment if exposed to hazardous materials.
Implementability	Not applicable, since no remedial action taken.	All technologies and process options are demonstrated and commercially available. Treatability study required to select and size optimum treatment processes. Investigations to determine full nature and extent of contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster would need to be conducted. If additional groundwater contamination of concern is identified, additional extraction wells and/or treatment units would be installed.	All technologies and process options are demonstrated and commercially available. Treatability study required to select and size optimum treatment processes. Investigations to determine full nature and extent of contamination in overburden and shallow bedrock aquifers attributable to NAWC Warminster would need to be conducted. If additional groundwater contamination of concern is identified, additional extraction wells and/or treatment units would be installed.
Costs	Capital: $ 72,000 Annual: $ 182,000 Present Worth: $ 2,871,100	Capital: $ 3,515,000 Annual: $ 628,000 Present Worth: $13,172,000	Capital: $ 3,515,000 Annual: $ 628,000 Present Worth: $13,172,000

5.0 COMPARATIVE ANALYSIS OF ALTERNATIVES

In the following analysis, the alternatives are evaluated in relation to one another for each of the evaluation criteria that were used for detailed analysis, except for state acceptance and community acceptance. State and community acceptance are to be addressed in the ROD following comments on the FFS report and the Proposed Plan for the interim remedial alternatives for OU-1. The purpose of this analysis is to identify the relative advantages and disadvantages of each alternative.

5.1 OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

Alternatives 2 and 3 would both protect both human health and the environment by minimizing the migration of contaminated groundwater in overburden and shallow bedrock aquifers. Additional studies to determine the full nature and extent of groundwater contamination attributable to NAWC Warminster would be conducted concurrently with the design, construction, and operation of the groundwater extraction and treatment system.

Under Alternative 1, the selection of a remedy addressing contaminated groundwater would not be initiated until the completion of the studies necessary to fully identify the nature and extent of contaminated groundwater attributable to NAWC Warminster.

5.2 COMPLIANCE WITH ARARS

Under Alternatives 2 and 3, all ARARs for discharge of treated water and air emissions would be met.

Since no action would be taken under Alternative 1, there would be no ARARs.

5.3 LONG-TERM EFFECTIVENESS AND PERMANENCE

By initiating an interim remedy at this time, Alternatives 2 and 3 may reduce the time necessary to restore affected aquifers relative to Alternative 1 and thus may be more effective over the long term.

Alternatives 2 and 3 require groundwater monitoring to evaluate their effectiveness. Operation and maintenance of the treatment plant and monitoring of the treated discharges would be required for both of these alternatives.

5.4 REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT

Alternatives 2 and 3 would reduce the volume and toxicity of contaminated groundwater. Further migration of groundwater in the overburden and shallow bedrock aquifers would be contained by the extraction systems. The treatment systems for these alternatives would generate residuals that would require further treatment or disposal.

Alternative 1 would not use treatment to reduce the toxicity, mobility, or volume of contaminated groundwater in overburden and shallow bedrock aquifers.

5.5 SHORT-TERM EFFECTIVENESS

Under Alternative 1, groundwater contaminants would continue to migrate and would present potential unacceptable risks to human health. There would be no additional risks to the public or the environment under Alternatives 2 and 3.

For Alternatives 2 and 3, workers would be required to wear protective equipment during activities where they may be exposed to hazardous materials.

5.6 IMPLEMENTABILITY

No remedial action is included under Alternative 1.

For Alternatives 2 and 3, the remedial technologies and process options proposed for groundwater extraction and treatment are all demonstrated and commercially available. Treatability studies would be required for both alternatives to ensure that NPDES discharge limits can be met on a consistent basis.

Under Alternative 2, it is reasonable to assume that extracted groundwater could be treated on site to meet NPDES effluent limits for discharge to a tributary of Little Neshaminy Creek or Southampton Creek.

Under Alternative 3, it is reasonable to assume that extracted groundwater could be pretreated on site as necessary to meet the requirements of either the NAWC Warminster WWTP or a POTW such as the WMA WWTP. At this time, it is unknown how long the NAWC Warminster WWTP will remain operational or whether the WMA WWTP would accept pretreated groundwater from the facility.

If contaminated groundwater is found in overburden or shallow bedrock aquifers outside Areas A and B, additional extraction wells or treatment units could be installed as part of RD/RA activities for OU-1 to provide a remedy for additional contaminated groundwater of concern.

5.7 COSTS

The cost estimates for the remedial alternatives are as follows:

Alternative		Capital Cost	Annual Cost	Present Worth
1:	No Action with Groundwater Monitoring	$72,000	$182,000	$2,871,000
2:	Groundwater Extraction, Onsite Treatment, and Discharge to Surface Water	$3,515,000	$628,000	$13,172,000
3:	Groundwater Extraction, Onsite Pretreatment, and Discharge to NAWC Warminster WWTP or POTW	$3,515,000	$628,000	$13,172,000

REFERENCES

Arienti, M. et al., 1986. Technical Resource Document: Treatment Technologies for Dioxin-Containing Wastes. U.S. EPA Hazardous Waste Environmental Research Laboratory, Contract No. 68-3-3243 (from EPA/600/2-87/098).

Berkowitz, J. B. et al., 1978. Physical, Chemical, and Biological Treatment Techniques for Industrial Waste. Noyes Data Corporation; Park Ridge, New Jersey. (From EPA/600/2-87/098).

Bonk, D., 1992. TreaTek, Inc., Personal Communication with G. Ruggaber, HALLIBURTON NUS Corporation, January 13.

Bouwer, E. J., Rittman, B. E., and McCarty, P. L., 1981. "Anaerobic Degradation of Halogenated 1- and 2-Carbon Organic Compounds," Environmental Science and Technology. 15:590 (from EPA-600/2-87-008).

Brenton, M. A. et al., 1986. Technical Resource Document: Treatment Technologies for Solvent-Containing Wastes. U.S. EPA Hazardous Waste Environmental Research Laboratory, Contract No. 68-03-3243 (from EPA/600/2-87/098).

Camp Dresser and McKee Incorporated, 1985. Alternative Treatment Technologies for Superfund Wastes. Versar EPA Contract No. 68-01-7053.

EPA, 1986. Mobile Treatment Technologies for Superfund Wastes. EPA 540/2-86/003(f), Office of Solid Waste and Emergency Response, Washington, D.C.

EPA, 1987. Technical Resource Document: Treatment Technologies for Halogenated Organic Containing Wastes. Hazardous Waste Engineering Laboratory, Cincinnati, Ohio, EPA 600/2-87/098.

EPA, October 1998. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Office of Emergency and Remedial Response, Washington, D.C., EPA 540/G-89-004.

EPA, December 1988. Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites. Office of Emergency and Remedial Response, Washington, D.C., EPA 540/G-88/003.

EPA, 1990a. "National Primary and Secondary Drinking Water Regulations; Synthetic Organic Chemicals and Inorganic Chemicals - Proposed Rule," 55 Federal Register 143, July 25.

EPA, 1990b. ARARs Q's and A's: Compliance with Federal Water Quality Criteria. Office of Solid Waste and Emergency Response, Publication 9234.2-09/FS.

EPA, 1991a. "National Primary Drinking Water Regulations - Synthetic Organic Chemicals and Inorganic Chemicals; Monitoring for Unregulated Contaminants; National Primary Drinking Water Regulations Implementation; National Secondary Drinking Water Regulations - Final Rule," 56 Federal Register 20, January 30.

EPA, 1991b. "Maximum Contaminant Level Goals and National Primary Drinking Water Regulations for Lead and Copper - Final Rule," 56 Federal Register 110, June 7.

EPA, 1992a. Drinking Water Regulations and Health Advisories. Office of Water, Washington, D.C., April.

EPA, 1992b. Health Effects Assessment Summary Tables; Annual FY92. Office of Emergency and Remedial Response, Washington, D.C.

Fogel, M. M., Taddeo, A. R., and Fogel, S., 1986. "Biodegradation of Chlorinated Ethenes by a Methane-Utilizing Mixed Culture," Applied Environmental Microbiology. 51:720.

Henry, S. M., and Grbic-Galic, D., 1986. "Aerobic Degradation of Trichloroethylene (TCE) by Methylotrophs Isolated from a Contaminated Aquifer," presented at the 86th Annual Meeting American Society of Microbiologists, Washington, D.C.

Litchfield, C., 1989. DuPont Biosystems. Personal Communication with G. Ruggaber, HALLIBURTON NUS Corporation. February 6.

McShea, L. J., et al., 1987. "Combining UV/Ozone to Oxidize Toxics," Pollution Engineering, March.

Nack, H., 1989. Batelle Corporation. Telephone Conversation with G. Ruggaber, HALLIBURTON NUS Corporation, February 2.

Strand, S. E., and Shippert, L., 1986. "Oxidation of Chloroform in Aerobic Soil Exposed to Natural Gas," Applied Environmental Microbiology. 52:203.

U.S. Navy, February 1992. Navy/Marine Corps Installation Restoration Manual. NAVFACENGCOM.

Voice, T., 1990. Michigan State University. Personal Communication with G. Ruggaber, HALLIBURTON NUS Corporation, March 29.

Wilson, B. H., and White, M. V., 1986. "A Fixed-Film Bioreactor to Treat Trichloroethylene Laden Waters from Interdiction Wells," Proceedings of the Sixth National Symposium and Exposition on Aquifer Restoration and Groundwater Monitoring. National Water Well Association, Columbus, Ohio.

Wilson, J., 1992. R. S. Kerr Environmental Research Laboratory, Ada, Oklahoma. Personal Communication with G. Ruggaber, HALLIBURTON NUS Corporation, January 15.

APPENDIX A

CONCEPTUAL DESIGN CALCULATIONS

CLIENT: Navy/Warminster	PROJ. NO.: 3933	BY: JPO	PAGE 1 OF 3
SUBJECT: FS GW extraction system designs, Sites 1,2,3	CKD BY: [illegible]	DATE: 1-21-93	

TECHNICAL APPROACH:

Develop conceptual design for groundwater extraction system for Sites 1,2,3, based on Phase II RI data regarding aquifer characteristics and extent of contamination. Assume deeper contamination (if any) is related to regional water quality and is not site-related. Extract groundwater along downgradient edge of contaminant plume. System design is intended to contain plume, not accelerate remediation.

BASELINE DATA/ASSUMPTIONS:

OVERBURDEN AQUIFER CHARACTERISTICS
- HYDRAULIC CONDUCTIVITY (K), FT/DAY: 2 ft/day
- SATURATED THICKNESS (B), FT: 20 ft
- TRANSMISSIVITY (T), FT^2/DAY: 40 ft^2/day
- STORATIVITY (S): n/a
- POROSITY (n): n/a
- GROUNDWATER FLOW GRADIENT (i): 0.015

BEDROCK AQUIFER CHARACTERISTICS (Shallow bedrock only)
- HYDRAULIC CONDUCTIVITY (K), FT/DAY: 1 ft/day
- SATURATED THICKNESS (B), FT: 67 ft
- TRANSMISSIVITY (T), FT^2/DAY: 67 ft^2/day
- STORATIVITY (S): 0.0004
- POROSITY (n): n/a
- GROUNDWATER FLOW GRADIENT (i): 0.025

CONTAMINANT DISTRIBUTIONS
- PLUME WIDTH (W), FT: 1000 ft
- PLUME DEPTH (D), FT: 87 ft (assumed OB & shallow BR)
- PLUME LENGTH (L), FT: n/a

DESIGN CONSIDERATIONS
- REQUIRED CAPTURE ZONE WIDTH @ LINE OF WELLS, FT: 1000 ft
- REQUIRED TOTAL CAPTURE ZONE WIDTH, FT (2x capture zone width at line of extraction wells): 2000 ft

GROUNDWATER FLOW RATES THRU PLUME CROSS SECTION

OVERBURDEN, Qob = KiA = KiWB = TiW
= (2 ft/day)(.015)(1000 ft)(20 ft)
= 600 ft^3/day

BEDROCK - $Qbr = KiA = KiWB = TiW$
$= (67\ ft^2/day)(.025)(1000\ ft)$
$= 1675\ ft^3/day$

TOTAL GROUNDWATER FLOW THROUGH RATE
$Qt = Qob + Qbr$
$= 600\ ft^3/day + 1675\ ft^3/day$
$= 2275\ ft^3/day$

GROUNDWATER EXTRACTION RATE:

Must be at least equal to the background groundwater flow thru rate for the plume cross section, or
Must be at least equal to 2x the background groundwater flow thru rate for the plume cross section at the line of extraction wells;
Depending on plume configuration/extraction well locations.

Qp = Qt, or 2Qt, or Other (Define)

$Qp = 2Qt$
$= 2(2275\ ft^3/day)$
$= 4550\ ft^3/day$ (24 gpm)

DESIGN SAFETY FACTOR (Sf), TO ACCOUNT FOR UNCERTAINTIES: 1.5x
$Qp(revised) = Qp \times Sf$
$= (4550\ ft^3/day)(1.5)$
$= 6825\ ft^3/day$ (36 gpm) - **Design pumping rate**

NUMBER OF EXTRACTION WELLS:

ASSUMPTIONS
Extraction wells installed in bedrock only -- hydraulic connection adequate between overburden and bedrock such that groundwater withdrawl from bedrock will also capture/contain contaminated groundwater in overburden. Use bedrock aquifer characteristics only to determine extraction well drawdowns.

TOTAL SYSTEM PUMPING RATE (Qp), FT^3/DAY: 6825 ft^3/day
ALLOWABLE DRAWDOWN PER INDIVIDUAL EXTRACTION WELL (s), FT: 10 ft
ASSUMED TIME TO REACH STEADY-STATE DRAWDOWN (t), DAYS: 30 days
EXTRACTION WELL RADIUS (R), FT: 0.25 ft

SINGLE WELL PUMPING RATE (Qw) TO ACHIEVE ALLOWABLE DRAWDOWN:

$Qw = (4\pi Ts/2.3)/Log(2.25\ Tt/R^2S)$
$= (3660\ ft^3/day)/8.26$
$= 443\ ft^3/day$ (2.3 gpm)

NUMBER OF EXTRACTION WELLS REQUIRED

$$Qp/Qw = (6825\ ft^3/day)/(443\ ft^3/day)$$
$$= 16 \text{ wells}$$

MAXIMUM EXTRACTION WELL SPACINGS (Wsp) FOR WELLS ALIGNED PERPENDICULAR TO GROUNDWATER FLOW DIRECTION:

FOR TWO WELLS, $Wsp = Qw/\pi Ti(Sf)$
FOR THREE WELLS, $Wsp = 1.26\ Qw/\pi Ti(Sf)$
FOR > THREE WELLS, $Wsp = 1.2\ Qw/\pi Ti(Sf)$

$$Wsp = 1.2\ Qw/\pi Ti(Sf)$$
$$= 1.2(443\ ft^3/day)/\pi(67\ ft^2/day)(.025)(1.5)$$
$$= 67 \text{ ft between wells}$$

For capture zone width of 1000 feet and 16 extraction wells, even spacing = 1000 ft/16 = 62.5 ft. This is closer than the maximum well spacing, so a 62.5 foot well spacing is acceptable.

EXTRACTION WELL SPACINGS FOR ALTERNATE WELL ALIGNMENTS (Define):

n/a

GROUNDWATER EXTRACTION SYSTEM DESIGN SUMMARY:

16 extraction wells, pumping at 2.3 gpm each, spaced 62 ft apart along the downgradient edge of the contaminant plume.

CLIENT: Navy/Warminster	PROJ. NO.: 3933	BY: JPO	PAGE 1 OF 3
SUBJECT: FS GW extraction system designs, Sites 5,6,7	CKD BY: JWRamser	DATE: 1-21-93	

TECHNICAL APPROACH:

Develop conceptual design for groundwater extraction system for Sites 5,6,7, based on Phase II RI data regarding aquifer characteristics and extent of contamination. Assume deeper contamination (if any) is related to regional water quality and is not site-related. Extract groundwater along downgradient edge of contaminant plume. System design is intended to contain plume, not accelerate remediation. Since hydrogeologic data is lacking for Sites 5 - 7, use hydrogeologic data for Sites 1 - 3 as basis for designs.

BASELINE DATA/ASSUMPTIONS:

OVERBURDEN AQUIFER CHARACTERISTICS
- HYDRAULIC CONDUCTIVITY (K), FT/DAY: 2 ft/day
- SATURATED THICKNESS (B), FT: 10 ft
- TRANSMISSIVITY (T), FT^2/DAY: 20 ft^2/day
- STORATIVITY (S): n/a
- POROSITY (n): n/a
- GROUNDWATER FLOW GRADIENT (i): 0.025

BEDROCK AQUIFER CHARACTERISTICS (Shallow bedrock only)
- HYDRAULIC CONDUCTIVITY (K), FT/DAY: 1 ft/day
- SATURATED THICKNESS (B), FT: 67 ft
- TRANSMISSIVITY (T), FT^2/DAY: 67 ft^2/day
- STORATIVITY (S): 0.0004
- POROSITY (n): n/a
- GROUNDWATER FLOW GRADIENT (i): 0.025

CONTAMINANT DISTRIBUTIONS
- PLUME WIDTH (W), FT: 600 ft
- PLUME DEPTH (D), FT: 77 ft (assumed OB & shallow BR)
- PLUME LENGTH (L), FT: n/a

DESIGN CONSIDERATIONS
- REQUIRED CAPTURE ZONE WIDTH @ LINE OF WELLS, FT: 600 ft
- REQUIRED TOTAL CAPTURE ZONE WIDTH, FT (2x capture zone width at line of extraction wells): 1200 ft

GROUNDWATER FLOW RATES THRU PLUME CROSS SECTION:

OVERBURDEN, Qob = KiA = KiWB = TiW
= (2 ft/day)(.025)(600 ft)(10 ft)

$= 300\ ft^3/day$

BEDROCK - $Qbr = KiA = KiWB = TiW$
$= (67\ ft^2/day)(.025)(600\ ft)$
$= 1005\ ft^3/day$

TOTAL GROUNDWATER FLOW THROUGH RATE
$Qt = Qob + Qbr$
$= 300\ ft^3/day + 1005\ ft^3/day$
$= 1305\ ft^3/day$

GROUNDWATER EXTRACTION RATE:

Must be at least equal to the background groundwater flow thru rate for the plume cross section, or
Must be at least 2x the background groundwater flow thru rate for the plume cross section at the line of extraction wells;
Depending on plume configuration/extraction well locations.

Qp = Qt, or 2Qt, or Other (Define)

$Qp = 2Qt$
$= 2(1305\ ft^3/day)$
$= 2610\ ft^3/day$ (14 gpm)

DESIGN SAFETY FACTOR (Sf), TO ACCOUNT FOR UNCERTAINTIES: 1.5x
$Qp(revised) = Qp \times Sf$
$= (2610\ ft^3/day)(1.5)$
$= 3915\ ft^3/day$ (20 gpm) - **Design pumping rate**

NUMBER OF EXTRACTION WELLS:

ASSUMPTIONS
Extraction wells installed in bedrock only - hydraulic connection adequate between overburden and bedrock such that groundwater withdrawl from bedrock will also capture/contain contaminated groundwater in overburden. Use bedrock aquifer characteristics only to determine extraction well drawdowns.

TOTAL SYSTEM PUMPING RATE (Qp), FT^3/DAY: 3915 ft^3/day
ALLOWABLE DRAWDOWN PER INDIVIDUAL EXTRACTION WELL (s), FT: 10 ft
ASSUMED TIME TO REACH STEADY-STATE DRAWDOWN (t), DAYS: 30 days
EXTRACTION WELL RADIUS (R), FT: 0.25 ft

SINGLE WELL PUMPING RATE (Qw) TO ACHIEVE ALLOWABLE DRAWDOWN:

$Qw = (4\pi Ts/2.3)/Log(2.25\ Tt/R^2S)$
$= (3660\ ft^3/day)/8.26$
$= 443\ ft^3/day$ (2.3 gpm)

NUMBER OF EXTRACTION WELLS REQUIRED

$$Qp/Qw = (3915\ ft^3/day)/(443\ ft^3/day)$$
$$= 9 \text{ wells}$$

MAXIMUM EXTRACTION WELL SPACINGS (Wsp) FOR WELLS ALIGNED PERPENDICULAR TO GROUNDWATER FLOW DIRECTION:

FOR TWO WELLS, $Wsp = Qw/\pi Ti(Sf)$
FOR THREE WELLS, $Wsp = 1.26\ Qw/\pi Ti(Sf)$
FOR > THREE WELLS, $Wsp = 1.2\ Qw/\pi Ti(Sf)$

$$Wsp = 1.2\ Qw/\pi Ti(Sf)$$
$$= 1.2(443\ ft^3/day)/\pi(67\ ft^2/day)(.025)(1.5)$$
$$= 67 \text{ ft between wells}$$

For capture zone width of 600 feet and 9 extraction wells, even spacing = 600 ft/9 = 67 feet. This is equal to the maximum well spacing allowable, thus 67 feet is acceptable.

EXTRACTION WELL SPACINGS FOR ALTERNATE WELL ALIGNMENTS (Define):

n/a

GROUNDWATER EXTRACTION SYSTEM DESIGN SUMMARY:

9 extraction wells, pumping at 2.3 gpm each, spaced 67 ft apart along the downgradient edge of the contaminant plume.

HALLIBURTON NUS Environmental Corporation and Subsidiaries — **STANDARD CALCULATION SHEET**

CLIENT: WARMINSTER	FILE NO.: 3933	BY: KCT	PAGE 1 OF 6
SUBJECT: GROUNDWATER TREATMENT - DISCHARGE TO SURFACE WATER		CHECKED BY:	DATE: 1/93

Influent concentrations based on flow-weighted average of representative concentrations from Sites 1, 2, 3 and Sites 5, 6, 7.

Effluent concentrations based on Pa. Water Quality Criteria (25 Pa. Code Chapters 16 and 93)

Treatment scheme
- Equalization
- Chemical precipitation
- Clarification
- Filtration
- Air stripping
- Carbon adsorption
- Sludge dewatering
- Pump station

Total flow rate	Sites 1, 2 & 3	36 gpm	16 wells @ 2.3 gpm	87' deep
	Sites 5, 6 & 7	20 gpm	9 wells @ 2.3 gpm	77' deep
		56 gpm		

1.0 EQUALIZATION

Assume 60 minute retention time

$V = (56\ gal/min)(60\ min) = 3{,}360\ gal \Rightarrow 3500\ gal\ tank$

mixer $1/2\ HP/1000\ gal = 1.75\ HP \Rightarrow 2\ HP$

2.0 CHEMICAL PRECIPITATION

<u>Lime feed</u> - assume 300 mg/l as CaO (60 lb/ft³)

$$CaO \quad \frac{300\ mg}{l} \left| \frac{56\ gal}{min} \right| \frac{3.785\ l}{gal} \left| \frac{lb}{454{,}000\ mg} \right| \frac{1440\ min}{day} = 202\ lb/day = 8.4\ lb/hr$$

$Ca(OH)_2$ $\frac{300\ mg\ CaO}{l} \cdot \frac{74.1\ Ca(OH)_2}{56.1\ CaO} \cdot \frac{56}{} \cdot \frac{3.785}{} \cdot \frac{1440}{454{,}000} = 266\ lb/day = 11.1\ lb/hr$

Polymer feed - assume 0.5 mg/l

$\frac{0.5\ mg}{l} \cdot \frac{56\ gal}{min} \cdot \frac{3.785\ l}{gal} \cdot \frac{lb}{454{,}000\ mg} \cdot \frac{1440\ min}{day} = 0.34\ lb/day = 0.014\ lb/hr$

feed @ 1% $\frac{0.014\ lb\ polymer}{hr} \cdot \frac{100\ lb\ sol'n}{1\ lb\ polymer} = \frac{1.4\ lb\ sol'n}{hr} = \frac{0.17\ gal}{hr}$

Rapid Mixing - assume 2 min. retention time

$(56\ gpm)(2\ min) = 112\ gal$

mixer 0.5 HP/1000 gal $\Rightarrow$ 0.06 Hp use 1/4 HP mixer

pH Control system - LS

Primary Settling

use overflow rate of 600 gpd/ft^2, 2 hr. min. detention time

$A = \frac{56\ gal}{min} \cdot \frac{1440\ min}{day} \cdot \frac{1\ ft^2}{600\ gpd} = 135\ ft^2 = \frac{\pi D^2}{4}$ $D = 13.1 \Rightarrow 14\ ft$ $(A = 154\ ft^2)$

assume SWD = 10 ft $V = (154\ ft^2)(10\ ft)(7.48\ gal/ft^3) = 11{,}519\ gal$

$D.T = \frac{11{,}519\ gal}{56\ gal} \cdot \frac{min}{} \cdot \frac{hr}{60\ min} = 3.4\ hrs$ OK

Sludge Volume

assume 1 lb dry solids / lb dry lime @ 5% solids

$$\frac{266\ \text{lb}}{\text{day}} \cdot \frac{\text{lb sludge}}{.05\ \text{lb}} \cdot \frac{\text{gal}}{8.34\ \text{lb}} = 638\ \text{gpd}\ (\sim 0.5\ \text{gpm})$$ need 2 pumps

3.0 GRAVITY FILTRATION

Assume loading rate = 2 gpm/ft²

56 gpm ÷ 2 gpm/ft² = 28 ft² Use 6'ϕ filter

Assume 4 ft media depth

Assume backwash is 2% of input 56 x 0.02 = 1.12 gpm = 1613 gpd
assume 2/3 recycle 1/3 waste waste sludge = 538 gpd

Backwash pumps 15 gpm/ft² x 28 ft² = 420 gpm

Backwash tank assume 100 gal/ft² x 28 ft² = 2800 ⇒ 3000 gal

4.0 AIR STRIPPING

Base design on removal of TCE to 1 ug/l, which will reduce carbon usage by about 2/3. (see attached air stripper design) All other volatiles, except 2-butanone, ~~ar~~ would be < 1 ug/l.

Liquid loading = 18 gpm/ft² 56 ÷ 18 = 3.1 ft² Dia ≅ 2 ft
Packing depth = 20 ft. Air/water ratio = 25

HALLIBURTON NUS Environmental Corporation and Subsidiaries — **STANDARD CALCULATION SHEET**

CLIENT: WARMINSTER	FILE NO.: 3933	BY: KCT	PAGE 4 OF 6
SUBJECT: GROUNDWATER TREATMENT - DISCHARGE TO SURFACE WATER		CHECKED BY:	DATE: 1/93

Air emissions (worst case) - total VOC = 0.56 mg/l

$$\frac{.56\ mg}{l} \cdot \frac{56\ gal}{min} \cdot \frac{3.785\ l}{gal} \cdot \frac{1440\ min}{day} \cdot \frac{lb}{454{,}000\ mg} = 0.38\ lb/day = 0.016\ lb/hr$$

Blower $\frac{450\ gpm}{ft^2} \cdot 3.14\ ft^2 \cdot \frac{ft^3}{7.48\ gal} = 190\ cfm$

Need feed pumps 2 @ 56 gpm

******* A N A L Y S I S O F S T R I P P I N G T O W E R *******

PROJECT : WARMINSTER FFS OU1 DATE : 1/16/1993

ENGINEER : TURNBULL PAGE : 1/2

PHYSICAL CONSTANTS

Design temperature	:	55.0 degrees F.
Density of water	:	62.4 lb/ft^3
Density of air	:	0.0771 lb/ft^3
Viscosity of water	:	8.13E-04 lb/ft.s
Viscosity of air	:	1.17E-05 lb/ft.s
Surface tension of water	:	74 dyne/cm
Atmospheric pressure	:	1.00 atm

CONTAMINANT PROPERTIES

Name	:	Trichloroethylene
Molecular weight	:	131.3 g/mol
Boiling point	:	189 degrees F.
Molal volume at boiling point	:	0.1071 L/mol
Henry's Constant	:	0.38000
Temperature constant	:	1909 deg K
Molecular diffusivity in air	:	8.68E-05 ft^2/s
Molecular diffusivity in water	:	7.27E-09 ft^2/s

PACKING PROPERTIES

Name	:	Jaeger Tripacks
Packing Material	:	Plastic
Nominal Size	:	1.00 inch
Specific Area	:	84.7 ft^2/ft^3
Critical surface tension	:	33 dyne/cm
Packing depth	:	20.0 ft
Air friction factor	:	28

******* A N A L Y S I S O F S T R I P P I N G T O W E R *******

PROJECT : WARMINSTER FFS OU1 DATE : 1/16/1993

ENGINEER : TURNBULL PAGE : 2/2

LOADING RATES

Water mass loading rate	:	2.5 lb/ft^2.s	*
Air mass loading rate	:	0.077 lb/ft^2.s	*
Water volumetric loading rate	:	17.99 gpm/ft^2	*
Air volumetric loading rate	:	450 gpm/ft^2	*
Air pressure gradient	:	<.06 " H2O/ft	#
Volumetric air/water ratio	:	25.0	
Stripping factor	:	6.7	

MASS TRANSFER PARAMETERS

Percentage of packing area wetted	:	42.7 %	
Wetted packing area	:	36.2 ft^2/ft^3	*
Transfer rate constant in water	:	0.000381 ft/s	
Transfer rate constant in air	:	0.019637 ft/s	
Overall transfer rate constant	:	0.000355 ft/s	
Overall mass transfer coefficient	:	0.0129 1/s	
NTU	:	6.4071	
HTU	:	3.1215 ft	

CONTAMINANT REMOVAL

Influent concentration	:	303.0 ug/L	
Effluent concentration	:	1.1 ug/L	
Fraction removed	:	99.6 %	
Mass of contaminant removed	:	0.06521 lb/ft^2.day	*
Concentration in airstream	:	0.03176 mg/ft^2.ft^3	

* Expressed per unit of stripping tower cross-sectional area

\# Expressed per unit of tower length

SUMMARY OF AIR STRIPPER EFFLUENT CONCENTRATIONS. (ug/l)

benzene	<0.1	trans-1,2-dichloroethene	<0.1
2-butanone	15	1,2-dichloropropane	<0.1
carbon tetrachloride	<0.1	ethyl benzene	<0.1
chloroform	0.2	tetrachloroethene	0.2
chloromethane	<0.1	toluene	0.1
1,2-dichlorobenzene	0.1	1,1,1-trichloroethane	<0.1
1,1-dichloroethane	<0.1	trichloroethene	1.0
1,1-dichloroethene	<0.1	trichlorofluoromethane	<0.1
1,2-dichloroethane	0.5	vinyl chloride	<0.1
cis-1,2-dichloroethene	0.3	xylenes	<0.1

5.0 CARBON ADSORPTION

(see separate calculations for carbon requirement)

assume loading of 2 gpm/ft^2

$A = (56\,gpm)\left(\frac{ft^2}{2\,gpm}\right) = 28\,ft^2$ ~~12~~ ft^2 Use 6' ϕ unit

Assume 8 ft bed depth $V = (28)(8) = 224\,ft^3 = 1{,}676$ gal

retention time $= (1676\,gal)\left(\frac{min}{56\,gal}\right) = 30$ min

carbon usage = 554 mg/l

$$\frac{554\,mg}{l} \cdot \frac{56\,gal}{min} \cdot \frac{3.785\,l}{gal} \cdot \frac{1440\,min}{day} \cdot \frac{lb}{454{,}000\,mg} = 372\,lb/day = 136{,}000\,lb/yr$$

Backwash - assume not required since water filtered prior to carbon adsorption.

Need feed pumps 2 @ 56 gpm

6.0 SLUDGE DEWATERING - assume plate + frame cake @ 40% solids

Primary sludge	638 gpd @ 5% solids	
Filter backwash	538 gpd @ 0.3% solids	
TOTAL	1176 gpd @ ~3% solids	(<1 gpm)

Dry solids Primary 266 lb/day

Filter $\frac{538 \text{ gal}}{\text{day}} \cdot \frac{8.34 \text{ lb sludge}}{\text{gal}} \cdot \frac{.3 \text{ lb ds}}{100 \text{ lb sludge}} = 13.5 \text{ lb ds/day}$

Total = 266 + 13.5 ≅ 280 lb ds/day @ 40% 700 lb sludge cake/day

Need holding tank => say 1500 gal (1 days volume)

7.0 PUMP STATION - CONVEY SITE 5, 6, 7 GROUNDWATER TO SITES 1, 2, 3

Q = 20 gpm L = 10,000 ft ΔH(elev) = 10 ft

use 2" PVC pipe h_L = 0.86 ft/100 ft

$h_L = \frac{.86}{100} \times 10{,}000 = 86 \text{ ft} + 10 \text{ ft} = 96 \text{ ft}$ provide 20 gpm @ 100 ft booster pumps

HALLIBURTON NUS Environmental Corporation and Subsidiaries	STANDARD CALCULATION SHEET

CLIENT: NAWC WARMINSTER	FILE NO.: 3933	BY: KCT	PAGE 1 OF 5
SUBJECT: DISCHARGE TO SURFACE WATER - ESTIMATED CARBON USAGE WITH NO AIR STRIPPING		CHECKED BY:	DATE: 1/13/93

GOAL: ESTIMATE CARBON USAGE RATES IF NO PRETREATMENT USING AIR STRIPPER

FROM "CARBON ADSORPTION ISOTHERMS FOR TOXIC ORGANICS" EPA 600/8-80-023

$$G_c = \frac{C_o}{(X/M)_{C_o}}$$

Where G_c = carbon requirement (gram/liter)
C_o = concentration (mg/l)
$(X/M)_{C_o}$ = ultimate capacity of carbon at C_o (mg/g)

The G_c value is for running the carbon to saturation, not breakthrough. Experience has shown that doubling the saturation value estimates the G_c for breakthrough.

$$\log X/M = \log K + 1/n \log C$$

where K, 1/n = empirical constants from isotherm data
C = concentration (mg/l)

Example Calculation for 2-butanone

$C_o = 0.015$ mg/l
$K = 2.42$
$1/n = 0.546$

$$\log X/M = \log 2.42 + 0.546 \log 0.015 = -0.61$$

$$X/M = 0.244$$

$$G_c = \frac{0.015}{0.244} \times 2 = 0.122 \text{ g/l} = \frac{122 \text{ mg}}{l}$$

CARBON REQUIREMENTS FOR ALL COMPOUNDS ARE SUMMARIZED IN TABLE 1.

TABLE 1

ESTIMATED GAC REQUIREMENT WITH NO AIR STRIPPING

Parameter	Co (mg/l)	K (mg/gm)	l/n	log X/M	X/M (mg/gm)	Gc (mg/l)
benzene	0.0013	3.3	0.43	−0.72	0.19	14
2−butanone	0.015	2.42	0.546	−0.61	0.24	123
carbon tetrachloride	0.011	11.1	0.83	−0.58	0.26	84
chloroform	0.0094	2.6	0.73	−1.06	0.09	218
chloromethane	0.0007	NA	NA			
1,2−dichlorobenzene	0.0004	129	0.43	0.65	4.46	0.2
1,1−dichloroethane	0.0051	1.79	0.53	−0.96	0.11	93
1,1−dichloroethene	0.0019	4.91	0.54	−0.78	0.17	23
1,2−dichloroethane	0.0023	3.57	0.83	−1.64	0.02	199
cis−1,2−dichloroethene	0.09	1.51	0.7	−0.55	0.28	643
trans−1,2−dichloroethene	0.0013	3.05	0.51	−0.99	0.10	25
1,2−dichloropropane	0.0006	5.86	0.6	−1.17	0.07	18
ethylbenzene	0.0001	53	0.79	−1.44	0.04	5.5
tetrachloroethene	0.083	50.8	0.56	1.10	12.61	13
toluene	0.0034	26.1	0.44	0.33	2.14	3.2
1,1,1−trichloroethane	0.0068	2.48	0.34	−0.34	0.45	30
trichloroethene	0.303	28	0.62	1.13	13.36	45
trichlorofluoromethane	0.019	5.6	0.24	0.34	2.16	18
vinyl chloride	0.001	NA	NA			
xylenes	0.0013	85	0.19	1.38	24.05	0.1
						=======
				TOTAL FOR VOCs		1,555
benzo(a)anthracene	0.0078	216	0.5	1.28	19.08	0.8
benzo(a)pyrene	0.012	33.6	0.44	0.68	4.80	5.0
benzo(b)fluoranthene	0.026	57	0.37	1.17	14.77	3.5
benzo(ghi)perylene	0.01	10.7	0.37	0.29	1.95	10
butylbenzylphthalate	0.0003	1520	1.26	−1.26	0.06	11
chrysene	0.013	6.07	0.5	−0.16	0.69	38
dibenz(ah)anthracene	0.0032	69.3	0.75	−0.03	0.93	6.9
diethylphthalate	0.001	110	0.27	1.23	17.04	0.1
di−n−octyl phthalate	0.0023	NA	NA			
fluoranthene	0.019	664	0.61	1.77	59.18	0.6
indeno(1,2,3−cd)pyrene	0.01	NA	NA			
phenanthrene	0.0078	215	0.44	1.40	25.41	0.6
pyrene	0.015	65.6	0.24	1.38	23.94	1.3
						=======
				TOTAL FOR SVOCs		78

The carbon requirement, with no air stripping, is 1,633 mg/l

Based on Table 1, several volatile organics are responsible for most of the carbon required. Therefore, provide air stripping to reduce the carbon usage.

Preliminary air stripping designs were evaluated to determine achievable carbon requirement reductions. TCE was used as the basis for design because it has the highest concentration.

Reducing the TCE to 5 ug/l resulted in a carbon requirement of 708 mg/l (see Table 2). The C_o values are the air stripper effluent (carbon unit influent) concentrations.

Reducing TCE to 1 ug/l resulted in a carbon requirement of 554 mg/l (see Table 3). This design was used.

TABLE 2

ESTIMATED GAC REQUIREMENT WITH AIR STRIPPING TO TCE = 5 UG/L

Parameter	Co (mg/l)	K (mg/gm)	1/n	log X/M	X/M (mg/gm)	Gc (mg/l)
benzene	0	3.3	0.43	ERR	ERR	
2-butanone	0.015	2.42	0.546	-0.61	0.24	123
carbon tetrachloride	0.0001	11.1	0.83	-2.27	0.01	38
chloroform	0.0004	2.6	0.73	-2.07	0.01	93
chloromethane	0	NA	NA			
1,2-dichlorobenzene	0.0001	129	0.43	0.39	2.46	0.1
1,1-dichloroethane	0.0001	1.79	0.53	-1.87	0.01	14.7
1,1-dichloroethene	0	4.91	0.54	ERR	ERR	
1,2-dichloroethane	0.0006	3.57	0.83	-2.12	0.01	159
cis-1,2-dichloroethene	0.0013	1.51	0.7	-1.84	0.01	180
trans-1,2-dichloroethene	0	3.05	0.51	ERR	ERR	
1,2-dichloropropane	0.0001	5.86	0.6	-1.63	0.02	8.6
ethylbenzene	0	53	0.79	ERR	ERR	
tetrachloroethene	0.0011	50.8	0.56	0.05	1.12	2.0
toluene	0.0002	26.1	0.44	-0.21	0.62	0.7
1,1,1-trichloroethane	0.0001	2.48	0.34	-0.97	0.11	1.8
trichloroethene	0.0046	28	0.62	-0.00	1.00	9
trichlorofluoromethane	0.0001	5.6	0.24	-0.21	0.61	0.3
vinyl chloride	0	NA	NA			
xylenes	0	85	0.19	ERR	ERR	
				TOTAL FOR VOCs		630
benzo(a)anthracene	0.0078	216	0.5	1.28	19.08	0.8
benzo(a)pyrene	0.012	33.6	0.44	0.68	4.80	5.0
benzo(b)fluoranthene	0.026	57	0.37	1.17	14.77	3.5
benzo(ghi)perylene	0.01	10.7	0.37	0.29	1.95	10
butylbenzylphthalate	0.0003	1520	1.26	-1.26	0.06	11
chrysene	0.013	6.07	0.5	-0.16	0.69	38
dibenz(ah)anthracene	0.0032	69.3	0.75	-0.03	0.93	6.9
diethylphthalate	0.001	110	0.27	1.23	17.04	0.1
di-n-octyl phthalate	0.0023	NA	NA			
fluoranthene	0.019	664	0.61	1.77	59.18	0.6
indeno(1,2,3-cd)pyrene	0.01	NA	NA			
phenanthrene	0.0078	215	0.44	1.40	25.41	0.6
pyrene	0.015	65.6	0.24	1.38	23.94	1.3
				TOTAL FOR SVOCs		78
					TOTAL	708

TABLE 3

ESTIMATED GAC REQUIREMENT WITH AIR STRIPPING TO TCE = 1 UG/L

Parameter	Co (mg/l)	K (mg/gm)	l/n	log X/M	X/M (mg/gm)	Gc (mg/l)
benzene	0	3.3	0.000001	ERR	ERR	
2-butanone	0.015	2.42	0.546	-0.61	0.24	123
carbon tetrachloride	0	11.1	0.83	ERR	ERR	
chloroform	0.0002	2.6	0.73	-2.29	0.01	77
chloromethane	0	NA	NA			
1,2-dichlorobenzene	0.0001	129	0.43	0.39	2.46	0.1
1,1-dichloroethane	0	1.79	0.53	ERR	ERR	
1,1-dichloroethene	0	4.91	0.54	ERR	ERR	
1,2-dichloroethane	0.0005	3.57	0.83	-2.19	0.01	154
cis-1,2-dichloroethene	0.0003	1.51	0.7	-2.29	0.01	116
trans-1,2-dichloroethene	0	3.05	0.51	ERR	ERR	
1,2-dichloropropane	0	5.86	0.6	ERR	ERR	
ethylbenzene	0	53	0.79	ERR	ERR	
tetrachloroethene	0.0002	50.8	0.56	-0.37	0.43	1
toluene	0.0001	26.1	0.44	-0.34	0.45	0.4
1,1,1-trichloroethane	0	2.48	0.34	ERR	ERR	
trichloroethene	0.001	28	0.62	-0.41	0.39	5
trichlorofluoromethane	0	5.6	0.24	ERR	ERR	
vinyl chloride	0	NA	NA			
xylenes	0	85	0.19	ERR	ERR	
						=======
				TOTAL FOR VOCs		477
benzo(a)anthracene	0.0078	216	0.5	1.28	19.08	0.8
benzo(a)pyrene	0.012	33.6	0.44	0.68	4.80	5.0
benzo(b)fluoranthene	0.026	57	0.37	1.17	14.77	3.5
benzo(ghi)perylene	0.01	10.7	0.37	0.29	1.95	10
butylbenzylphthalate	0.0003	1520	1.26	-1.26	0.06	11
chrysene	0.013	6.07	0.5	-0.16	0.69	38
dibenz(ah)anthracene	0.0032	69.3	0.75	-0.03	0.93	6.9
diethylphthalate	0.001	110	0.27	1.23	17.04	0.1
di-n-octyl phthalate	0.0023	NA	NA			
fluoranthene	0.019	664	0.61	1.77	59.18	0.6
indeno(1,2,3-cd)pyrene	0.01	NA	NA			
phenanthrene	0.0078	215	0.44	1.40	25.41	0.6
pyrene	0.015	65.6	0.24	1.38	23.94	1.3
						=======
				TOTAL FOR SVOCs		78
					TOTAL	554

515

HALLIBURTON NUS Environmental Corporation and Subsidiaries | **STANDARD CALCULATION SHEET**

CLIENT: WARMINSTER	FILE NO.: 3933	BY: KCT	PAGE 1 OF 1
SUBJECT: GROUNDWATER TREATMENT - DISCHARGE TO WWTP		CHECKED BY: Tea	DATE: 3/93

For purposes of FFS, assume same treatment as for discharge to surface water.

If organics removal is not required; based on treatability studies, then air stripping and/or carbon need not be included in design.

Assume cost of hookup to WMA WWTP has already occurred because NAWC Warminster has to do this anyway.

Sludge disposal provided by WWTP; however, provide cost for excess sludge disposal (from precip) and replacement of activated carbon.

THEREFORE - COST FOR DISCHARGE TO WWTP WILL BE SAME AS DISCHARGE TO SURFACE WATER (for purposes of FFS)

APPENDIX B

DETAILED COST ESTIMATES

NAVAL AIR WARFARE CENTER
Warminster, Pennsylvania
No Action With Monitoring
Alternate No. GW-1
(NANAGW1)
1/20/93

Item	Qty	Unit	Unit Cost Sub.	Unit Cost Mat.	Unit Cost Labor	Unit Cost Equip.	Total Cost Sub.	Total Cost Mat.	Total Cost Labor	Total Cost Equip.	Total Direct Cost	Comments
1) Monitoring Wells	360	LF	100.00				36000				36000	4 @ 90'
							36000	0	0	0	36000	
Burden @ 30% of Labor Cost									0		0	
Labor @ 15% of Labor Cost									0		0	
Material @ 10% of Material Cost								0			0	
SubContract @ 10% of Sub. Cost							3600				3600	
Total Direct Cost							39600	0	0	0	39600	
Indirects @ 75% of Total Direct Labor Cost									0		0	
Profit @ 10% of Total Direct Cost											3960	
											43560	
Health & Safety Monitoring @ 10%											4356	
Total Field Cost											47916	
Contingency @ 20% of Total Field Cost											9583	
Engineering											15000	
TOTAL COST THIS PAGE											72499	

NAVAL AIR WARFARE CENTER
Warminster, Pennsylvania
No Action With Monitoring
Alternate GW-1
(O&MNAGW1) 1/20/93

Annual Costs

ITEM	ITEM $ QUARTERLY SAMPLING	NOTES
1. Sampling	16000.00	20 groundwater samples 80 manhours per sampling period. (quarterly) plus travel, living & shipping costs.
2. Analysis	162000.00	24 groundwater samples, per sampling period. (inc. blank & duplicate) Metals, VOCs, SVOCs
3. Reporting	4000.00	20 manhours per report plus other direct costs
TOTAL ANNUAL COST	182000.00	Post Remedial monitoring will be performed quarterly for years 1 thru 30

NAVAL AIR WARFARE CENTER
Warminster, Pennsylvania
No Action With Monitoring
Alternate No. GW-1
(PWANAGW2) 1/20/93
2871

PRESENT WORTH ANALYSIS

COST/YEAR COST OCCURS ($000'S)

COST COMPONENT	0	1	2	3	4	5	6	7	8	9	10	11
1. CAPITAL COST	72.5											
2. O & M COSTS		182										
3. ANNUAL COSTS	72.5	182	182	182	182	182	182	182	182	182	182	182
4. ANNUAL DISCOUNT RATE=5%	1	.952	.907	.864	.823	.784	.746	.711	.677	.645	.614	.585
PRESENT WORTH =	73	173	165	157	150	143	136	129	123	117	112	106

	12	13	14	15	16	17	18	19	20	21	22	23
O & M COSTS	182	182	182	182	182	182	182	182	182	182	182	182
ANNUAL DISCOUNT RATE=5%	.557	.53	.505	.481	.458	.436	.416	.396	.377	.359	.342	.326
PRESENT WORTH =	101	96	92	88	83	79	76	72	69	65	62	59

	24	25	26	27	28	29	30	TOTAL PRESENT WORTH (000'S)
O & M COSTS	182	182	182	182	182	182	182	
ANNUAL DISCOUNT RATE=5%	.31	.295	.281	.268	.255	.243	.231	
PRESENT WORTH =	56	54	51	49	46	44	42	2871

NAVAL AIR WARFARE CENTER
Warminster, Pennsylvania
Groundwater Treatment System
Discharge To Surface Water
Alternate No. GW-2
(NAGTGW2S) 1/20/93

SUMMARY

Item	Sub.	Mat.	Labor	Equip.	
1) EQUIPMENT	333600	396050	52450	9500	791600
2) PIPING & INSTRUMENTATION	0	97288	119275	40828	257391
3) FOUNDATION & STRUCTURAL	96000	17550	32500	1950	148000
4) ELECTRICAL	10000	197605	172210	0	379815
	439600	708493	376435	52278	1576806
Burden @ 30% of Labor Cost			112931		112931
Labor @ 15% of Labor Cost			56465		56465
Material @ 10% of Material Cost		70849			70849
Subcontract @ 10% of Sub. Cost	43960				43960
Total Direct Cost	483560	779342	545831	52278	1861011
Indirects @ 75% of Total Direct Labor Cost			409373		409373
Profit @ 10% Total Direct Cost					186101
					2456485
Health & Safety Monitoring @ 6%					147389
Total Field Cost					2603874
Contingency @ 20% of Total Field Cost					520775
Engineering @ 15% of Total Field Cost					390581
Total Cost This Page					3515230

Note: The cost estimate for this alternative is the same as the estimate for Alternative No. 3. Alternative No. 3 involves discharging pretreated water to the NAWC Warminster wastewater treatment plant or a publicly owned treatment works such as the Warminster Municipal Authority wastewater treatment plant.

NAVAL AIR WARFARE CENTER
Warminster, Pennsylvania
Groundwater Treatment System
Discharge To Surface Water
Alternate No. GW-2

(NAGTSGW2)

Item	Qty	Unit	Unit Cost Sub.	Unit Cost Mat.	Unit Cost Labor	Unit Cost Equip.	Total Cost Sub.	Total Cost Mat.	Total Cost Labor	Total Cost Equip.	Total Direct Cost	Comments
1) Extraction Wells	2085	LF	160.00				333600				333600	16 @ 87' 9 @ 77'
2) Extraction Well Pumps	25			2200.00	400.00			55000	10000		65000	2.5 gpm @ 120' tdh
3) Well Booster Pump	2			2500.00	400.00			5000	800		5800	20 gpm @ 100' tdh
4) Equalization Tank	1			5300.00	600.00			5300	600		5900	3500 gallon
5) Equalization Tank Mixer	1			4000.00	400.00			4000	400		4400	
6) Flash Mix Tank Supply Pump	2			2500.00	400.00			5000	800		5800	56 gpm @ 50' tdh
7) Lime Feed System	1			15000.00	1000.00			15000	1000		16000	
8) Polymer Feed System	1			8000.00	600.00			8000	600		8600	
9) Flash Mix Tank	1			250.00	50.00			250	50		300	120 gallon
10) Flash Mix Tank Mixer	1			1300.00	200.00			1300	200		1500	
11) Clarifier	1			39200.00	9800.00			39200	9800		49000	14' dia.
12) Clarifier Underflow Pump	2			2000.00	300.00			4000	600		4600	
13) Transfer Tank	1			500.00	100.00			500	100		600	400 gallon
14) Filter Supply Pump	2			2600.00	400.00			5200	800		6000	56 gpm @ 100' tdh
15) Sand Filter	2			63800.00	6000.00	2000.00		127600	12000	4000	143600	6' dia.
16) Filter Backwash Pump	2			4000.00	400.00			8000	800		8800	420 gpm @ 50' tdh
17) Filter Backwash Blower	2			5000.00	800.00			10000	1600		11600	
18) Sludge Holding Tank	1			3000.00	400.00			3000	400		3400	1500 gallon
19) Filter Press Feed Pump	2			4000.00	800.00			8000	1600		9600	
20) Filter Press	1			25000.00	2500.00	2500.00		25000	2500	2500	30000	8 c.f.
21) Backwash Supply Tank	1			4500.00	600.00			4500	600		5100	3000 gallon
22) Filtrate Recycle Pump	2			1600.00	300.00			3200	600		3800	
23) Carbon Adsorption	1			20000.00	2000.00	2000.00		20000	2000	2000	24000	
24) Carbon Adsorption Transfer Pump	2			2500.00	400.00			5000	800		5800	56 gpm @ 50' tdh
25) Air Stripper Tower incl. Packing, Blower	1			25000.00	2500.00	1000.00		25000	2500	1000	28500	2' dia.
26) Air Compressor	1			5000.00	1000.00			5000	1000		6000	
27) Air Dryer	1			4000.00	300.00			4000	300		4300	
							333600	396050	52450	9500	791600	
PIPING & INSTRUMENTATION												
1) Extraction Wells To Equalization Tank												
a) Well Piping - 1"	2085	LF		6.50	3.50			13553	7298		20850	
b) Collection Piping - 2"	11800	LF		2.00	3.80			23600	44840		68440	
c) Excavation, Backfill, Compaction	11800				2.66	1.82			31388	21476	52864	
d) Pipe Bedding	11800	LF			1.12	1.55			13216	18290	31506	
e) Revegetation	118	MSF		50.00	11.00	9.00		5900	1298	1062	8260	
2) System Interconnection Piping												
a) 1-1/2"	200			9.75	5.25			1950	1050		3000	
b) 2"	400			13.00	7.00			5200	2800		8000	
3) Polymer Piping - 1/2"	100	LF		3.25	1.75			325	175		500	
4) Lime Piping - 1-1/2"	100	LF		9.75	5.25			975	525		1500	

NAVAL AIR WARFARE CENTER
Warminster, Pennsylvania
Groundwater Treatment System
Discharge To Surface Water
Alternate No. GW-2

(NAGTSGW2)

Item	Qty	Unit	Unit Cost Sub.	Unit Cost Mat.	Unit Cost Labor	Unit Cost Equip.	Total Cost Sub.	Total Cost Mat.	Total Cost Labor	Total Cost Equip.	Total Direct Cost	Comments
PIPING & INSTRUMENTATION												
5) Air Piping												
a) 1-1/2"	200			9.75	5.25			1950	1050		3000	
6) Service Water Piping - 1-1/2"	100			9.75	5.25			975	525		1500	
7) Valves												
a) 1/2"	6			60.00	30.00			360	180		540	
b) 1"	50			80.00	35.00			4000	1750		5750	
c) 1-1/2"	6			150.00	50.00			900	300		1200	
d) 2"	48			200.00	60.00			9600	2880		12480	
8) PH Control System	1			8000.00	2500.00			8000	2500		10500	
9) Level Control System	5			2500.00	1000.00			12500	5000		17500	
10) Flow Control System	1			7500.00	2500.00			7500	2500		10000	
							0	97288	119275	40828	257390	
FOUNDATION & STRUCTURAL												
1) Treatment Building	2400	SF	40.00				96000				96000	40' x 60'
2) Treatment Building Foundation	130	CY		135.00	250.00	15.00		17550	32500	1950	52000	
							96000	17550	32500	1950	148000	
ELECTRICAL												
1) Power Supply		LS	10000.00				10000				10000	
2) Well Pump Feeder Cable	11800	LF		3.00	4.50			35400	53100		88500	
3) Starters #1	51			1350.00	550.00			68850	28050		96900	
4) Disconnect Switch	51			200.00	75.00			10200	3825		14025	
5) Conduit, Cable, Control #1	51			655.00	735.00			33405	37485		70890	
6) Grounding		LS		12750.00	12750.00			12750	12750		25500	
7) Miscellaneous Wiring		LS		25500.00	25500.00			25500	25500		51000	
8) Instrumentation		LS		7500.00	7500.00			7500	7500		15000	
9) Lighting		LS		4000.00	4000.00			4000	4000		8000	
							10000	197605	172210	0	379815	

NAVAL AIR WARFARE CENTER
Warminster, Pennsylvania
Groundwater Treatment System
Discharge To Surface Water
Alternate GW-2
(O&MNAGW2) 1/20/93

Annual Costs

ITEM	ITEM $ QUARTERLY SAMPLING	NOTES
1. Sampling	16000.00	20 groundwater samples 80 manhours per sampling period. (quarterly) plus travel, living & shipping costs.
2. Analysis	162000.00	24 groundwater samples, per sampling period. (inc. blank & duplicate) Metals, VOCs, SVOCs
3. Reporting	4000.00	20 manhours per report plus other direct costs
4. NPDES Analysis	90000.00	2 samples per week Metals, VOCs, SVOCs
5. NPDES Reporting	10400.00	4 manhours per report
TOTAL ANNUAL COST	282400.00	Post Remedial monitoring will be performed quarterly for years 1 thru 30

NAVAL AIR WARFARE CENTER
Warminster, Pennsylvania
Groundwater Treatment System
Discharge To Surface Water
Alternate No. GW-2
(O&MNGW2a) 1/20/93

Annual Costs - (24 hr/day - 365 days/year)

ITEM	QTY	UNIT	UNIT$	ITEM $	NOTES
1. Energy					
a. Electric	426235	Kw-hr	.085	$36230	Treatment Plant
2. Maintenance				$55900	3% of Capital C
3. Operator	1	EA.	40000.00	$40000	8 hrs/day-5 day
4. Chemical					
a. Lime	49	TON	80.00	$3920	
b. Polymer	125	LB	2.00	$250	
5. Activated Carbon	136000	LB	1.50	$204000	
6. Sludge Disposal					
a. Hauling & Disposal	128	TON	42.00	$5376	
TOTAL ANNUAL COSTS				$345676	

NAVAL AIR WARFARE CENTER
Warminster, Pennsylvania
Groundwater Treatment System
Discharge To Surface Water
Alternate No. GW-2
(PWANGW2) 1/20/93
13172

PRESENT WORTH ANALYSIS

COST/YEAR COST OCCURS ($000'S)

COST COMPONENT	0	1	2	3	4	5	6	7	8	9	10	11
1. CAPITAL COST	3515.2											
2. O & M COSTS		628.1										
3. ANNUAL COSTS	3515.2	628.1	628.1	628.1	628.1	628.1	628.1	628.1	628.1	628.1	628.1	628.1
4. ANNUAL DISCOUNT RATE=5%	1	.952	.907	.864	.823	.784	.746	.711	.677	.645	.614	.585
PRESENT WORTH =	3515	598	570	543	517	492	469	447	425	405	386	367

	12	13	14	15	16	17	18	19	20	21	22	23
O & M COSTS	628.1	628.1	628.1	628.1	628.1	628.1	628.1	628.1	628.1	628.1	628.1	628.1
ANNUAL DISCOUNT RATE=5%	.557	.53	.505	.481	.458	.436	.416	.396	.377	.359	.342	.326
PRESENT WORTH =	350	333	317	302	288	274	261	249	237	225	215	205

	24	25	26	27	28	29	30	TOTAL PRESENT WORTH (000'S)
O & M COSTS	628.1	628.1	628.1	628.1	628.1	628.1	628.1	
ANNUAL DISCOUNT RATE=5%	.31	.295	.281	.268	.255	.243	.231	
PRESENT WORTH =	195	185	176	168	160	153	145	13172