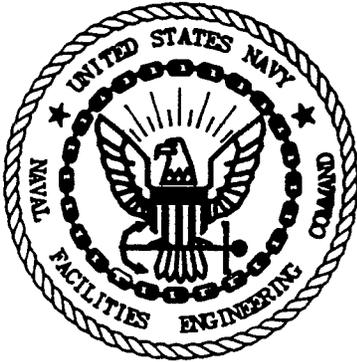


N61165.AR.004967
CNC CHARLESTON
5090.3a

ZONE C RCRA FACILITY INVESTIGATION (RFI) REPORT VOLUME I SECTIONS 1
THROUGH 9 CNC CHARLESTON SC
11/14/1997
ENSAFE INC

**ZONE C
RCRA FACILITY
INVESTIGATION REPORT
NAVBASE CHARLESTON**

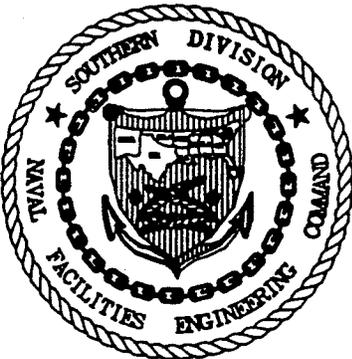


**VOLUME I
SECTIONS 1-9**

**CONTRACT N62467-89-D-0318
CTO-029**

Prepared for:

**Comprehensive Long-Term Environmental Action Navy
(CLEAN)
Charleston Naval Shipyard
Charleston, South Carolina**



Prepared by:

**EnSafe Inc.
5724 Summer Trees Drive
Memphis, Tennessee 38134
(901)372-7962**

**November 14, 1997
Revision: 0**



ENSAFE INC.

ENVIRONMENTAL AND MANAGEMENT CONSULTANTS

5724 Summer Trees Drive • Memphis, Tennessee 38134 • Telephone 901-372-7962 • Facsimile 901-372-2454 • www.ensafe.com

April 10, 1998

U.S. Environmental Protection Agency
Attn: Dann J. Spariosu
Atlanta Federal Center
51 Forsyth Street
Atlanta, Georgia 30303-3104

Re: Zone C RCRA Facility Investigation Report Addendum
AOC 522, NAVBASE Charleston
Contract # N62467-89-D-0318/2903

Dear Mr. Spariosu:

On behalf of the Navy, EnSafe Inc. is pleased to submit one copy of the Zone C RCRA Facility Investigation Report Addendum, AOC 522, NAVBASE Charleston in Charleston, South Carolina. If you should have any questions or need any additional information regarding the document, please do not hesitate to call me.

Sincerely,

EnSafe Inc.

Allison L. Dennen
Project Geologist

Enclosure

cc: Tony Hunt, Code 1877 SOUTHNAVFACENGCOM without enclosure
Daryle Fontenot, Code 18B1 SOUTHNAVFACENGCOM without enclosure
Reece Batten, Code 1876 SOUTHNAVFACENGCOM without enclosure
EnSafe Inc. file without enclosure
Todd Haverkost, EnSafe Inc. Charleston without enclosure
EnSafe Inc. Library without enclosure



ENSAFE INC.

ENVIRONMENTAL AND MANAGEMENT CONSULTANTS

5724 Summer Trees Drive • Memphis, Tennessee 38134 • Telephone 901-372-7962 • Facsimile 901-372-2454 • www.ensafe.com

April 20, 1998

Commanding Officer
Attn: Mr. Tony Hunt, Code 1877
SOUTHNAVFACENGCOM
P.O. Box 190010
North Charleston, South Carolina 29419-9010

Subject: Delivery of Report
CTO-2903, Zone C

Reference: Contract # N62467-89-D-0318, CLEAN II

Dear Mr. Hunt:

EnSafe Inc. is pleased to submit one copy of the Zone C RCRA Facility Investigation Report Addendum, AOC 522. If you should have any questions or need any additional information regarding the document, please do not hesitate to call me.

Sincerely,

EnSafe Inc.

Allison L. Dennen
Project Geologist

Enclosure: Zone C RCRA Facility Investigation Report Addendum, AOC 522, NAVBASE Charleston

cc: Daryle Fontenot, Code 18B1 SOUTHNAVFACENGCOM - 1 copy
Reece Batten, Code 1876 SOUTHNAVFACENGCOM - 1 copy
Ms. Kimberly Reavis, Code 0233KR SOUTHNAVFACENGCOM without enclosure
EnSafe Inc. CTO 2903 file without enclosure
Todd Haverkost, EnSafe Inc. Charleston file - 1 copy
EnSafe Inc. Library - 1 copy
EnSafe Inc. file - 1 copy

Zone C RCRA Facility Investigation Report Addendum
AOC 522

Introduction

AOC 522 is the site of former Building 1252, a grease and wash building, located at the southeast corner of Building 198, near the loading docks. Soil was the only medium sampled during the RFI and no chemicals of concern were identified. Methylene chloride was detected in the subsurface and exceeded its soil screening level at three locations. As a result of questions raised by the project team, additional sampling was performed to investigate the potential for methylene chloride to impact the groundwater.

Method

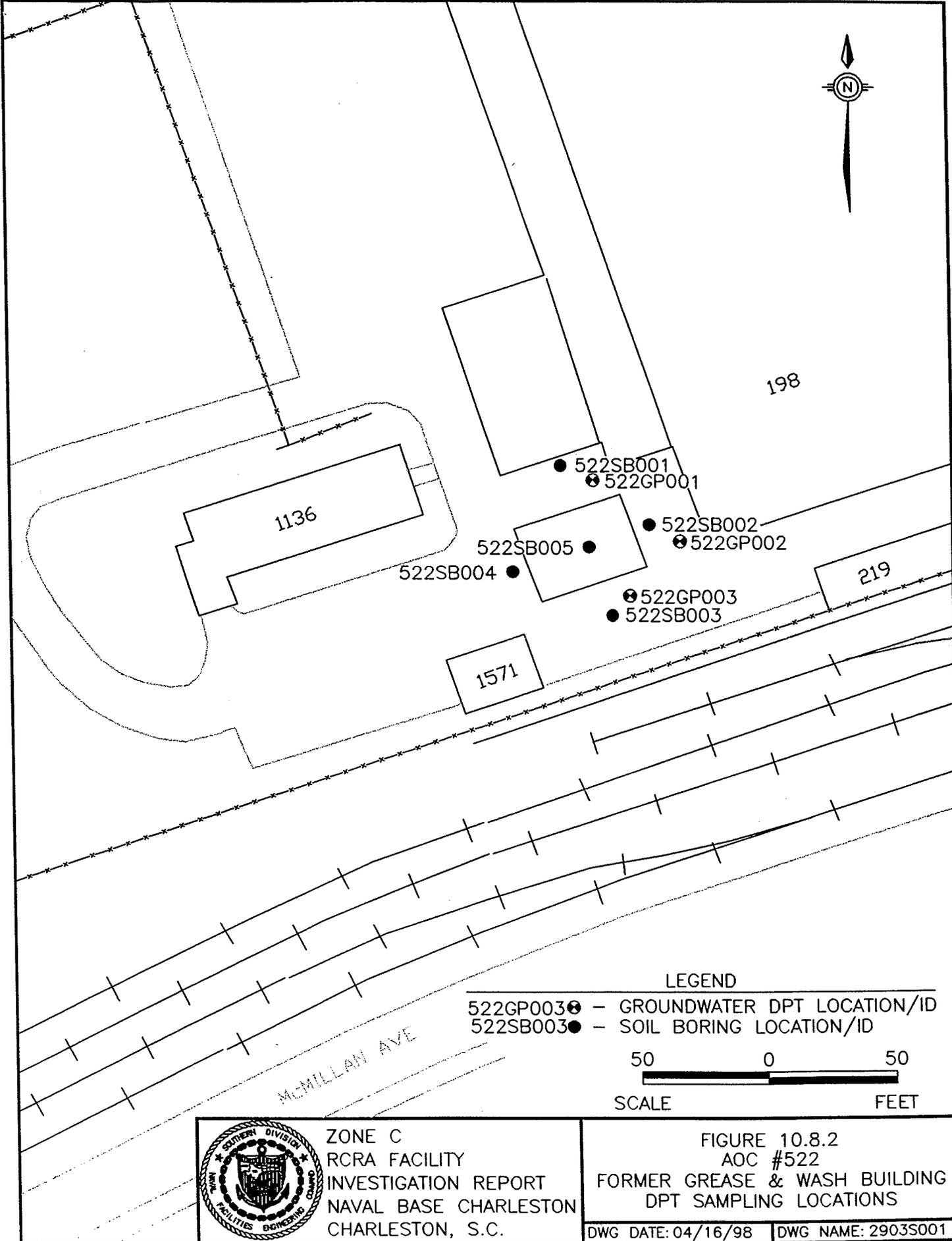
Three direct point technology (DPT) points were advanced to collect groundwater samples for VOC analysis to confirm the presence or absence of methylene chloride in groundwater. The DPT sampling locations are shown on Figure 10.8.2. Two groundwater samples were collected at each location. The first sample interval (522GP00101) was from the 5-8 ft below ground surface (bgs) depth and the second sample interval (522GP00102) was from the 15-18 ft bgs depth.

Analytical Results

All groundwater samples were submitted for volatile organic compound (VOC) analysis at Data Quality Objective Level III. VOCs were not detected in any of the groundwater samples. Analytical results are presented in Attachment 1.

Recommendations and Conclusion

VOCs were not detected in the DPT groundwater samples collected at AOC 522 indicating that the methylene chloride concentrations in soil are sufficiently low to protect groundwater. Therefore, AOC 522 is recommended for no further action.



198

1136

1571

219

● 522SB001
⊕ 522GP001

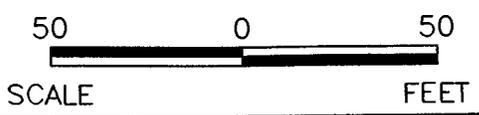
● 522SB002
⊕ 522GP002

● 522SB005
● 522SB004

⊕ 522GP003
● 522SB003

LEGEND

- 522GP003⊕ - GROUNDWATER DPT LOCATION/ID
- 522SB003● - SOIL BORING LOCATION/ID



ZONE C
RCRA FACILITY
INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.

FIGURE 10.8.2
AOC #522
FORMER GREASE & WASH BUILDING
DPT SAMPLING LOCATIONS

DWG DATE: 04/16/98 DWG NAME: 2903S001

Attachment 1
AOC 522 DPT Analytical Results

CHARLESTON - ZONE C
CHARLESTON ZONE C - QUARTERLY SAMPLING
AOC 522 - Groundwater Screening Data

SW846-VOA		SAMPLE ID -----> 522-G-P001-01	522-G-P001-02	522-G-P002-01	522-G-P002-02	522-G-P003-01	522-G-P003-02
	ORIGINAL ID ----->	522GP00101	522GP00102	522GP00201	522GP00202	522GP00301	522GP00302
	LAB SAMPLE ID ---->	32604.05	32604.06	32604.03	32604.04	32604.01	32604.02
	ID FROM REPORT -->	522GP00101	522GP00102	522GP00201	522GP00202	522GP00301	522GP00302
	SAMPLE DATE ----->	01/26/98	01/26/98	01/26/98	01/26/98	01/26/98	01/26/98
	DATE ANALYZED ---->	02/02/98	02/02/98	02/02/98	02/02/98	02/02/98	02/02/98
	MATRIX ----->	Water	Water	Water	Water	Water	Water
	UNITS ----->	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L
CAS #	Parameter	32604	32604	32604	32604	32604	32604
74-87-3	Chloromethane	5. U	5. U	5. U	5. U	5. U	5. U
74-83-9	Bromomethane	5. U	5. U	5. U	5. U	5. U	5. U
75-01-4	Vinyl chloride	5. U	5. U	5. U	5. U	5. U	5. U
75-00-3	Chloroethane	5. U	5. U	5. U	5. U	5. U	5. U
75-09-2	Methylene chloride	5. U	5. U	5. U	5. U	5. U	5. U
67-64-1	Acetone	5. U	5. U	5. U	5. U	5. U	5. U
75-15-0	Carbon disulfide	5. U	5. U	5. U	5. U	5. U	5. U
75-35-4	1,1-Dichloroethene	5. U	5. U	5. U	5. U	5. U	5. U
75-34-3	1,1-Dichloroethane	5. U	5. U	5. U	5. U	5. U	5. U
540-59-0	1,2-Dichloroethene (total)	5. U	5. U	5. U	5. U	5. U	5. U
67-66-3	Chloroform	5. U	5. U	5. U	5. U	5. U	5. U
107-06-2	1,2-Dichloroethane	5. U	5. U	5. U	5. U	5. U	5. U
78-93-3	2-Butanone (MEK)	5. U	5. U	5. U	5. U	5. U	5. U
71-55-6	1,1,1-Trichloroethane	5. U	5. U	5. U	5. U	5. U	5. U
56-23-5	Carbon tetrachloride	5. U	5. U	5. U	5. U	5. U	5. U
108-05-4	Vinyl acetate	5. U	5. U	5. U	5. U	5. U	5. U
75-27-4	Bromodichloromethane	5. U	5. U	5. U	5. U	5. U	5. U
79-34-5	1,1,2,2-Tetrachloroethane	5. U	5. U	5. U	5. U	5. U	5. U
78-87-5	1,2-Dichloropropane	5. U	5. U	5. U	5. U	5. U	5. U
10061-02-6	trans-1,3-Dichloropropene	5. U	5. U	5. U	5. U	5. U	5. U
79-01-6	Trichloroethene	5. U	5. U	5. U	5. U	5. U	5. U
124-48-1	Dibromochloromethane	5. U	5. U	5. U	5. U	5. U	5. U
79-00-5	1,1,2-Trichloroethane	5. U	5. U	5. U	5. U	5. U	5. U
71-43-2	Benzene	5. U	5. U	5. U	5. U	5. U	5. U
10061-01-5	cis-1,3-Dichloropropene	5. U	5. U	5. U	5. U	5. U	5. U
110-75-8	2-Chloroethyl vinyl ether	5. U	5. U	5. U	5. U	5. U	5. U
75-25-2	Bromoform	5. U	5. U	5. U	5. U	5. U	5. U
591-78-6	2-Hexanone	5. U	5. U	5. U	5. U	5. U	5. U
108-10-1	4-Methyl-2-Pentanone (MIBK)	5. U	5. U	5. U	5. U	5. U	5. U
127-18-4	Tetrachloroethene	5. U	5. U	5. U	5. U	5. U	5. U
108-88-3	Toluene	5. U	5. U	5. U	5. U	5. U	5. U
108-90-7	Chlorobenzene	5. U	5. U	5. U	5. U	5. U	5. U
100-41-4	Ethylbenzene	5. U	5. U	5. U	5. U	5. U	5. U
100-42-5	Styrene	5. U	5. U	5. U	5. U	5. U	5. U
1330-20-7	Xylene (Total)	5. U	5. U	5. U	5. U	5. U	5. U
1634-04-4	Methyl tert-butyl ether	NR	NR	NR	NR	NR	NR



DEPARTMENT OF THE NAVY

SOUTHERN DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
P.O. BOX 190010
2155 EAGLE DRIVE
NORTH CHARLESTON, S.C. 29419-9010

5090/11
Code 1877
13 November 1997

Mr. John Litton, P.E.
Director, Division of Hazardous and Infectious Waste Management
Bureau of Land and Waste Management
South Carolina Department of Health and Environmental Control
2600 Bull Street
Columbia, SC 29201

Subj: ZONE C RCRA FACILITY INVESTIGATION REPORT CORRECTIONS AND
RESPONSE TO COMMENTS

Dear Mr. Litton:

The purpose of this letter is to submit the Zone C Draft Final RCRA Facility Investigation report for Naval Base Charleston. The Report is submitted to fulfill the requirements of condition IV.B.2 of the RCRA Part B permit issued to the Navy by the South Carolina Department of Health and Environmental Control and U.S. Environmental Protection Agency.

Comments made by the Department and the EPA on the January 1996 submittal have been addressed and included in this submittal. We request that the Department and the EPA review the report and provide comment or approval as appropriate. If you should have any questions, please contact Billy Drawdy or Matthew Hunt at (803) 743-9985 and (803) 820-5525 respectively.

Sincerely,

A handwritten signature in black ink, appearing to read "P. M. Rose".

P. M. ROSE
LCDR, CEC, U.S. Navy
Caretaker Site Officer
By direction

Encl: (1) Zone C Draft Final RFI Report, dated 13 November 1997

Copy to:

SCDHEC (Paul Bergstrand, Johnny Tapia)

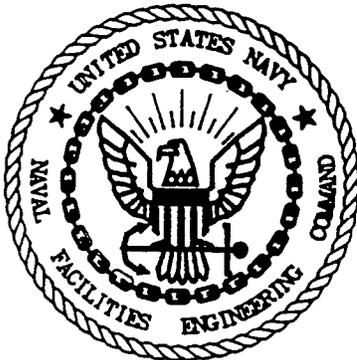
USEPA (Dann Spariosu)

SOUTHDIV (Matthew Hunt)

CSO Naval Base Charleston (Billy Drawdy, Daryle Fontenot)

SPORTENVDETCASN (Bobby Dearhart)

**COMPREHENSIVE LONG-TERM
ENVIRONMENTAL ACTION NAVY
NAVAL BASE CHARLESTON
CHARLESTON, SOUTH CAROLINA
CTO-029**



**ZONE C
RCRA FACILITY INVESTIGATION REPORT
NAVBASE CHARLESTON**

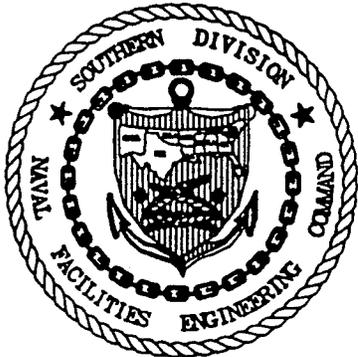
Prepared for:

**Department of the Navy
Southern Division
Naval Facilities Engineering Command
Charleston, South Carolina**

**SOUTHDIV Contract Number:
N62467-89-D-0318**

Prepared by:

**EnSafe Inc.
5724 Summer Trees Drive
Memphis, Tennessee 38134
(901) 372-7962**



The Contractor, EnSafe/Allen & Hoshall, hereby certifies that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. N62467-89-D-0318 is complete, accurate, and complies with all requirements of the contract.

Date

11/13/97

Signature

Todd Haverkost P.C.

Name:

Todd Haverkost

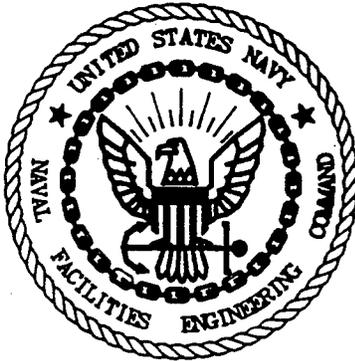
Title:

Task Order Manager

November 14, 1997

Revision: 0

**ZONE C
RCRA FACILITY
INVESTIGATION REPORT
NAVBASE CHARLESTON**

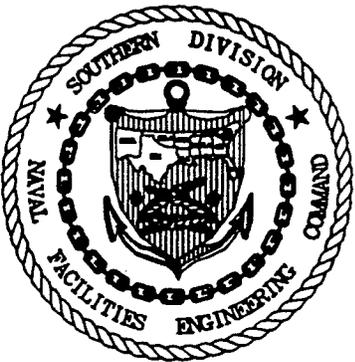


**VOLUME I
SECTIONS 1-9**

**CONTRACT N62467-89-D-0318
CTO-029**

Prepared for:

**Comprehensive Long-Term Environmental Action Navy
(CLEAN)
Charleston Naval Shipyard
Charleston, South Carolina**



Prepared by:

**EnSafe Inc.
5724 Summer Trees Drive
Memphis, Tennessee 38134
(901)372-7962**

**November 14, 1997
Revision: 0**

Table of Contents

ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C	A.1
1.0 INTRODUCTION	1.1
1.1 NAVBASE Description and Background	1.1
1.2 Base Closure Process for Environmental Cleanup	1.5
1.3 Investigative Zone Delineation	1.7
1.4 Current Investigation	1.9
1.5 Previous Investigations	1.10
1.6 RFI Report Organization	1.13
2.0 NAVBASE PHYSICAL SETTING	2.1
2.1 Geology	2.1
2.1.1 Regional Physiographic and Geologic Description	2.1
2.1.2 NAVBASE Geologic Investigation	2.2
2.1.3 Ashley Formation (Ta)	2.6
2.1.4 Quaternary-Age Sediments	2.9
2.1.5 Soil	2.11
2.2 NAVBASE Hydrogeology	2.11
2.2.1 Regional Hydrologic and Hydrogeologic Background	2.11
2.2.2 NAVBASE Hydrogeologic Investigation	2.12
2.2.3 Lower Confining Unit	2.12
2.2.4 Surficial Aquifer	2.13
2.2.5 Groundwater Flow Direction	2.14
2.2.6 Vertical Hydraulic Gradient	2.16
2.2.7 Horizontal Hydraulic Gradient	2.18
2.2.8 Hydraulic Conductivity (K_h)	2.19
2.2.9 Horizontal Groundwater Velocity	2.21
2.3 Climate	2.23
3.0 FIELD INVESTIGATION	3.1
3.1 Investigation Objectives	3.1
3.2 Sampling Procedures, Protocols, and Analyses	3.1
3.2.1 Sample Identification	3.1
3.2.2 Soil Sampling	3.2
3.2.2.1 Soil Sample Locations	3.2
3.2.2.2 Soil Sample Collection	3.3
3.2.2.3 Soil Sample Preparation, Packaging, and Shipment	3.3
3.2.2.4 Soil Sample Analysis	3.4
3.2.3 Monitoring Well Installation and Development	3.6
3.2.3.1 Shallow Monitoring Well Installation	3.6
3.2.3.2 Deep Monitoring Well Installation	3.7
3.2.3.3 Monitoring Well Protector Construction	3.8
3.2.3.4 Monitoring Well Development	3.10

3.2.4	Groundwater Sampling	3.11
3.2.4.1	Groundwater Sampling Locations	3.11
3.2.4.2	Groundwater Sample Collection	3.11
3.2.4.3	Groundwater Sample Preparation, Packaging, and Shipment	3.13
3.2.4.4	Groundwater Sample Analysis	3.14
3.2.5	Sediment and Surface Water Sampling	3.16
3.2.5.1	Sediment and Surface Water Sample Locations	3.16
3.2.5.2	Sediment and Surface Water Sample Collection	3.16
3.2.5.3	Sediment and Surface Water Sample Preparation, Packaging, and Shipment	3.17
3.2.5.4	Sediment and Surface Water Sample Analysis	3.18
3.2.6	Wipe Sampling	3.19
3.2.6.1	Wipe Sampling Locations	3.19
3.2.6.2	Wipe Sample Collection	3.19
3.2.6.3	Wipe Sample Preparation, Packaging, and Shipment	3.20
3.2.6.4	Wipe Sample Analysis	3.20
3.2.7	Vertical and Horizontal Surveying	3.20
3.2.8	Aquifer Characterization	3.20
3.2.9	Decontamination Procedures	3.21
3.2.9.1	Decontamination Area Setup	3.22
3.2.9.2	Cross-Contamination Prevention	3.22
3.2.9.3	Nonsampling Equipment	3.22
3.2.9.4	Sampling Equipment	3.23
4.0	DATA VALIDATION	4.1
4.1	Introduction	4.1
4.2	Validation Summary	4.3
4.2.1	Organic Evaluation Criteria	4.5
4.2.1.1	Holding Times	4.7
4.2.1.2	GC/MS Instrument Performance Checks	4.7
4.2.1.3	Surrogate Spike Recoveries	4.8
4.2.1.4	Instrument Calibration	4.8
4.2.1.5	Matrix Spike/Matrix Spike Duplicate (MS/MSD)	4.10
4.2.1.6	Laboratory Control Samples and Laboratory Duplicates	4.11
4.2.1.7	Blank Analysis	4.11
4.2.1.8	Field-Derived Blanks	4.12
4.2.1.9	Internal Standard Performance	4.13
4.2.1.10	Diluted Samples	4.14
4.2.2	Inorganic Evaluation Criteria	4.14
4.2.2.1	Holding Times	4.16
4.2.2.2	Instrument Calibration	4.16
4.2.2.3	Blank Analysis	4.17

	4.2.2.4	ICAP Interference Check Samples	4.17
	4.2.2.5	Laboratory Control Samples (LCS)	4.18
	4.2.2.6	Spike Sample Analysis	4.18
	4.2.2.7	Laboratory Duplicates	4.18
	4.2.2.8	Inductively Coupled Argon Plasma Serial Dilutions	4.18
	4.2.2.9	Atomic Absorption (AA) Duplicate Injections and Post-Digestion Spike Recoveries	4.19
4.3		Zone C Data Validation Reports	4.19
5.0		DATA EVALUATION AND BACKGROUND COMPARISON	5.1
5.1		Organic Compound Analytical Results Evaluation	5.1
5.2		Inorganic Analytical Results Evaluation	5.2
	5.2.1	Grid-Based Background Datasets	5.4
	5.2.2	Nondetect Data	5.7
	5.2.3	Developing Datasets for Sites	5.7
	5.2.4	Comparing Site Values to Background	5.7
	5.2.5	Tolerance-Interval or Reference Concentration Test	5.10
	5.2.6	Wilcoxon Rank Sum Test	5.12
	5.2.7	Summary of Statistical Techniques Used	5.14
	5.2.8	Combined results of the UTL (Reference Concentration) and the Wilcoxon Rank Sum Tests	5.14
	5.2.9	Conclusion	5.14
6.0		FATE AND TRANSPORT	6.1
6.1		Properties Affecting Fate and Transport	6.2
	6.1.1	Chemical and Physical Properties Affecting Fate and Transport	6.2
	6.1.2	Media Properties Affecting Fate and Transport	6.10
6.2		Fate and Transport Approach for Zone C	6.13
	6.2.1	Soil-to-Groundwater Cross Media Transport	6.14
	6.2.2	Groundwater-to-Surface Water Cross Media Transport	6.16
	6.2.3	Soil-to-Air Cross-Media Transport	6.18
	6.2.4	Surface Soil-to-Sediment Cross-Media Transport	6.19
7.0		HUMAN HEALTH RISK ASSESSMENT	7.1
7.1		Introduction	7.1
7.2		Objectives	7.3
7.3		Site Characterization	7.5
	7.3.1	Data Sources	7.6
	7.3.2	Data Validation	7.6
	7.3.3	Management of Site-Related Data	7.7
	7.3.4	Selection of Chemicals of Potential Concern	7.9
	7.3.4.1	Comparison of Site-Related Data to Risk-Based Screening Concentrations	7.10

7.3.4.2	Comparison of Site-Related Data to Background Concentrations	7.11
7.3.4.3	Elimination of Essential Elements: Calcium, Iron, Magnesium, Potassium, and Sodium	7.13
7.3.4.4	Summary of COPCs	7.13
7.3.5	Calculation of Risk and Hazard	7.14
7.3.6	Exposure Assessment	7.14
7.3.6.1	Exposure Setting and Land Use	7.15
7.3.6.2	Potentially Exposed Populations	7.15
7.3.6.3	Exposure Pathways	7.16
7.3.6.4	Exposure Point Concentrations	7.16
7.3.6.5	Quantification of Exposure	7.18
7.3.7	Toxicity Assessment	7.28
7.3.7.1	Carcinogenicity and Noncancer Effects	7.28
7.3.7.2	Toxicity Profiles for COPCs	7.29
7.3.8	Risk Characterization	7.30
7.3.8.1	Surface Soil Pathways	7.34
7.3.8.2	Groundwater Pathways	7.34
7.3.8.3	Other Applicable Pathways	7.34
7.3.8.4	COCs Identified	7.34
7.3.8.5	Risk/Hazard Maps	7.35
7.3.9	Risk Uncertainty	7.36
7.3.9.1	General	7.36
7.3.9.2	Quality of Data	7.38
7.3.9.3	Identification of COPCs	7.39
7.3.9.4	Characterization of Exposure Setting and Identification of Exposure Pathways	7.41
7.3.9.5	Toxicity Assessment Information	7.45
7.3.9.6	Quantification of Risk/Hazard	7.46
7.3.9.7	Mapping Risk/Hazard	7.47
7.3.10	Risk Summary	7.49
7.3.11	Remedial Goal Options	7.49
7.4	Site-Specific Human Health Risk Assessments	7.50
8.0	ECOLOGICAL RISK ASSESSMENT	8.1
8.1	Zone Rationale	8.1
8.2	Problem Formulation	8.5
8.3	Conceptual Model	8.9
8.4	Selection of Ecological Chemicals of Potential Concern	8.9
8.5	Contaminant Fate and Transport	8.19
8.6	Exposure Pathways and Assessment	8.19
8.7	Ecological Effects Assessment	8.22
8.8	Risk Characterization	8.30
8.8.1	Infaunal Invertebrates	8.30

8.8.2	Terrestrial Wildlife	8.34
8.8.3	Vegetation	8.49
8.8.4	Aquatic Wildlife	8.52
8.9	Uncertainty	8.53
8.10	Risk Summary	8.54
9.0	CORRECTIVE MEASURES	9.1
9.1	Introduction	9.1
9.2	Remedy Selection Approach	9.6
9.3	Proposed Remedy	9.7
9.4	Development of Target Media Cleanup Goals	9.7
9.4.1	Groundwater Cleanup Goals	9.7
9.4.2	Soil Cleanup Goals	9.8
9.4.3	Surface Water and Sediment Cleanup Goals	9.9
9.4.4	Air Cleanup Goals	9.11
9.5	Identification, Screening, and Development of Corrective Measures Technologies	9.12
9.5.1	Identification of Corrective Measure Technologies	9.12
9.5.2	Description of Pre-screened Technologies	9.17
9.5.3	Screening Criteria	9.21
9.6	Identification of Corrective Measure Alternatives	9.22
9.7	Evaluation of Corrective Measure Alternatives	9.23
9.7.1	Protect Human Health and the Environment	9.23
9.7.2	Attain Media Cleanup Standards Set by the Implementing Agency	9.24
9.7.3	Control the Sources of Releases	9.24
9.7.4	Comply with Any Applicable Standards for Management of Wastes	9.25
9.7.5	Other Factors	9.25
9.8	Ranking the Corrective Measures Alternatives	9.28
10.0	SITE-SPECIFIC EVALUATIONS	10.1
10.1	SWMU 44 – Coal Storage Area	10.1.1
10.1.1	Soil Sampling and Analysis at SWMU 44	10.1.3
10.1.2	Nature and Extent of Soil Contamination at SWMU 44	10.1.4
10.1.3	Groundwater Sampling and Analysis at SWMU 44	10.1.9
10.1.4	Nature and Extent of Groundwater Contamination at SWMU 44	10.1.11
10.1.5	Sediment Sampling and Analysis	10.1.14
10.1.6	Nature and Extent of Sediment Contamination	10.1.14
10.1.7	Surface Water Sampling and Analysis	10.1.17
10.1.8	Nature and Extent of Surface Water Contamination	10.1.19
10.1.9	Fate and Transport Assessment	10.1.19
10.1.9.1	Soil-to-Groundwater Cross-Media Transport	10.1.19

	10.1.9.2	Groundwater-to-Surface Water Cross-Media Transport	10.1.25
	10.1.9.3	Soil-to-Air Cross-Media Transport	10.1.26
	10.1.9.4	Surface Soil-to-Sediment Cross-Media Transport	10.1.26
	10.1.9.5	Fate and Transport Summary	10.1.26
10.1.10		Human Health Risk Assessment	10.1.29
	10.1.10.1	Site Background and Investigative Approach	10.1.29
	10.1.10.2	COPC Identification	10.1.34
	10.1.10.3	Exposure Assessment	10.1.42
	10.1.10.4	Toxicity Assessment	10.1.61
	10.1.10.5	Risk Characterization	10.1.74
	10.1.10.6	Risk Uncertainty	10.1.96
	10.1.10.7	Risk Summary	10.1.103
	10.1.10.8	Remedial Goal Options	10.1.103
10.1.11		Interim Measure	10.1.110
10.1.12		Corrective Measures Considerations for SWMU 44	10.1.118
10.2		SWMU 47 — Former Burning Dump and AOC 516 — Wash Area/Battery Charging	10.2.1
	10.2.1	Soil Sampling and Analysis	10.2.1
	10.2.2	Nature and Extent of Soil Contaminants	10.2.4
	10.2.3	Groundwater Sampling and Analysis	10.2.12
	10.2.4	Nature and Extent of Groundwater Contamination	10.2.12
	10.2.5	Fate and Transport Assessment	10.2.17
	10.2.5.1	Soil to Groundwater Cross Media Transport	10.2.18
	10.2.5.2	Groundwater-to-Surface Water Cross-Media Transport	10.2.21
	10.2.5.3	Soil-to-Air Cross Media Transport	10.2.22
	10.2.5.4	Fate and Transport Summary	10.2.22
10.2.6		Human Health Risk Assessment	10.2.22
	10.2.6.1	Site Background and Investigative Approach	10.2.22
	10.2.6.2	COPC Identification	10.2.25
	10.2.6.3	Exposure Assessment	10.2.35
	10.2.6.4	Toxicity Assessment	10.2.41
	10.2.6.5	Risk Characterization	10.2.53
	10.2.6.6	Risk Uncertainty	10.2.64
	10.2.6.7	Risk Summary	10.2.69
	10.2.6.8	Remedial Goal Options	10.2.69
10.3		AOC 508 — Former Incinerator, and AOC 511 — Former Oil Storage House	10.3.1
	10.3.1	Soil Sampling and Analysis	10.3.1
	10.3.2	Nature and Extent of Soil Contamination	10.3.4
	10.3.3	Groundwater Sampling and Analysis	10.3.10
	10.3.4	Fate and Transport Assessment	10.3.11
	10.3.4.1	Soil-to-Groundwater Cross-Media Transport	10.3.11

	10.3.4.2	Soil-to-Air Cross-Media Transport	10.3.15
	10.3.4.3	Fate and Transport Summary	10.3.15
10.3.5		Human Health Risk Assessment for	10.3.15
	10.3.5.1	Site Background and Investigative Approach	10.3.15
	10.3.5.2	COPC Identification	10.3.18
	10.3.5.3	Exposure Assessment	10.3.23
	10.3.5.4	Toxicity Assessment	10.3.27
	10.3.5.5	Risk Characterization	10.3.36
	10.3.5.6	Risk Uncertainty	10.3.40
	10.3.5.7	Risk Summary	10.3.46
	10.3.5.8	Remedial Goal Options	10.3.46
10.3.6		Corrective Measures Considerations for AOCs 508 and 511	10.3.46
10.4		AOC 515 — Former Incinerator and AOC 519 — Former Boiler House	10.4.1
	10.4.1	Soil Sampling and Analysis	10.4.1
	10.4.2	Nature and Extent of Soil Contamination	10.4.3
	10.4.3	Fate and Transport of Contaminants	10.4.10
	10.4.3.1	Soil-to-Groundwater Cross-Media Transport	10.4.11
	10.4.3.2	Soil-to-Air Cross Media Transport	10.4.11
	10.4.4	Human Health Risk Assessment	10.4.15
	10.4.4.1	Site Background and Investigative Approach	10.4.15
	10.4.4.2	COPC Identification	10.4.15
	10.4.4.3	Exposure Assessment	10.4.19
	10.4.4.4	Toxicity Assessment	10.4.24
	10.4.4.5	Risk Characterization	10.4.29
	10.4.4.6	Risk Uncertainty	10.4.33
	10.4.4.7	Risk Summary	10.4.36
	10.4.4.8	Remedial Goal Options	10.4.36
10.4.5		Corrective Measures Considerations	10.4.36
10.5		AOC 523 — Former Gas Station	10.5.1
	10.5.1	Soil Sampling and Analysis	10.5.1
	10.5.2	Nature and Extent of Soil Contamination	10.5.3
	10.5.3	Groundwater Sampling and Analysis	10.5.8
	10.5.4	Nature and Extent of Groundwater Contamination	10.5.10
	10.5.5	Fate and Transport Assessment	10.5.13
	10.5.5.1	Soil-to-Groundwater Cross-Media Transport	10.5.13
	10.5.5.2	Groundwater-to-Surface Water Cross-Media Transport	10.5.13
	10.5.5.3	Soil-to-Air Cross Media Transport	10.5.13
10.5.6		Human Health Risk Assessment	10.5.15
	10.5.6.1	Site Background and Investigative Approach	10.5.15
	10.5.6.2	COPC Identification	10.5.15
	10.5.6.3	Exposure Assessment	10.5.22
	10.5.6.4	Toxicity Assessment	10.5.27
	10.5.6.5	Risk Characterization	10.5.32

	10.5.6.6	Risk Uncertainty	10.5.40
	10.5.6.7	Risk Summary	10.5.42
	10.5.6.8	Remedial Goal Options	10.5.43
	10.5.7	Corrective Measures Considerations	10.5.43
10.6		Other Sites Designated CSI (Includes AOCs 510, 512, 513, 517, 518, and 520)	10.6.1.1
	10.6.1	AOC 510 — Geotechnical Laboratory	10.6.1.1
	10.6.1.1	Soil Sampling and Analysis	10.6.1.1
	10.6.1.2	Nature and Extent of Contamination	10.6.1.4
	10.6.1.3	Groundwater Sampling and Analysis	10.6.1.10
	10.6.1.4	Nature and Extent of Groundwater Contamination	10.6.1.10
	10.6.1.5	Fate and Transport Assessment	10.6.1.13
	10.6.1.5.1	Soil-to-Groundwater Cross-Media Transport	10.6.1.13
	10.6.1.5.2	Groundwater-to-Surface Water Cross-Media Transport	10.6.1.16
	10.6.1.5.3	Soil-to-Air Cross-Media Transport	10.6.1.16
	10.6.1.6	Human Health Risk Assessment for AOC 510	10.6.1.16
	10.6.1.6.1	Site Background and Investigative Approach	10.6.1.16
	10.6.1.6.2	COPC Identification	10.6.1.19
	10.6.1.6.3	Exposure Assessment	10.6.1.19
	10.6.1.6.4	Toxicity Assessment	10.6.1.27
	10.6.1.6.5	Risk Characterization	10.6.1.35
	10.6.1.6.6	Risk Uncertainty	10.6.1.42
	10.6.1.6.7	Risk Summary	10.6.1.46
	10.6.1.6.8	Remedial Goal Options	10.6.1.46
	10.6.1.7	Corrective Measures Considerations for AOC 510	10.6.1.46
10.6.2		AOC 512 — Former Incinerator	10.6.2.1
	10.6.2.1	Soil Sampling and Analysis	10.6.2.1
	10.6.2.2	Nature and Extent of Soil Contamination	10.6.2.3
	10.6.2.3	Groundwater Sampling and Analysis	10.6.2.10
	10.6.2.4	Nature and Extent of Groundwater Contamination	10.6.2.11
	10.6.2.5	Fate and Transport Assessment	10.6.2.11
	10.6.2.5.1	Soil-to-Groundwater Cross-Media Transport	10.6.2.11
	10.6.2.5.2	Soil-to-Air Cross-Media Transport	10.6.2.11
	10.6.2.6	Human Health Risk Assessment	10.6.2.14
	10.6.2.6.1	Site Background and Investigative Approach	10.6.2.14
	10.6.2.6.2	COPC Identification	10.6.2.14

	10.6.2.6.3	Exposure Assessment	10.6.2.14
	10.6.2.6.4	Toxicity Assessment	10.6.2.20
	10.6.2.6.5	Risk Characterization	10.6.2.28
	10.6.2.6.6	Risk Uncertainty	10.6.2.32
	10.6.2.6.7	Risk Summary	10.6.2.37
	10.6.2.6.8	Remedial Goal Options	10.6.2.37
	10.6.2.7	Corrective Measures Considerations for AOC 512	10.6.2.37
10.6.3	AOC 513	— Former Morgue	10.6.3.1
	10.6.3.1	Soil Sampling and Analysis	10.6.3.1
	10.6.3.2	Nature and Extent of Soil Contamination	10.6.3.1
	10.6.3.3	Fate and Transport Assessment	10.6.3.8
	10.6.3.3.1	Soil-to-Groundwater Cross Media Transport	10.6.3.8
	10.6.3.3.2	Soil-to-Air Cross-Media Transport	10.6.3.8
	10.6.3.4	Human Health Risk Assessment	10.6.3.10
	10.6.3.4.1	Site Background and Investigative Approach	10.6.3.10
	10.6.3.4.2	COPC Identification	10.6.3.10
	10.6.3.5	Corrective Measures Considerations	10.6.3.10
10.6.4	AOC 517	— Former Firing Range	10.6.4.1
	10.6.4.1	Soil Sampling and Analysis	10.6.4.1
	10.6.4.2	Nature and Extent of Contamination	10.6.4.3
	10.6.4.3	Wipe Sampling and Analysis	10.6.4.8
	10.6.4.4	Wipe Sample Results	10.6.4.8
	10.6.4.5	Fate and Transport Assessment	10.6.4.8
	10.6.4.5.1	Soil to Groundwater Cross Media Transport	10.6.4.8
	10.6.4.5.2	Soil-to-Air Cross-Media Transport	10.6.4.10
	10.6.4.6	Human Health Risk Assessment	10.6.4.10
	10.6.4.6.1	Site Background and Investigative Approach	10.6.4.10
	10.6.4.6.2	COPC Identification	10.6.4.13
	10.6.4.7	Corrective Measures Considerations	10.6.4.13
10.6.5	AOC 518	— Coal Storage Bins	10.6.5.1
	10.6.5.1	Soil Sampling and Analysis	10.6.5.1
	10.6.5.2	Nature and Extent of Soil Contamination	10.6.5.3
	10.6.5.3	Fate and Transport Assessment	10.6.5.10
	10.6.5.3.1	Soil-to-Groundwater Cross-Media Transport	10.6.5.10
	10.6.5.3.2	Soil-to-Air Cross-Media Transport	10.6.5.13
	10.6.5.4	Human Health Risk Assessment	10.6.5.13
	10.6.5.4.1	Site Background and Investigative Approach	10.6.5.13

	10.6.5.4.2	COPC Identification	10.6.5.16
	10.6.5.4.3	Exposure Assessment	10.6.5.16
	10.6.5.4.4	Toxicity Assessment	10.6.5.21
	10.6.5.4.5	Risk Characterization	10.6.5.30
	10.6.5.4.6	Risk Uncertainty	10.6.5.34
	10.6.5.4.7	Risk Summary	10.6.5.37
	10.6.5.4.8	Remedial Goal Options	10.6.5.37
	10.6.5.4.9	Corrective Measures	10.6.5.40
10.6.6	AOC 520 — Former Garbage House		10.6.6.1
	10.6.6.1	Soil Sampling and Analysis	10.6.6.1
	10.6.6.2	Nature and Extent of Soil Contamination	10.6.6.3
	10.6.6.3	Fate and Transport Assessment	10.6.6.8
	10.6.6.3.1	Soil-to-Groundwater Cross-Media Transport	10.6.6.9
	10.6.6.3.2	Soil-to-Air Cross-Media Transport	10.6.6.9
10.6.6.4	Human Health Risk Assessment		10.6.6.12
	10.6.6.4.1	Site Background and Investigative Approach	10.6.6.12
	10.6.6.4.2	COPC Identification	10.6.6.12
	10.6.6.4.3	Exposure Assessment	10.6.6.12
	10.6.6.4.4	Toxicity Assessment	10.6.6.18
	10.6.6.4.5	Risk Characterization	10.6.6.18
	10.6.6.4.6	Risk Uncertainty	10.6.6.26
	10.6.6.4.7	Risk Summary	10.6.6.28
	10.6.6.4.8	Remedial Goal Options	10.6.6.28
	10.6.6.4.9	Corrective Measures	10.6.6.28
10.7	GRID-BASED SAMPLING		10.7.1
	10.7.1	Soil Sampling and Analysis	10.7.1
	10.7.2	Nature and Extent of Contamination in Soil	10.7.4
	10.7.3	Groundwater Sampling and Analysis	10.7.14
	10.7.4	Nature and Extent of Chemicals Detected in Groundwater	10.7.15
10.8	AOC 522 — Former Grease and Wash Building		10.8.1
	10.8.1	Soil Sampling and Analysis	10.8.1
	10.8.2	Nature and Extent of Soil Contamination	10.8.3
	10.8.3	Fate and Transport Assessment	10.8.7
	10.8.3.1	Soil-to-Groundwater Cross-Media Transport	10.8.7
	10.8.3.2	Soil-to-Air Cross-Media Transport	10.8.9
10.8.4	Human Health Risk Assessment		10.8.9
	10.8.4.1	Site Background and Investigative Approach	10.8.9
	10.8.4.2	COPC Identification	10.8.9
	10.8.5	Corrective Measures Considerations	10.8.13
10.9	AOC 700 — Golf Course Maintenance Building		10.9.1
	10.9.1	Soil Sampling and Analysis	10.9.1
	10.9.2	Nature and Extent of Soil Contamination	10.9.1

10.9.3	Nature and Extent of Groundwater Contamination	10.9.8
10.9.4	Fate and Transport Assessment	10.9.10
10.9.4.1	Soil-to-Groundwater Cross-Media Transport	10.9.10
10.9.4.2	Soil-to-Air Cross-Media Transport	10.9.13
10.9.5	Human Health Risk Assessment for	10.9.13
10.9.5.1	Site Background and Investigative Approach	10.9.13
10.9.5.2	COPC Identification	10.9.15
10.9.5.3	Exposure Assessment	10.9.18
10.9.5.4	Toxicity Assessment	10.9.22
10.9.5.5	Risk Characterization	10.9.29
10.9.5.6	Risk Uncertainty	10.9.34
10.9.5.7	Risk Summary	10.9.36
10.9.5.8	Remedial Goal Options	10.9.36
10.9.6	Corrective Measures Considerations for AOC 700	10.9.40
11.0	CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS	11.1
11.1	SWMU 44	11.3
11.2	SWMU 47 and AOC 516	11.4
11.3	AOCs 508 and 511	11.5
11.4	AOCs 515 and 519	11.6
11.5	AOC 510	11.7
11.6	AOC 512	11.8
11.7	AOC 513	11.8
11.8	AOC 517	11.9
11.9	AOC 518	11.9
11.10	AOC 520	11.9
11.11	AOC 522	11.10
11.12	AOC 523	11.10
11.13	AOC 700	11.11
11.14	Ecological Risk Summary	11.12
11.14.1	Terrestrial Wildlife	11.13
11.14.2	Vegetation	11.14
11.14.3	Aquatic Wildlife	11.14
12.0	REFERENCES	12.1
13.0	SIGNATORY REQUIREMENT	13.1

List of Figures

Figure 1.1	Vicinity Map	1.2
Figure 1.2	Locations of Land Holdings and Occupants	1.3
Figure 1.3	Investigative Zone Boundaries	1.8
Figure 1.4	Zone C Location Map	1.11
Figure 2.1	Zone C Monitoring Well Locations	2.5
Figure 2.2	Lithologic Cross Section A-A'	2.7
Figure 2.3	Top of the Confining Unit Elevation Contour Map	2.8
Figure 2.4	Shallow Groundwater Elevation Map — June 28, 1996	2.15
Figure 2.5	Zone C Vertical Hydraulic Gradients	2.17
Figure 2.6	Hydraulic Conductivity Geometric Means	2.20
Figure 7.1	Formulae for Calculating CDI for Soil	7.23
Figure 7.2	Formulae for Calculating CDI for Groundwater	7.26
Figure 8.1	Ecological Study Areas	8.2
Figure 8.2	Ecological Subzones within Zone C	8.3
Figure 8.3	Contaminant Pathway Model for Ecological Receptors	8.10
Figure 10.1.1	SWMU 44 — Coal Storage Area, Soil Sample Locations	10.1.2
Figure 10.1.2	SWMU 44 — Monitoring Well Locations	10.1.10
Figure 10.1.3	SWMU 44 — Sediment Sampling Locations	10.1.15
Figure 10.1.4	SWMU 44 — Surface Water Sampling Locations	10.1.16
Figure 10.1.5	Soil and Sediment COPC concentrations	10.1.50
Figure 10.1.6	Aluminum in Shallow Groundwater Contour Map	10.1.112
Figure 10.1.7	Arsenic in Shallow Groundwater Contour Map	10.1.113
Figure 10.1.8	Beryllium in Shallow Groundwater Contour Map	10.1.114
Figure 10.1.9	Manganese in Shallow Groundwater Contour Map	10.1.115
Figure 10.2.1	SWMU 47 — Soil Sampling Locations	10.2.2
Figure 10.2.2	SWMU 47 — Monitoring Well Locations	10.2.13
Figure 10.2.3	Surface Soil BEQ & TPH Concentrations	10.2.37
Figure 10.2.4	BEQs in Surface Soil Contour Map	10.2.60
Figure 10.2.5	Arsenic in Surface Soil Contour Map	10.2.61
Figure 10.3.1	Soil Sampling Locations	10.3.2
Figure 10.3.2	BEQs in Surface Soil Contour Map	10.3.42
Figure 10.3.3	Dieldrin in Surface Soil Contour Map	10.3.43
Figure 10.4.1	Soil Sampling Locations	10.4.2
Figure 10.5.1	Soil Sample Locations	10.5.2
Figure 10.5.2	Monitoring Well Locations	10.5.9
Figure 10.6.1.1	AOC 510 — Soil Sample Locations	10.6.1.2
Figure 10.6.1.2	AOC 510 — Monitoring Well Locations	10.6.1.11
Figure 10.6.1.3	BEQs in Surface Soil Contour Map	10.6.1.41
Figure 10.6.2.1	AOC 512 — Soil Sample Locations	10.6.2.2
Figure 10.6.2.2	BEQs in Surface Soil Contour Map	10.6.2.33
Figure 10.6.2.3	Beryllium in Surface Soil Contour Map	10.6.2.34
Figure 10.6.3.1	AOC 513 — Soil Sample Locations	10.6.3.2

Figure 10.6.4.1	AOC 517 — Soil Sample Locations	10.6.4.2
Figure 10.6.5.1	AOC 518 — Soil Sample Locations	10.6.5.2
Figure 10.6.6.1	AOC 520 — Soil Sample Location	10.6.6.2
Figure 10.7.1	Grid Based Sample Location	10.7.2
Figure 10.8.1	AOC 522 — Soil Sample Locations	10.8.2
Figure 10.9.1	AOC 700 — Soil Sample Locations	10.9.2

List of Tables

Table 1.1	Zone C SWMUs and AOCs with Investigatory Designations	1.12
Table 2.1	Zone C Monitoring Well Construction Data	2.3
Table 2.2	Vertical Hydraulic Gradients	2.16
Table 2.3	Horizontal Hydraulic Gradient	2.18
Table 2.4	Zone C Shallow-Well Slug Test Hydraulic Conductivity Results	2.19
Table 2.5	Zone C Deep-Well Slug Test Hydraulic Conductivity Results	2.19
Table 2.6	Groundwater Velocity Results	2.22
Table 2.7	Mean Temperature and Wind Data for Charleston Harbor between 1970 and 1985	2.23
Table 2.8	Monthly and Annual Mean Precipitation, Relative Humidity, and Cloud Cover for Charleston Harbor between 1960 and 1985	2.25
Table 4.1	NAVBASE Analytical Program	4.4
Table 4.2	Surrogate Compound Summary	4.8
Table 4.3	Diluted Samples	4.15
Table 5.1	Zone C Inorganic Background Reference Values for Soil and Groundwater	5.3
Table 5.2	Probability of Possible Conclusions of a Hypothesis Test	5.8
Table 6.1	Chemical and Physical Properties	6.3
Table 6.2	Fate and Transport Properties and Screening Levels for Constituents Detected in Soil and Groundwater	6.4
Table 6.3	Soil Parameters Used to Evaluate Fate and Transport	6.12
Table 6.4	Travel Time Analysis	6.13
Table 7.1	Parameters Used to Estimate CDI at RME	7.19
Table 8.1	AOCs/SWMUs associated with Zone C Subzones	8.4
Table 8.2	Federal and State Listed Threatened, Endangered, and Candidate Species That Occur or Potentially Occur on NAVBASE	8.7
Table 8.3a	Subzone C-1 Inorganic Constituents in Surface Soil	8.13
Table 8.3b	Subzone C-1 Inorganic Constituents in Sediment	8.14
Table 8.3c	Subzone C-1 Inorganic Constituents in Surface Water	8.15
Table 8.4a	Subzone C-2 Organic ECPCs in Surface Soil	8.16
Table 8.4b	Subzone C-2 Inorganic Constituents in Surface Soil	8.18
Table 8.5	Wildlife Contaminant Exposure Model for Surface Soil	8.21
Table 8.6	Chemical Effects Studies on Terrestrial Infaunal Invertebrates	8.27
Table 8.7	Bioaccumulation Data	8.35

Table 8.8	Exposure Parameters and Assumptions for Representative Wildlife Species at Subzone C-1	8.39
Table 8.9	Exposure Parameters and Assumptions for Representative Wildlife Species at Subzone C-2	8.40
Table 8.10a	Hazard Quotients for Potential <u>Lethal</u> Effects for Wildlife Species Associated with <u>Maximum</u> Exposure Concentrations of ECPCs in Surface Soil at Subzone C-1	8.41
Table 8.10b	Hazard Quotients for Potential <u>Lethal</u> Effects for Wildlife Species Associated with <u>Mean</u> Exposure Concentrations of ECPCs in Surface Soil at Subzone C-1	8.42
Table 8.10c	Hazard Quotients for Potential Sublethal Effects for Wildlife Species Associated with <u>Maximum</u> Exposure Concentrations of ECPCs in Soil at Subzone C-1	8.43
Table 8.11a	Hazard Quotients for Potential Lethal Effects for Wildlife Species Associated with Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-2	8.44
Table 8.11b	Hazard Quotients for Potential Sub-Lethal Effects for Wildlife Species Associated with Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-2	8.46
Table 8.12	Summary of Chemical Effects Studies on Vegetation	8.50
Table 9.1	Removal/Containment/Disposal Options	9.14
Table 9.2	Treatment Technology Options	9.15
Table 9.3	Comparison and Ranking of Alternatives	9.29
Table 10.1.1	First Round – Soil Sampling and Analysis	10.1.3
Table 10.1.2	Second Round – Soil Sampling and Analysis Summary	10.1.4
Table 10.1.3	Organic Compound Analytical Results for Soil	10.1.4
Table 10.1.4	Inorganic Analytical Results for Soil	10.1.6
Table 10.1.5	Groundwater Sampling and Analysis	10.1.11
Table 10.1.6	Organic Compound Analytical Results for Shallow Groundwater	10.1.11
Table 10.1.7	Inorganic Analytical Results for Groundwater	10.1.12
Table 10.1.8	Sediment Sampling and Analysis Summary	10.1.14
Table 10.1.9	Inorganic Analytical Results for Sediments	10.1.17
Table 10.1.10	Surface Water Sampling and Analysis Summary	10.1.18
Table 10.1.11	Organic Compound Analytical Results for Surface Water	10.1.20
Table 10.1.12	Inorganic Analytical Results for Surface Water	10.1.21
Table 10.1.13	Soil-to-Groundwater Cross-Media	10.1.22
Table 10.1.14	Soil-to-Air Cross-Media	10.1.27
Table 10.1.15	Summary of Constituents and Migration Pathways	10.1.28
Table 10.1.16	Soil Analytical Methods	10.1.30
Table 10.1.17	Sediment Analytical Methods	10.1.31
Table 10.1.18	Groundwater Analytical Methods	10.1.32
Table 10.1.19	Surface Water Analytical Methods	10.1.33
Table 10.1.20	Soil COPCs	10.1.35
Table 10.1.21	Sediment COPCs	10.1.38

Table 10.1.22	Groundwater COPCs	10.1.39
Table 10.1.23	Surface Water COPCs	10.1.41
Table 10.1.24	Exposure Pathways Summary – SWMU 44	10.1.44
Table 10.1.25	Soil and Sediment Samples Containing COPCs	10.1.48
Table 10.1.26	Area 1	10.1.53
Table 10.1.27	Area 1	10.1.54
Table 10.1.28	Area 2 CDI	10.1.55
Table 10.1.29	Area 2 CDI	10.1.56
Table 10.1.30	Area 3 CDI	10.1.57
Table 10.1.31	Area 3 CDI	10.1.58
Table 10.1.32	Area 4 CDI	10.1.59
Table 10.1.33	Area 4 CDI	10.1.60
Table 10.1.34	Adolescent Trespassers Soil	10.1.62
Table 10.1.35	Adolescent Trespassers Sediment	10.1.63
Table 10.1.36	CDIs for Shallow Groundwater Ingestion	10.1.64
Table 10.1.37	Toxicological risk for COPCs	10.1.65
Table 10.1.38	Area 1 – Carcinogenic Risk – Incidental Ingestion	10.1.75
Table 10.1.39	Area 1 – Carcinogenic Risk – Dermal Contact	10.1.76
Table 10.1.40	Area 2 – Carcinogenic Risk – Incidental Ingestion	10.1.79
Table 10.1.41	Area 2 – Carcinogenic Risk – Dermal Contact	10.1.80
Table 10.1.42	Area 3 – Carcinogenic Risk – Incidental Ingestion	10.1.82
Table 10.1.43	Area 3 – Carcinogenic Risk – Dermal Contact	10.1.83
Table 10.1.44	Area 4 – Carcinogenic Risk – Incidental Ingestion	10.1.86
Table 10.1.45	Area 4 – Carcinogenic Risk – Dermal Contact	10.1.87
Table 10.1.46	Adolescent Trespasser – Carcinogenic Risk – Incidental Ingestion	10.1.89
Table 10.1.47	Adolescent Trespasser – Carcinogenic Risk – Dermal Contact	10.1.90
Table 10.1.48	Ingestion Exposure Pathway – Shallow Groundwater	10.1.92
Table 10.1.49	COCs Identified – Medium- and Area-Specific Basis	10.1.97
Table 10.1.50	Risk for Pathway/Receptor Groups	10.1.104
Table 10.1.51	Residential-Based RGOs for Surface Soil	10.1.105
Table 10.1.52	Worker-Based RGOs for Surface Soil	10.1.106
Table 10.1.53	RGOs for Adolescent Trespasser Scenario	10.1.107
Table 10.1.54	Shallow groundwater RGOs Site Residents	10.1.108
Table 10.1.55	Shallow groundwater RGOs Site Workers	10.1.109
Table 10.1.56	Comparison of Confirmation Soil Samples to Residential RGOs	10.1.111
Table 10.1.57	Comparison of Confirmation Groundwater Samples to Residential RGOs	10.1.116
Table 10.1.58	Potential Corrective Measures	10.1.117
Table 10.2.1	First Round – Soil Sampling and Analysis Summary	10.2.3
Table 10.2.2	Second Round – Soil Sampling and Analysis Summary	10.2.3
Table 10.2.3	Organic Compound Analytical Results for Soil	10.2.4
Table 10.2.4	Inorganics Analytical Results for Soil	10.2.8

Table 10.2.5	Groundwater Sampling and Analysis	10.2.12
Table 10.2.6	Organic Compound Analytical Results for Shallow Groundwater .	10.2.14
Table 10.2.7	Inorganic Analytical Results for Groundwater	10.2.15
Table 10.2.8	Chemicals Detected in Surface Soil, Subsurface Soil and Groundwater	10.2.19
Table 10.2.9	Soil-to-Air Volatilization Screening Analysis	10.2.23
Table 10.2.10	Significant Migration Pathways	10.2.24
Table 10.2.11	Methods Run at SWMU 47 Surface Soil	10.2.26
Table 10.2.12	Methods Run at SWMU 47 Shallow Groundwater, Sampling Round 01	10.2.27
Table 10.2.13	SWMU 47 Surface Soil	10.2.28
Table 10.2.14	SWMU 47 Shallow Groundwater, Sampling Round 01	10.2.33
Table 10.2.15	Exposure Pathways Summary — SWMU 47 (AOC 516 and SWMU 47)	10.2.38
Table 10.2.16	Statistical Analysis of COPCs Surface Soils at SWMU 47 and AOC 516	10.2.40
Table 10.2.17	Chronic Daily Intakes (CDI) Incidental Ingestion of Surface Soil (0-1')	10.2.42
Table 10.2.18	Chronic Daily Intakes (CDI) Dermal Contact with Surface Soil (0-1')	10.2.43
Table 10.2.19	Chronic Daily Intakes (CDI) Ingestion of COPCs in Shallow Groundwater	10.2.44
Table 10.2.20	Toxicological Database Information for Chemicals of Potential Concern	10.2.45
Table 10.2.21	Hazard Quotients and Incremental Lifetime Cancer Risks Incidental Surface Soil Ingestion SWMU 47 and AOC 516	10.2.54
Table 10.2.22	Hazard Quotients and Incremental Lifetime Cancer Risks Dermal Contact with Surface Soil SWMU 47 and 516	10.2.55
Table 10.2.23	Hazard Quotients and Incremental Lifetime Cancer Risks Shallow Groundwater Ingestion SWMU 47 and 516	10.2.57
Table 10.2.24	Summary of Risk and Hazard-Based COCs for SWMU 47 and AOC 516	10.2.62
Table 10.2.25	Summary of Risk and Hazard for SWMU 47 and AOC 516	10.2.70
Table 10.2.26	Residential-Based Remedial Goal Options Surface Soil SWMU 47 and AOC 516	10.2.71
Table 10.2.27	Worker-Based Remedial Goal Options Surface Soil SWMU 47 and AOC 516	10.2.72
Table 10.2.28	Residential-Based Remedial Goal Options Shallow Groundwater SWMU 47 and AOC 516	10.2.73
Table 10.2.29	Worker-Based Remedial Goal Options Shallow Groundwater SWMU 47 and AOC 516	10.2.74
Table 10.3.1	AOC 508 — Former Incinerator/AOC 511 — Oil Storage House First Round — Soil Sampling and Analysis	10.3.3

Table 10.3.2	AOC 508 — Former Incinerator/AOC 511 — Oil Storage House Second Round — Soil Sampling and Analysis	10.3.3
Table 10.3.3	AOC 508 — Former Incinerator/AOC 511 — Oil Storage House Organic Compound Analytical Results for Soil	10.3.4
Table 10.3.4	AOC 508 — Former Incinerator/AOC 511 — Oil Storage House Inorganic Analytical Results for Soil	10.3.7
Table 10.3.5	Groundwater Sampling and Analysis	10.3.11
Table 10.3.6	Chemicals Detected in Surface Soil and Subsurface Soil Comparison to Groundwater Protection SSLs and Background UTLs for AOCs 508 and 511	10.3.12
Table 10.3.7	Soil-to-Air Volatilization Screening Analysis for AOCs 508 and 511	10.3.16
Table 10.3.8	Significant Migration Pathways for AOCs 508 and 511	10.3.17
Table 10.3.9	Methods Run at AOC 508 Surface Soil	10.3.19
Table 10.3.10	AOC 508 Surface Soil	10.3.20
Table 10.3.11	Exposure Pathways Summary — AOC 508	10.3.24
Table 10.3.12	Statistical Analysis of COPCs Surface Soils at AOCs 508 and 511	10.3.26
Table 10.3.13	CDIs — Incidental Ingestion (Surface Soil)	10.3.28
Table 10.3.14	CDIs — Dermal Contact (Surface Soil)	10.3.29
Table 10.3.15	Toxicological Database Information	10.3.30
Table 10.3.16	HQs and ILCR — Incidental Ingestion (Surface Soil)	10.3.37
Table 10.3.17	HQs and ILCR — Dermal Contact (Surface Soil)	10.3.38
Table 10.3.18	Summary of Risk and Hazard COCs	10.3.41
Table 10.3.19	Summary of Exposure Pathway/Exposure Scenario Risk and Hazard	10.3.47
Table 10.3.20	RGOs — Hypothetical Site Residential Scenario	10.3.48
Table 10.3.21	RGOs — Hypothetical Future Site Worker Scenario	10.3.49
Table 10.3.22	Potential Corrective Measures	10.3.50
Table 10.4.1	First Round — Soil Sampling and Analysis	10.4.3
Table 10.4.2	Second Round — Soil Sampling and Analysis	10.4.3
Table 10.4.3	Organic Compound Analytical Results for Soil	10.4.4
Table 10.4.4	Inorganic Analytical Results for Soil	10.4.7
Table 10.4.5	Soil-to-Groundwater Cross-Media Transport	10.4.12
Table 10.4.6	VOCs in Soil	10.4.14
Table 10.4.7	Soil Analytical Methods	10.4.16
Table 10.4.8	Screening Comparisons in Soil	10.4.17
Table 10.4.9	Exposure Pathways Summary — AOC 515	10.4.21
Table 10.4.10	CDIs — Incidental Ingestion (Surface Soil)	10.4.22
Table 10.4.11	CDIs — Dermal Contact (Surface Soil)	10.4.23
Table 10.4.12	Toxicological Database Information	10.4.25
Table 10.4.13	HQ and ILCR — Incidental Ingestion (Surface Soil)	10.4.31
Table 10.4.14	HQ and ILCR — Dermal Contact (Surface Soil)	10.4.32
Table 10.4.15	Summary of Exposure Pathway/Exposure Scenario Risk and Hazard	10.4.37

Table 10.5.1	AOC 523 — Former Gas Station Soil Sampling and Analysis	10.5.3
Table 10.5.2	AOC 523 — Former Gas Station Organic Compound Analytical Results for Soil	10.5.3
Table 10.5.3	AOC 523 — Former Gas Station Inorganic Analytical Results for Soil	10.5.5
Table 10.5.4	AOC 523 — Former Gas Station Groundwater Sampling and Analysis	10.5.10
Table 10.5.5	AOC 523 — Former Gas Station Organic Compound Analytical Results for Groundwater	10.5.10
Table 10.5.6	AOC 523 — Former Gas Station Inorganic Analytical Results for Groundwater	10.5.11
Table 10.5.7	Soil and Groundwater Comparison to Corresponding Screening Values	10.5.14
Table 10.5.8	Analytical Method Summary in Soil	10.5.16
Table 10.5.9	Analytical Method Summary in Groundwater	10.5.17
Table 10.5.10	COPC Identified in Surface Soil	10.5.18
Table 10.5.11	COPC Identified in Shallow Groundwater	10.5.20
Table 10.5.12	Exposure Pathways Summary — AOC 523 NAVBASE — Zone C	10.5.23
Table 10.5.13	CDIs for Incidental Ingestion (Surface Soil)	10.5.25
Table 10.5.14	CDIs for Dermal Contact	10.5.26
Table 10.5.15	CDIs for Incidental Ingestion (Shallow Groundwater)	10.5.28
Table 10.5.16	Toxicological Database Information	10.5.29
Table 10.5.17	Estimated HQ and ILCR — Incidental Ingestion	10.5.34
Table 10.5.18	Estimated HQ and ILCR — Dermal Contact (Surface Soil)	10.5.35
Table 10.5.19	Estimated HQ and ILCR—Incidental Ingestion (Shallow Groundwater)	10.5.36
Table 10.5.20	Summary of Risk and Hazard-Based COCs	10.5.39
Table 10.5.21	Summary of Risk and Hazard	10.5.44
Table 10.5.22	Residential-Based RGOs	10.5.45
Table 10.5.23	Worker-Based RGOs (Shallow Groundwater)	10.5.46
Table 10.5.24	Potential Corrective Measures	10.5.47
Table 10.6.1.1	First Round — Soil Sampling and Analysis	10.6.1.3
Table 10.6.1.2	Second Round — Soil Sampling and Analysis Summary	10.6.1.3
Table 10.6.1.3	Organic Compound Analytical Results for Soil	10.6.1.4
Table 10.6.1.4	Soil Inorganics Analytical Results for Soil	10.6.1.7
Table 10.6.1.5	Groundwater Sampling and Analysis	10.6.1.10
Table 10.6.1.6	Organic Compound Analytical Results for Groundwater	10.6.1.10
Table 10.6.1.7	Inorganics Analytical Results for Groundwater	10.6.1.12
Table 10.6.1.8	Screening Comparisons for Soil	10.6.1.14
Table 10.6.1.9	Soil-to-Air Volatilization Screening Analysis	10.6.1.17
Table 10.6.1.10	Soil Analytical Methods	10.6.1.18
Table 10.6.1.11	Groundwater Analytical Methods	10.6.1.20

Table 10.6.1.12	Screening Comparisons for Soil	10.6.1.21
Table 10.6.1.13	Groundwater Screening Comparisons	10.6.1.23
Table 10.6.1.14	Exposure Pathways Summary — AOC 510 NAVBASE — Zone C	10.6.1.25
Table 10.6.1.15	CDIs - Incidental Ingestion (Surface Soil)	10.6.1.28
Table 10.6.1.16	CDIs - Dermal Contact (Surface Soil)	10.6.1.29
Table 10.6.1.17	CDIs - Ingestion/Inhalation (Shallow Groundwater)	10.6.1.30
Table 10.6.1.18	Toxicological Database Information	10.6.1.31
Table 10.6.1.19	HQs and ICLRs - Incidental Ingestion (Surface Soil)	10.6.1.36
Table 10.6.1.20	HQs and ILCRs - Dermal Contact (Surface Soil)	10.6.1.37
Table 10.6.1.21	HQs and ILCRs — Ingestion (Shallow Groundwater)	10.6.1.39
Table 10.6.1.22	Risk Summary	10.6.1.47
Table 10.6.1.23	RGOs — Surface Soil	10.6.1.48
Table 10.6.1.24	Potential Corrective Measures	10.6.1.49
Table 10.6.2.1	First Round — Soil Sampling and Analysis Summary AOC 512 — Former Incinerator	10.6.2.3
Table 10.6.2.2	Second Round — Soil Sampling and Analysis Summary AOC 512 — Former Incinerator	10.6.2.3
Table 10.6.2.3	Organic Compound Analytical Results for Soil AOC 512 — Former Incinerator	10.6.2.3
Table 10.6.2.4	Inorganic Analytical Results for Soil AOC 512 — Former Incinerator	10.6.2.7
Table 10.6.2.5	Groundwater Sampling and Analysis	10.6.2.10
Table 10.6.2.6	Chemicals Detected in Surface Soil and Subsurface Soil	10.6.2.12
Table 10.6.2.7	Methods Run at AOC 512	10.6.2.15
Table 10.6.2.8	AOC 512 Surface Soil	10.6.2.16
Table 10.6.2.9	Exposure Pathways Summary — AOC 512	10.6.2.19
Table 10.6.2.10	Chronic Daily Intakes (CDI)	10.6.2.21
Table 10.6.2.11	CDI Dermal Contact with Surface Soil	10.6.2.22
Table 10.6.2.12	Toxicological Database Information for Chemicals of Potential Concern	10.6.2.23
Table 10.6.2.13	Hazard Quotients and Incremental Lifetime Cancer Risk — Incidental Surface Soil Ingestion	10.6.2.29
Table 10.6.2.14	Hazard Quotients and Incremental Lifetime Cancer Risk — Dermal Contact with Surface Soil	10.6.2.30
Table 10.6.2.15	Summary of Risk and Hazard for AOC 512	10.6.2.38
Table 10.6.2.16	Residential-Based Remedial Goal Options Surface Soil	10.6.2.39
Table 10.6.2.17	Potential Corrective Measures	10.6.2.40
Table 10.6.3.1	Soil Sampling and Analysis Summary	10.6.3.3
Table 10.6.3.2	Organic Compound Analytical Results for Soil	10.6.3.3
Table 10.6.3.3	Inorganic Analytical Results for Soil	10.6.3.5
Table 10.6.3.4	Chemicals Detected in Surface Soil and Subsurface Soil	10.6.3.9
Table 10.6.3.5	Methods Run at AOC 513 — Surface Soil	10.6.3.11
Table 10.6.3.6	AOC 513 Surface Soil	10.6.3.12

Table 10.6.4.1	Soil Sampling and Analysis Summary	10.6.4.1
Table 10.6.4.2	Organic Compound Analytical Results for Soil	10.6.4.3
Table 10.6.4.3	Inorganic Analytical Results for Soil	10.6.4.5
Table 10.6.4.4	Chemicals Detected in Surface Soil and Subsurface Soil	10.6.4.9
Table 10.6.4.5	Soil-to-Air Volatilization Screening Analysis	10.6.4.11
Table 10.6.4.6	Methods Run at AOC 517	10.6.4.12
Table 10.6.4.7	AOC Surface Soil	10.6.4.14
Table 10.6.5.1	First Round — Soil Sampling and Analysis Summary	10.6.5.1
Table 10.6.5.2	AOC 518 — Coal Storage Bins Second Round — Soil Sampling and Analysis Summary	10.6.5.3
Table 10.6.5.3	Organic Compound Analytical Results for Soil	10.6.5.4
Table 10.6.5.4	Inorganic Analytical Results for Soil	10.6.5.7
Table 10.6.5.5	Soil-to-Groundwater Cross-Media Transport	10.6.5.11
Table 10.6.5.6	Soil-to-Air Volatilization Screening Analysis	10.6.5.14
Table 10.6.5.7	Methods Run at AOC 518	10.6.5.15
Table 10.6.5.8	AOC 518 Surface Soil	10.6.5.17
Table 10.6.5.9	Exposure Pathways Summary	10.6.5.19
Table 10.6.5.10	Chronic Daily Intakes — Incidental Ingestion of Surface Soil . . .	10.6.5.22
Table 10.6.5.11	Chronic Daily Intakes — Dermal Contact with Surface Soil	10.6.5.23
Table 10.6.5.12	Toxicological Database Information for Chemicals of Potential Concern	10.6.5.24
Table 10.6.5.13	Hazard Quotients and Incremental Lifetime Cancer Risks — Incidental Surface Soil Ingestion	10.6.5.31
Table 10.6.5.14	Hazard Quotients and Incremental Lifetime Cancer Risks — Dermal Contact with Surface Soil	10.6.5.32
Table 10.6.5.15	Summary of Risk and Hazard for AOC 518	10.6.5.38
Table 10.6.5.16	Residential-Based Remedial Goal Options Surface Soil	10.6.5.39
Table 10.6.6.1	First Round — Soil Sampling and Analysis Summary	10.6.6.1
Table 10.6.6.2	Second Round — Soil Sampling and Analysis Summary	10.6.6.3
Table 10.6.6.3	Organic Compound Analytical Results for Soil	10.6.6.3
Table 10.6.6.4	Inorganic Analytical Results for Soil	10.6.6.6
Table 10.6.6.5	Chemicals Detected in Surface Soil and Subsurface Soil — Comparison to Groundwater Protection SSLs and Background UTLs	10.6.6.10
Table 10.6.6.6	Soil-to-Air Volatilization Screening Analysis	10.6.6.11
Table 10.6.6.7	Methods Run at AOC 520	10.6.6.13
Table 10.6.6.8	AOC 520 Surface Soil	10.6.6.14
Table 10.6.6.9	Exposure Pathways Summary — AOC 520	10.6.6.17
Table 10.6.6.10	Chronic Daily Intakes (CDI) — Incidental Ingestion of Surface Soil (0-1')	10.6.6.19
Table 10.6.6.11	Chronic Daily Intakes (CDI) — Dermal Contact with Surface Soil (0-1')	10.6.6.20
Table 10.6.6.12	Toxicological Database Information for Chemicals of Potential Concern	10.6.6.21

Table 10.6.6.13	Hazard Quotients and Incremental Lifetime Cancer Risks — Incidental Surface Soil Ingestion	10.6.6.24
Table 10.6.6.14	Hazard Quotients and Incremental Lifetime Cancer Risks — Dermal Contact with Surface Soil	10.6.6.25
Table 10.6.6.15	Summary of Risk and Hazard for AOC 520	10.6.6.29
Table 10.7.1	First Round — Soil Sampling and Analysis	10.7.1
Table 10.7.2	Second Round — Soil Sampling and Analysis	10.7.3
Table 10.7.3	Organic Compound Analytical Results for Soil Zone C	10.7.4
Table 10.7.4	Inorganic Analytical Results for Soil	10.7.9
Table 10.7.5	Groundwater Sampling and Analysis	10.7.14
Table 10.7.6	Organic Compound Analytical Results for Groundwater	10.7.15
Table 10.7.7	Inorganics Analytical Results for Groundwater	10.7.15
Table 10.8.1	Soil Sampling and Analysis Summary	10.8.1
Table 10.8.2	AOC 522 — Former Grease and Wash Building Organic Compound Analytical Results for Soil	10.8.3
Table 10.8.3	AOC 522 — Former Grease and Wash Building Inorganic Analytical Results for Soil	10.8.4
Table 10.8.4	Chemicals Detected in Surface Soil and Subsurface Soil — Comparison to Groundwater Protection SSLs and Background UTLs	10.8.8
Table 10.8.5	Soil-to-Air Volatilization Screening Analysis	10.8.10
Table 10.8.6	Methods Run at AOC 522 Surface Soil	10.8.11
Table 10.8.7	Statistical Analysis of COPCs Surface Soils at AOC 522	10.8.12
Table 10.9.1	Soil Sampling and Analysis Summary	10.9.3
Table 10.9.2	Organic Compound Analytical Results for Soil	10.9.3
Table 10.9.3	Inorganic Analytical Results for Soil	10.9.6
Table 10.9.4	Inorganics Analytical Results for Groundwater	10.9.9
Table 10.9.5	Chemicals Detected in Surface Soil and Subsurface Soil Comparison to Groundwater Protection SSLs and Background UTLs for AOCs 508 and 511	10.9.11
Table 10.9.6	Methods Run at AOC 700 Soil	10.9.14
Table 10.9.7	AOC 700 Screening Soil	10.9.16
Table 10.9.8	Exposure Pathways Summary — AOC 700	10.9.19
Table 10.9.9	Statistical Analysis of COPCs Surface Soils at AOC 700	10.9.21
Table 10.9.10	CDIs — Incidental Ingestion (Surface Soil)	10.9.23
Table 10.9.11	CDIs — Dermal Contact (Surface Soil)	10.9.24
Table 10.9.12	Toxicological Database Information	10.9.25
Table 10.9.13	HQs and ILCR — Incidental Ingestion (Surface Soil)	10.9.30
Table 10.9.14	HQs and ILCR — Dermal Contact (Surface Soil)	10.9.31
Table 10.9.15	Summary of Risk and Hazard COCs	10.9.33
Table 10.9.16	Summary of Exposure Pathway/Exposure Scenario Risk and Hazard	10.9.37
Table 10.9.17	Residential-Based Remedial Goal Options, AOC 700	10.9.38
Table 10.9.18	Worker-Based Remedial Goal Options, AOC 700	10.9.39

Table 11.1	Zone C Site Conclusions and Preliminary Recommendations	11-2
Table 11.2	SWMU 44 Conclusion Summary	11-3
Table 11.3	AOC 516 and SWMU 47 Conclusion Summary	11-5
Table 11.4	AOCs 508 and 511 Conclusion Summary	11-6
Table 11.5	AOC 510 Conclusion Summary	11-7
Table 11.6	AOC 512 Conclusion Summary	11-8
Table 11.7	AOC 518 Conclusion Summary	11-9
Table 11.8	AOC 523 Conclusion Summary	11-11
Table 11.9	AOC 700 Conclusion Summary	11-11
Table 11.10	AOCs/SWMUs Associated with Zone C Subzones	11-12

List of Appendices

Appendix A	Lithologic Boring Logs and Well Construction Diagrams
Appendix B	Geotechnical/Physical Parameter Data Reports
Appendix C	Aquifer Characterization Data
Appendix D	Analytical Data
Appendix E	Analytical Data Validation
Appendix F	Terrestrial Species List
Appendix G	Wildlife Toxicity Data
Appendix H	Detection Only Tables

ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C

The following abbreviations, acronyms, and units of measurement are used in this report.

AA	Atomic Absorption
ABF	Absorption Factor
AEC	Area of Ecological Concern
AL	Action Level
AOC	Area of Concern
AOI	Area of Interest
AQTESOLV	Aquifer Test Solver
ARAR	Applicable or Relevant and Appropriate Requirement
AST	Aboveground Storage Tank
ASTM	American Society for Testing and Materials
atm	Atmospheres
AWQC	Ambient Water Quality Criteria
BAF	Bioaccumulation Factor
BAP	Benzo(a)pyrene
BDL	Below Detection Limit
BE	Barometric Efficiency
BEHP	bis(2-ethylhexyl)phthalate
BEQ	Benzo(a)pyrene Equivalent
BEST	Building Economic Solutions Together
bgs	Below ground surface
BHC	Benzenehexachloride
BOD	Biochemical Oxygen Demand
BRA	Baseline Risk Assessment
BRAC	Base Realignment and Closure Act of 1988 and Defense Base Closure and Realignment Act of 1990, collectively
BTEX	Benzene, toluene, ethylbenzene, and xylene
CAMP	Corrective Action Management Plan
CAMU	Corrective Action Management Unit
CDD	Chlorinated dibenzo-p-dioxin
CDF	Chlorinated dibenzofuran
CDI	Chronic Daily Intake
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CF	Calibration Factor
CFR	Code of Federal Regulations
cm	centimeter
cm/sec	centimeters per second
CLEAN	Comprehensive Long-Term Environmental Action Navy

**ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C
(Continued)**

CLP	Contract Laboratory Program
CM	Corrective Measures
CMI	Corrective Measures Implementation
CMS	Corrective Measures Study
COD	Chemical Oxygen Demand
CNS	Central Nervous System
CNSY	Charleston Naval Shipyard
COC	Chemical of Concern
COPC	Chemical of Potential Concern
cPAH	Carcinogen Polynuclear Aromatic Hydrocarbon
CPSS	Chemical Present in Site Samples
CRAVE	Carcinogen Risk Assessment Verification Endeavor
CRDL	Contract Required Detection Limit
CSAP	Comprehensive Sampling and Analysis Plan
CSI	Confirmatory Sampling Investigation
CT	Central Tendency
CV	Coefficient of Variation
CWA	Clean Water Act
DCAA	2,4-dichlorophenylacetic acid
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyl-trichloroethane
DMA	Dredged Material Area
DNAPL	Dense Non-Aqueous Phase Liquid
DOD	Department of Defense
DQO	Data Quality Objectives
DRO	Diesel Range Organics
DWEL	Drinking Water Equivalent Level
E/A&H	EnSafe/Allen & Hoshall
ECAO	Environmental Criteria and Assessment Office
ECPC	Ecological Chemical of Potential Concern
EMPC	Estimated Maximum Possible Concentration
EOD	Explosive Ordnance Disposal
EPC	Exposure Point Concentration
ERA	Environmental Risk Assessment
ESA	Ecological Study Area
ESDSOPQAM	Environmental Services Division Standard Operating Procedures and Quality Assurance Manual

**ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C
(Continued)**

FC	Fraction contracted
FFI	Focused Field Investigation
FI	Fraction Ingested
FID	Flameionization detector
ft ² /day	Square feet per day
GC/MS	Gas Chromatography/Mass Spectroscopy
gpm	Gallons per minute
GPS	Global Positioning System
GRO	Gasoline Range Organics
HASP	Health and Safety Plan
HEAST	Health Effects Assessment Summary Table
HMW	High Molecular Weight
HI	Hazard Index
HQ	Hazard Quotient
HSWA	Hazardous and Solid Waste Amendments
HTTD	High-Temperature Thermal Desorption
ICAP	Inductively Coupled Argon Plasma
ICM	Interim Corrective Measure
ICP	Inductively Coupled Plasma
ID	Inside Diameter
IDL	Instrument Detection Limit
ILCR	Incremental Lifetime Excess Cancer Risk
ILO	Indeterminate Lubricating Oil
IRIS	Integrated Risk Information System
IRP	Installation Restoration Program
IS	Internal Standard
kph	Kilometers per hour
LCS	Laboratory Control Sample
LC ₅₀	Lethal Concentration to 50 percent of test population
LD ₅₀	Lethal Dose to 50 percent of test population
LDR	Land Disposal Restriction
LMW	Low Molecular Weight
LN	Natural Logarithm
LNAPL	Light Nonaqueous Phase Liquid
LQAC	Laboratory QA Coordinator
LTTD	Low-Temperature Thermal Desorption
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal

ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C
(Continued)

meq/L	Milliequivalent per liter
mg/kg	Milligram per kilogram
mg/L	Milligram per liter
mg/m ³	Milligram per cubic meter
ml	Milliliter
mm	Millimeter
mph	Miles per hour
msl	Mean sea level
MS/MSD	Matrix Spike/Matrix Spike Duplicate
NA	Not Applicable
NAD	North American Datum
NAVBASE	Naval Base Charleston
NBS	National Bureau of Standards
NCEA	National Center for Environmental Assessment
NCR	NEESA Contract Representative
ND	Not Detected
NEESA	Naval Energy and Environmental Support Activity
NFI	No Further Investigation
ng/kg	Nanogram per kilogram
NGVD	National Geodetic Vertical Datum
NIOSH	National Institute for Occupational Safety and Health
NL	Not Listed
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observable Adverse Effect Level
NPDES	National Pollutant Discharge Elimination System
NR	Not Reported
NTP	National Toxicology Program
NTU	Nephelometric Turbidity Unit
OERR	Office of Emergency and Remedial Response
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
OVA	Organic Vapor Analyzer
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated biphenyl
PDE	Potential Dietary Exposure
PE	Performance Evaluation
PEM	Performance Evaluation Mixture
pg/g	Picogram per gram

**ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C
(Continued)**

pg/L	Picogram per liter
POTW	Publicly Owned Treatment Works
ppb	Parts per billion
PPE	Personal Protective Equipment
ppm	Parts per million
ppt	Parts per trillion
PRC	Preliminary Risk Characterization
PRG	Preliminary Remedial Goal
PSA	Preliminary Site Assessment
psi	Pounds per square inch
PVC	Polyvinyl Chloride
%R	Percent Recovery
%RSD	Percent Relative Standard Deviation
%D	Percent Difference
QA/QC	Quality Assurance/Quality Control
RAB	Restoration Advisory Board
RAD	Recommended Daily Allowance
RAGS	Risk Assessment Guidance for Superfund
RBC	Risk-Based Concentration
RBSL	Risk-Based Screening Level
RCRA	Resource Conservation and Recovery Act
RDA	Charleston Naval Complex Redevelopment Authority
RFA	RCRA Facility Assessment
RfC	Reference Concentration
RfD	Reference Dose
RFI	RCRA Facility Investigation
RGO	Remedial Goal Option
RME	Reasonable Maximum Exposure
RPD	Relative Percent Difference
RRF	Relative Response Factor
RTC	Reserve Training Center
RTV	Reference Toxicity Value
SAA	Satellite Accumulation Area
SAS	Special Analytical Services
SC	South Carolina
SCDHEC	South Carolina Department of Health and Environmental Control
SDG	Sample Delivery Group
SF	Slope Factor

ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C
(Continued)

SFF	Site Foraging Factor
SMCL	Secondary Maximum Contaminant Level
SOP	Standard Operating Procedure
SOUTHDIV	Southern Division Naval Facilities Engineering Command
SPLP	Synthetic Precipitation Leaching Procedure
SQL	Sample Quantitation Limit
SSL	Soil Screening Level
SSV	Sediment Screening Value
SVE	Soil Vapor Extraction
SVOA	Semivolatile Organic Analysis
SVOC	Semivolatile Organic Compound
SWMU	Solid Waste Management Unit
TCDD	Tetrachlorodibenzo-p-dioxin
TD/MS	Thermal Desorption/Mass Spectrometry
TD-GS/MS	Thermal Desorption-Gas Chromatography/Mass Spectrometry
TDS	Total Dissolved Solids
TEF	Toxic Equivalency Factor
TEM	Transmission Electron Microscopy
TEQ	TCDD Equivalency Quotient
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TSCA	Toxic Substances Control Act
TSS	Total Suspended Solid
TTAL	Treatment Technique Action Level
TU	Temporary Unit
UCL	Upper Confidence Limit
USDOT	United States Department of Transportation
USEPA	United States Environmental Protection Agency
UST	Underground Storage Tank
UTL	Upper Tolerance Limit
UV	Ultraviolet
UXO	Unexploded Ordinance
VOA	Volatile Organic Analysis
VOC	Volatile Organic Compound
WBZ	Water-Bearing Zone
WQC	Water Quality Control

ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C
(Continued)

$\mu\text{g}/\text{cm}^2$	Microgram per square centimeter
$\mu\text{g}/\text{g}$	Micrograms per gram
$\mu\text{g}/\text{kg}$	Microgram per kilogram
$\mu\text{g}/\text{L}$	Microgram per liter
2,4-D	2,4-dichlorophenoxyacetic acid
2,4-DB	2,4-dichlorophenoxybutyric acid
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
2,4,5-TP	Silvex

1.0 INTRODUCTION

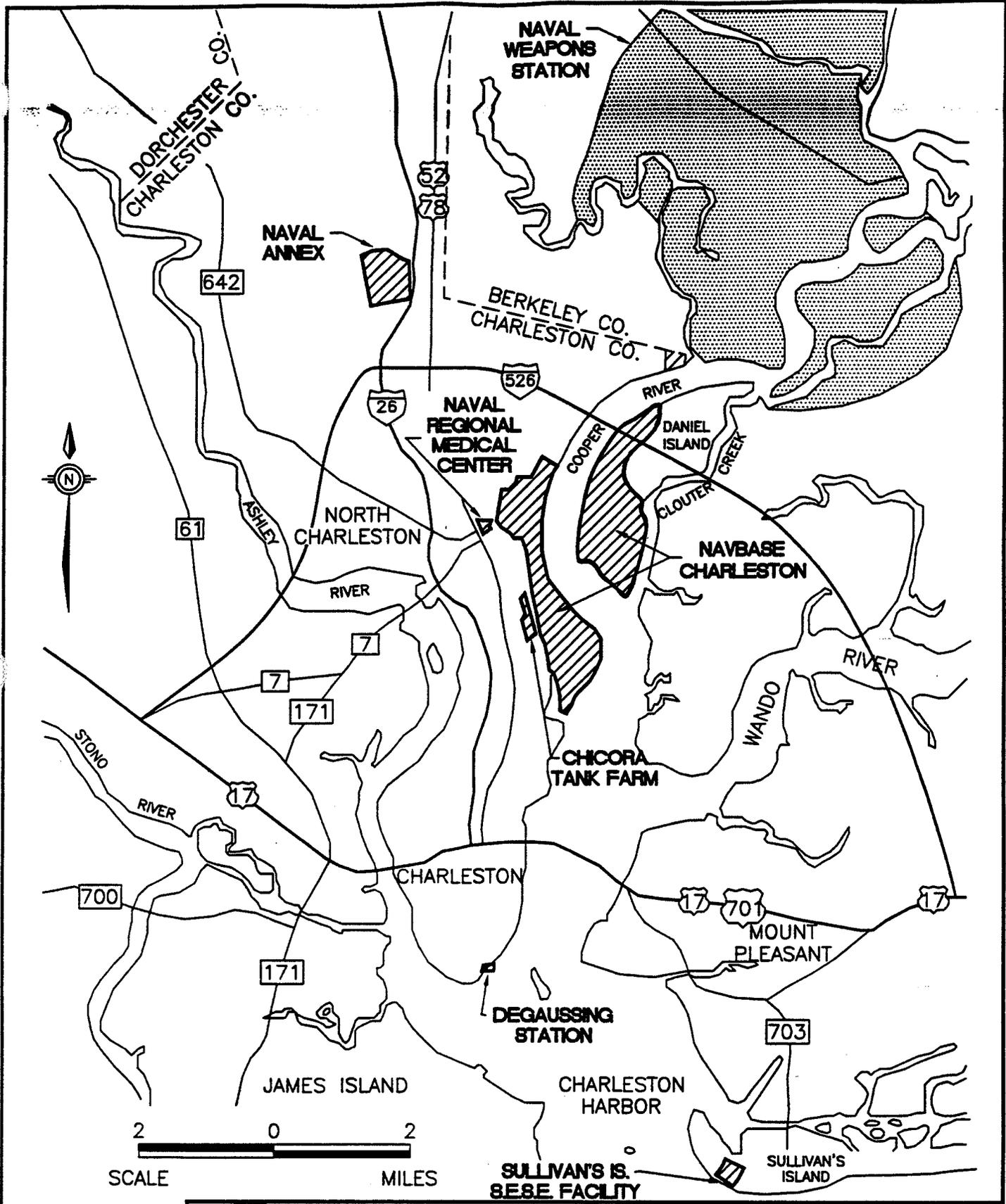
The environmental investigation and remediation at Naval Base Charleston (NAVBASE) are required by the Hazardous and Solid Waste Amendments (HSWA) portion of the Resource Conservation and Recovery Act (RCRA) Part B permit. These conditions are consistent with the RCRA Corrective Action Program, whose objectives are to evaluate the nature and extent of any hazardous waste or constituent releases, and to identify, develop, and implement appropriate corrective measures to protect human health and the environment. The scope of the RCRA Facility Investigation (RFI) includes the entire naval base, which has been divided into Zones A through L to accelerate the RFI process. This Zone C RFI Report, prepared by EnSafe Inc. (EnSafe), is submitted to satisfy condition II.C.6 of the HSWA portion of the Part B permit.

1.1 NAVBASE Description and Background

Location

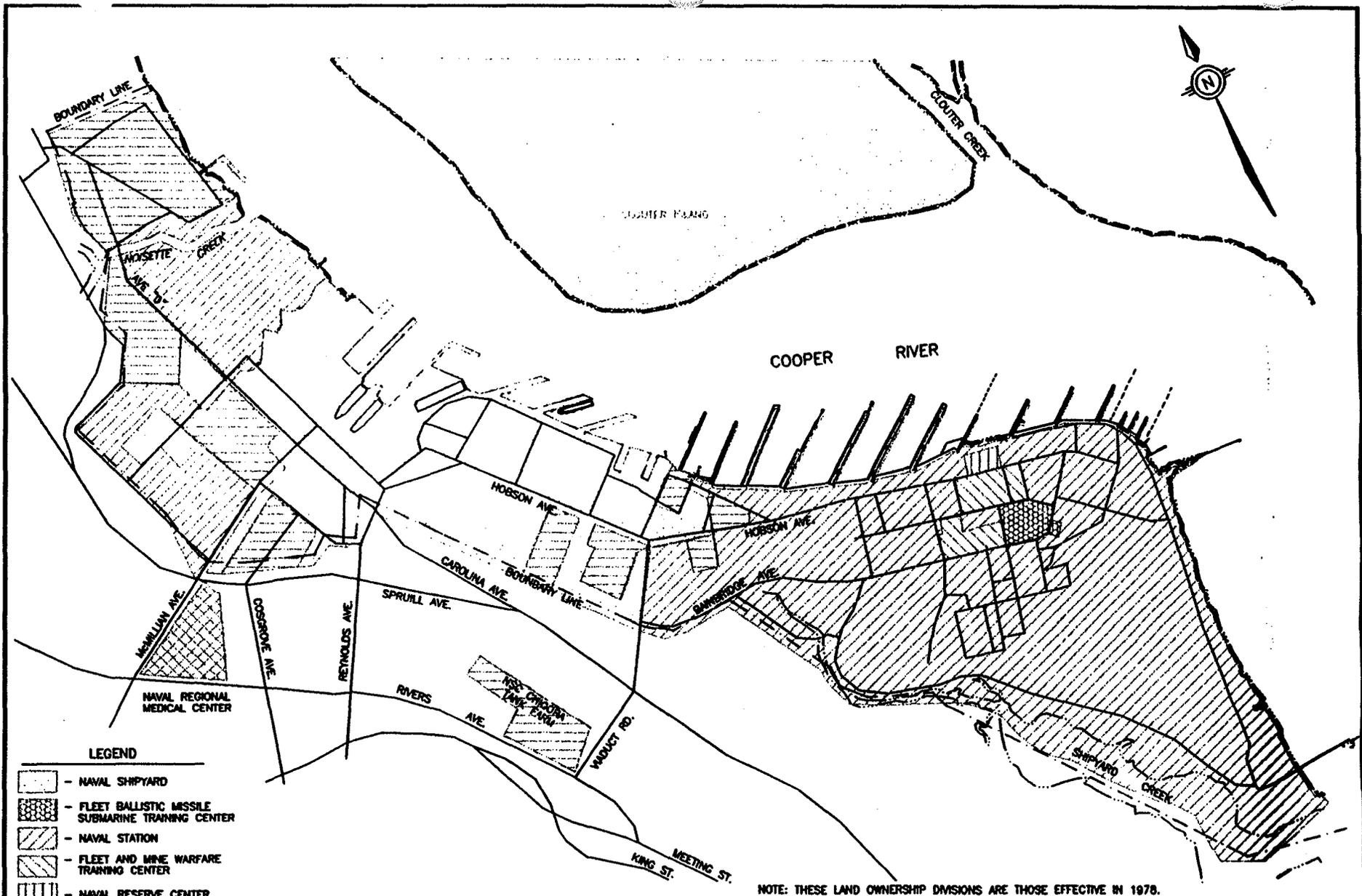
NAVBASE is in the city of North Charleston, on the west bank of the Cooper River in Charleston County, South Carolina (Figure 1.1). This installation consists of two major areas: an undeveloped dredged materials area on the east bank of the Cooper River on Daniel Island in Berkeley County, and a developed area on the west bank of the Cooper River (Figure 1.1).

The developed portion of the base is on a peninsula bounded on the west by the Ashley River and on the east by the Cooper River. Major commands that formerly occupied areas of the base include Charleston Naval Shipyard, Fleet Ballistic Missile Submarine Training Center, Fleet and Industrial Supply Center, Fleet and Mine Warfare Training Center, Naval Hospital Charleston, and Naval Station (Figure 1.2). NAVBASE also included the degaussing facility in downtown Charleston, the Shipboard Electronics System Evaluation Facility on Sullivan's Island, and the Naval Station Annex adjacent to the Charleston Air Force Base.



ZONE C
RCRA FACILITY
INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.

FIGURE 1.1
VICINITY MAP
NAVAL BASE CHARLESTON
CHARLESTON, SOUTH CAROLINA



- LEGEND**
- NAVAL SHIPYARD
 - FLEET BALLISTIC MISSILE SUBMARINE TRAINING CENTER
 - NAVAL STATION
 - FLEET AND MINE WARFARE TRAINING CENTER
 - NAVAL RESERVE CENTER
 - FLEET AND INDUSTRIAL SUPPLY CENTER
 - NAVAL REGIONAL MEDICAL CENTER

2000 0 2000
 SCALE FEET

SOURCES: SOUTHCOV, n.d. ESE, 1981.

NOTE: THESE LAND OWNERSHIP DIVISIONS ARE THOSE EFFECTIVE IN 1978.



ZONE C
 RCRA FACILITY
 INVESTIGATION REPORT
 NAVAL BASE CHARLESTON
 CHARLESTON, S.C.

FIGURE 1.2
 LOCATIONS OF
 LAND HOLDINGS AND OCCUPANTS

DWG DATE: 09/25/97 | DWG NAME: 29EBSLOC

The areas surrounding NAVBASE are *mature urban*, having long been developed with commercial, industrial, and residential land uses. Commercial areas are primarily west of NAVBASE; industrial areas lie primarily north of NAVBASE and along the west bank of Shipyard Creek.

The area west of Shipyard Creek has been concentrated with industrial users for many years. Railways have served the area since the early 1900s. The presence of railways, when combined with nearby waterways, has made the area ideal for industry. While ownership has changed from time to time, the land adjacent to NAVBASE remains dedicated to chemical, fertilizer, oil refining, metallurgy, and lumber operations.

In contrast, the east bank of the Cooper River is undeveloped and contains extensive wetlands, particularly along Clouter Creek and Thomas Island. Active dredged materials disposal areas are on Navy property between the Cooper River and Clouter Creek.

History

In 1901, the U.S. Navy acquired 2,250 acres near Charleston to build a naval shipyard, and the first naval officer was assigned duty in early 1902. A work force was organized, the navy yard surveyed, and construction of buildings and a drydock began. The drydock was finished in 1909, along with several other brick buildings and the main power plant, which are still in use today. With a work force of approximately 300 civilians, the first ship was placed in drydock and work began on fleet vessels in 1910. World War I brought about an expansion of the yard, land area, and work force. Employment levels dropped following the war. Work increased at the yard beginning in 1933, when a larger workload, principally in construction of several Coast Guard tugs, a Coast Guard cutter, and a Navy gunboat, created the need for more facilities and a much larger work force.

Civilian employment peaked in 1943 with almost 26,000 employees divided among three daily shifts. In 1956, construction began on new piers, barracks, and buildings for mine warfare ships and personnel. Later in the decade, Charleston became a major homeport for combatant ships and submarines of the U.S. Atlantic Fleet.

Base Closure

Today, NAVBASE Charleston is in the process of shutting down operations. In 1993, NAVBASE Charleston was added to the list of bases scheduled for closure under the Defense Base Realignment and Closure Act (BRAC), which regulates the closure and transition of property to the community. Operations have been scaled back and environmental cleanup has begun to make the property available for redevelopment after closure on April 1, 1996.

1.2 Base Closure Process for Environmental Cleanup

The Installation Restoration Program

In 1980, the Department of Defense established the Installation Restoration Program (IRP) to investigate and clean up contamination which may have resulted from past operations, storage, and disposal practices at federal facilities around the country. The Navy adopted this program, which has regulatory requirements similar to those developed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Although federal installations were not required to comply with this act until it was amended in 1986, the Navy has, in effect, been complying with its environmental regulations through participation in the IRP since 1980.

Resource Conservation and Recovery Act

The primary focus of NAVBASE environmental cleanup activities falls under RCRA, which was passed by Congress to control the handling of hazardous materials and wastes and to set standards for hazardous waste generation, transportation, treatment, storage, and disposal. NAVBASE was issued a hazardous waste permit in 1990 in accordance with this act, allowing the base to operate

within these guidelines. Hazardous materials include substances such as chemicals, pesticides, petroleum products, paints, and cleaners identified by the U. S. Environmental Protection Agency (USEPA) as being potentially harmful to human health or the environment.

The NAVBASE hazardous waste permit covers the investigation and cleanup of individual sites called solid waste management units (SWMUs) as well as areas of concern (AOCs) resulting from past hazardous waste spills. SWMUs and AOCs are defined in the Part B permit as follows:

- **SWMU** — "Any unit which has been used for the treatment, storage, or disposal of solid waste at any time, regardless of whether the unit is or ever was intended for the management of solid waste. RCRA-regulated hazardous waste management units are also solid waste management units. SWMUs include areas that have been contaminated by routine and systematic releases of hazardous constituents, excluding one-time accidental spills that are immediately remediated and cannot be linked to solid waste management activities (e.g., product or process spills)."

- **AOC** — "Any area having a probable release of a hazardous waste or a hazardous constituent which is not from a solid waste management unit and is determined by the Regional Administrator to pose a current or potential threat to human health or the environment. Such areas of concern may require investigations and remedial actions as required under Section 3005(c)(3) of the Resource Conservation and Recovery Act and 40 CFR §270.32(b)(2) in order to ensure adequate protection of human health and the environment."

Where appropriate in this document, SWMUs and AOCs are collectively referred to as *sites*.

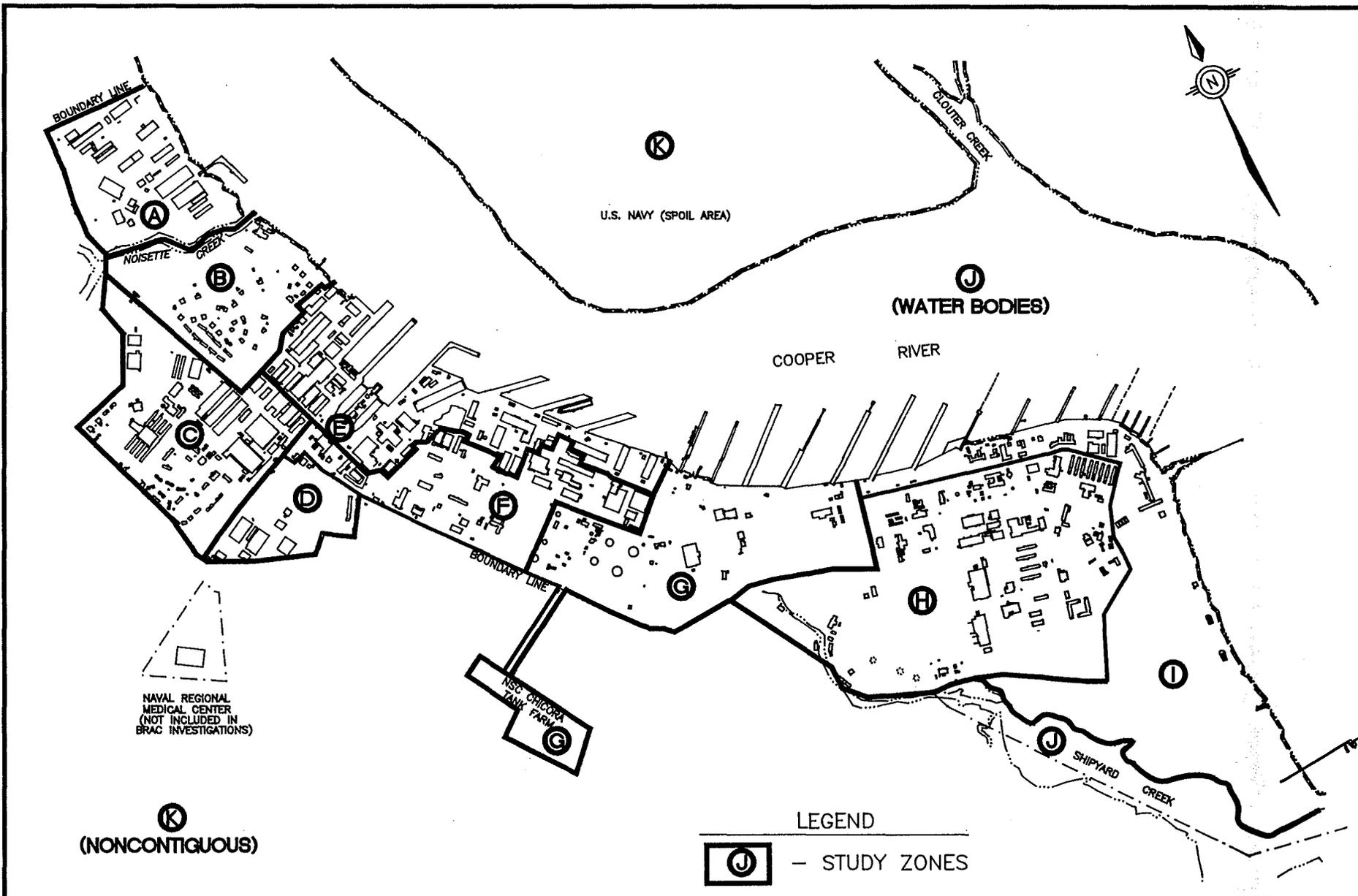
The investigation and cleanup activities are referred to as "corrective measures." The main steps of the corrective measures process are outlined below.

- *RCRA Facility Assessment (RFA)* identifies potential or actual contaminant releases through a records review and visual examination of every SWMU and AOC.
- *RCRA Facility Investigation (RFI)* confirms contamination and determines its nature. This investigation also examines the extent and rate of any migration and provides baseline data to evaluate corrective measures.
- *Corrective Measures Study (CMS)* determines and evaluates cleanup alternatives for the site. This study also recommends a preferred cleanup option or corrective measure.
- During *Corrective Measures Implementation (CMI)*, the selected corrective measure is designed, constructed, operated, maintained, and monitored for performance.
- *Interim Corrective Measures (ICMs)* are used to stabilize, control, or limit further releases from a site. Interim measures can be imposed at any point in the process.

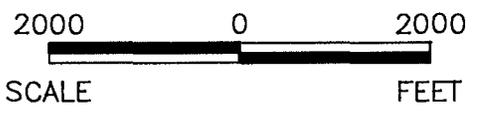
1.3 Investigative Zone Delineation

Due to the size of the base and the level of detail required for investigations, NAVBASE has been divided into 12 investigative zones, identified as A through L, as shown in Figure 1.3.

The zone investigations and cleanups were ranked by the Restoration Advisory Board and the BEST (Building Economic Solutions Together) committee (a board authorized by the state to study and report on the best reuse options for the property being transferred). In 1994, BEST was



(K)
(NONCONTIGUOUS)



SOURCES: SOUTHDM, n.d. ESE, 1981.

LEGEND
 - STUDY ZONES



ZONE C
 RCRA FACILITY
 INVESTIGATION REPORT
 NAVAL BASE CHARLESTON
 CHARLESTON, S.C.

FIGURE 1.3
 INVESTIGATIVE
 ZONE BOUNDARIES

DWG DATE: 10/03/97 | DWG NAME: 029ZONEC

replaced by the Charleston Naval Complex Redevelopment Authority, which has authority to establish leases for the transferred property. Zone C is on the western edge of the northern portion of NAVBASE. The zone is bounded by McMillian Avenue on the south; Hobson Avenue on the east; Avenue "D" on the northeast and the NAVBASE property boundary on the west and north. Zone C contains properties identified in the *Final Environmental Impact Statement for Disposal and Reuse of the Charleston Naval Base* (Ecology and Environment, Inc., June 1995) to be used for housing, open space/buffer, community support, and office/training.

1.4 Current Investigation

Objective

The objectives of the RFI are to characterize the nature and extent of contaminants associated with releases from SWMUs and AOCs, to evaluate contaminant migration pathways, and to identify both actual and potential receptors. The ultimate goal is to determine the need for ICMs or a CMS. This need will be evaluated by conducting a baseline risk assessment (BRA) to assess the risks posed to human health and the environment by individual and/or groups of sites within a zone.

Scope

Twenty-four sites were identified in Zone C through the RFA process. Each site in Zone C is detailed in the *Final RCRA Facility Assessment* (E/A&H, June 6, 1995).

Recommendations for investigative approach at each site were based on the best information available at that time and are subject to change should more information become available.

These investigatory designations are as follows:

- *No Further Investigation (NFI)* — This designation was applied to an AOC or SWMU if sufficient data were available during the RFA process to thoroughly assess the potential

hazards associated with the site and to determine that it does not pose a threat to human health or the environment.

- *Confirmatory Sampling Investigation (CSI)* — This designation was applied to an AOC or SWMU if insufficient data were available during the RFA process to thoroughly assess the potential hazards associated with the AOC or SWMU. Generally, a limited amount of confirmatory samples are needed to determine whether a hazard exists. The result of the confirmatory sampling will determine whether no further investigation finding is appropriate or a full-scale RFI is warranted.

- *RFI* — This designation was applied to AOCs or SWMUs if visual evidence, historical information such as spill reports, or analytical data indicate that hazardous substances have been released to the environment. The RFI characterizes the site to determine the nature and extent of contamination, to identify migration pathways, to identify actual and potential receptors, and to evaluate the ecological and human health risks posed by the site.

Of the 24 SWMUs and AOCs identified in the RFA, 16 required further investigation. The *Final Zone C RFI Work Plan* (E/A&H, November 1995) outlined an investigative strategy for each site designated for a CSI or RFI. This RFI report only addresses sites included in the work plan and addendum. Table 1.1 summarizes each Zone C SWMU and AOC requiring further investigation and its investigative approach, and Figure 1.4 shows the SWMU and AOC locations.

1.5 Previous Investigations

In addition to data generated during this investigation, information from previous Zone C investigations was reviewed for this report. Pertinent data have been incorporated where appropriate. A previous investigation at SWMU 44 included physical and confirmatory sampling.



AOC #700
GOLF
MAINTENANCE
BUILDING

SWMU #44
COAL
STORAGE
AREA

SWMU #47
BURNING
DUMP

AOC #512
INCINERATOR
BLDG. (67)

AOC #516
BLDG. 233
WASH AREA

AOC #515
BLDG. 51
INCINERATOR

AOC #513
OLD
MORGUE

AOC #510
BLDG. NH-21
GEOTECHNICAL
LABORATORY

AOC #508
INCINERATOR
(19)

AOC #511
OIL
HOUSE

AOC #517
BLDG. M-192
FIRING RANGE

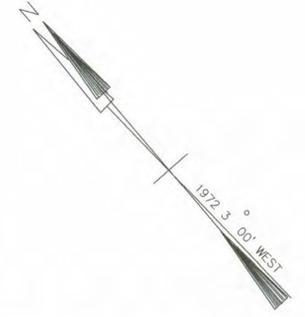
AOC #520
BLDG. M-1051
GARBAGE HOUSE

AOC #519
BLDG. 1081
BOILERHOUSE

AOC #518
COAL
BINS

AOC #523
BLDG. M-1234
GAS STATION
STORAGE

AOC #522
FORMER
BLDG M-1252
GREASE & WASH
BUILDING



LEGEND

-  CSI - CSI
-  RFI - RFI
-  - RCRA INVESTIGATION ZONES

300 0 300 600 900
GRAPHIC SCALE

REVISION	
Rev Number: 001	Rev Date: 04/04/96 Added AOCs 522 and 700. (LM)
Rev Number: 000	Rev Date: 00/00/00
Rev Number: 000	Rev Date: 00/00/00
Rev Number: 000	Rev Date: 00/00/00

ZONE C
RCRA FACILITY
INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.

FIGURE 1.4
ZONE C LOCATION MAP

Dr by: E/A&H
Tr by:
Ck by: D.Niesse
App by:
Date: 10/09/97
DWG Name: 29AOC5MU
Sheet 1
Of 1

Table 1.1
Zone C SWMUs and AOCs with Investigatory Designations

Zone C AOCs and SWMUs	Site Description	Investigative Approach	Investigation Grouping
SWMU 44	Coal Storage Area	RFI	Investigated independently
AOC 516	Wash Area/Battery Charging	RFI	AOC and SWMU were investigated together.
SWMU 47	Former Burning Dump	RFI	
AOC 508	Former Incinerator	CSI	AOCs were investigated together.
AOC 511	Former Oil Storage	CSI	
AOC 515	Former Incinerator and Paint Shop	CSI	AOCs were investigated together.
AOC 519	Former Boiler House	CSI	
AOC 510	Geotechnical Laboratory	CSI	Investigated independently
AOC 512	Former Incinerator	CSI	Investigated independently
AOC 513	Former Morgue	CSI	Investigated independently
AOC 517	Former Indoor Firing Range	CSI	Investigated independently
AOC 520	Former Garbage House	CSI	Investigated independently
AOC 522	Former Grease and Wash Area	CSI	Investigated independently
AOC 518	Former Coal Bins	CSI	Investigated independently
AOC 523	Former Gas Station	CSI	Investigated independently
AOC 700	Golf Course Maintenance Building	RFI	Investigated independently

Soil, surface water, and sediment samples collected were analyzed for metals and physical parameters. 1
2

1.6 RFI Report Organization

To facilitate review of the RFI report, sections have been formatted to discuss zone-wide information, overall technical approach, and evaluation methodologies first. These general informational sections are sequenced according to the natural progression of an RFI investigation.

The zone-wide sections are:

- 1.0 INTRODUCTION
- 2.0 PHYSICAL SETTING
- 3.0 FIELD INVESTIGATION
- 4.0 DATA VALIDATION
- 5.0 DATA EVALUATION AND BACKGROUND COMPARISON
- 6.0 FATE AND TRANSPORT
- 7.0 HUMAN HEALTH RISK ASSESSMENT
- 8.0 ECOLOGICAL RISK ASSESSMENT
- 9.0 CORRECTIVE MEASURES

The site-specific sections are:

- 10.0 SITE-SPECIFIC (SWMU and AOC) EVALUATIONS
- 11.0 CONCLUSIONS

and:

- 12.0 REFERENCES
- 13.0 SIGNATORY REQUIREMENT

Section 10 of the RFI Report follows the same chronology as Sections 1 through 9 (zone-wide) 1
except on a site-specific (SWMU and AOC) basis. The section is subdivided by specific AOCs 2
or SWMUs and includes the actual data summaries, risk calculations, and corrective measures 3
evaluations specific to that site. In this manner, the entire investigation sequence, including 4
conclusions, is contained within a specific tabbed section for easy reference. 5

Section 11 of the RFI Report summarizes the conclusion sections derived from each Section 10 6
site-specific summary. In this manner, conclusions regarding which sites are recommended for 7
the CMS and which are recommended for no further action can be easily determined. Section 12 8
is a compilation of references. 9

2.0 NAVBASE PHYSICAL SETTING

2.1 Geology

2.1.1 Regional Physiographic and Geologic Description

NAVBASE is in the Lower South Carolina Coastal Plain Physiographic Province, on the Cooper River side of the Charleston Peninsula, which is formed by the confluence of the Cooper and Ashley rivers. Topography in the area is typical of the South Carolina lower coastal plain, having low-relief plains broken only by the meandering courses of sluggish streams and rivers which flow toward the coast past occasional marine terrace escarpments. NAVBASE is essentially flat. Elevations range from just over 20 feet above mean sea level (msl) in the northwest part of the base to sea level at the Cooper River. Most of the original topography at NAVBASE has been modified by activities such as dredge spoil deposition. The southern end of the base was originally tidal marsh drained by Shipyard Creek and its tributaries. The original elevations in other portions of the base were only slightly higher. The land surface at NAVBASE has been elevated with both solid wastes and dredged materials (primarily the latter) in increments over the last 93 years. Nonetheless, most of NAVBASE remains within the 100-year flood zone of less than 10 feet above msl.

Charleston area geology is typical of the southern Atlantic Coastal Plain. Cretaceous and younger sediments thicken seaward and are underlain by older igneous and metamorphic basement rock. Surface exposures at NAVBASE, in the limited areas which remain undisturbed, consist of recent and/or Pleistocene sands, silts, and clays of high organic content referred to as the Wando Formation (Weems and Lemon, 1993). Underlying the Wando Formation, increasing with age, are the Oligocene-age Cooper Group and the Eocene-age Santee Limestone. The Cooper Group consists of the Parker's Ferry, Ashley, and Harleyville formations. The formation of particular importance in the Cooper Group is the Ashley Formation, which was formerly referred to as the Cooper Marl in most NAVBASE reports and regional geologic literature. In more recent geologic nomenclature, the name *Cooper* has been given to a group of formations

which includes the Ashley Formation, which is a pale-green to olive-brown, sandy, phosphatic limestone or marl, locally muddy and/or sandy. The Ashley Formation in the vicinity of Charleston is encountered at a depth of approximately 30 to 70 feet below ground surface (bgs). The relief of the top of the Ashley Formation is associated with an erosional basin (Park, 1985). Park identifies the entire Cooper Unit, of which the Ashley Formation is a member and hydrogeologically similar, as being approximately 300 feet thick.

Surface soil at NAVBASE has been extensively disturbed. Native soil is the fine-grained silts, silty sands, and clay typical of terrigenous tidal marsh environments. Sand lenses are present in localized areas; however, these are generally only a few feet thick. Much of NAVBASE has been filled using dredged materials from the Cooper River and Shipyard Creek. The dredged materials are an unsorted mixture of sands, silts, and clays.

2.1.2 NAVBASE Geologic Investigation

Geological and stratigraphic information has been obtained from soil and monitoring well borings installed during the RFIs for Zones A, B, E, and C. Data for the Zone C investigation have been assessed and are included in the geologic and hydrogeologic assessment presented in this report. The soil was classified and logged by an EnSafe geologist as described in the Final RFI Comprehensive Sampling and Analysis Plan (CSAP), (E/A&H, August 1994). Shelby tubes collected during soil sampling were analyzed for porosity, grain size, and vertical permeability.

Two phases of drilling and well installation occurred during the Zone C RFI. The initial phase occurred between March and April 1995 with the installation of 26 shallow wells and two shallow/deep well pairs. After collecting and evaluating the groundwater and soil data from the initial investigation, a second shallow well installation phase took place in August 1997. In all, four temporary shallow wells were installed at AOCs 508, 511, and 512. Additionally, two deep soil borings were drilled to the top of the Ashley Formation at SWMU 44 for lithologic data (044SB027 and 044SB028).

Monitoring well construction data are summarized in Table 2.1. Figure 2.1 presents all Zone C well locations. Monitoring well construction diagrams and associated lithologic boring logs are included in Appendix A.

Table 2.1
Zone C Monitoring Well Construction Data

Monitoring Well ID	Date Installed	TOC Elev. (msl)	Grnd. Elev. (msl)	Drilled Data (feet bgs)			DTW (TOC)	GW Elev.* (msl)
				TOS	BOS	BOW		
<i>Zone C RFI Monitoring Wells</i>								
NBCC044001	3/29/95	11.70	9.3	2.0	12.0	12.0	4.82	7.18
NBCC044002	3/29/95	11.20	8.9	3.1	13.1	13.1	7.23	5.87
NBCC044003	3/29/95	11.14	9.1	3.0	13.0	13.0	7.23	5.77
NBCC044004	3/30/95	10.95		4.3	14.3	14.4	7.11	7.29
NBCC044005	3/30/95	7.77	5.5	3.6	13.6	14.5	4.38	10.12
NBCC044006	3/30/95	7.75	5.3	2.0	12.0	12.0	2.78	9.22
NBCC044007	4/3/95	9.74	7.3	2.9	12.9	12.9	8.02	4.88
NBCC044008	4/3/95	11.13	8.7	3.4	13.4	13.5	6.03	7.47
NBCC047001	4/11/95	8.35	8.3	2.9	12.9	12.9	4.17	8.73
NBCC047002	4/6/95	9.80	10.1	3.0	13.0	13.0	6.67	6.33
NBCC047003	4/10/95	9.26	9.1	2.9	12.9	12.9	6.12	6.78
NBCC047004	4/10/95	9.08	9.2	2.5	12.5	12.5	5.54	6.96
NBCC047005	4/5/95	11.14	8.7	2.0	12.0	12.0	7.30	4.70
NBCC047006	4/5/95	12.27	9.8	2.1	12.1	12.1	7.53	4.57
NBCC047007	4/12/95	9.28	9.4	2.5	12.5	12.5	4.47	8.03
NBCC047008	4/12/95	9.16	9.4	2.6	12.6	12.6	4.58	8.02
NBCC047009	4/11/95	8.62	8.8	2.9	12.9	12.9	4.45	8.45
NBCC047010	4/12/95	8.30	8.4	2.6	12.6	12.6	4.09	8.51
NBCC047011	4/10/95	8.21	8.3	2.6	12.6	12.6	4.60	8.00
NBCC047012	4/10/95	8.56	8.6	2.9	12.9	12.9	5.15	7.75
NBCC047013	4/17/95	9.25	9.3	2.5	12.5	15.0	5.66	9.34
NBCC047015	4/17/95	8.96	9.1	2.5	12.5	15.0	4.92	10.08
NBCC510001	4/4/95	29.16	27.0	11.0	21.0	21.0	17.82	3.18
NBCC510002	4/5/95	28.30	26.3	11.0	21.0	21.0	17.27	3.73
NBCC523001	4/4/95	7.89	8.3	2.5	12.5	12.6	4.63	7.97
NBCC523002	4/4/95	9.10	9.5	2.4	12.4	12.4	5.40	7.00
NBCCGDC001	3/28/95	26.98	25.4	3.5	13.5	14.0	12.05	1.95
NBCCGDC01D	4/4/95	11.45	24.8	26.0	36.0	36.0	12.66	23.34
NBCCGDC002	3/29/95	27.69	9.0	2.0	12.0	14.0	7.29	6.71
NBCCGDC02D	4/5/95	11.17	9.3	61.0	71.0	9.3	7.84	1.46

Table 2.1
Zone C Monitoring Well Construction Data

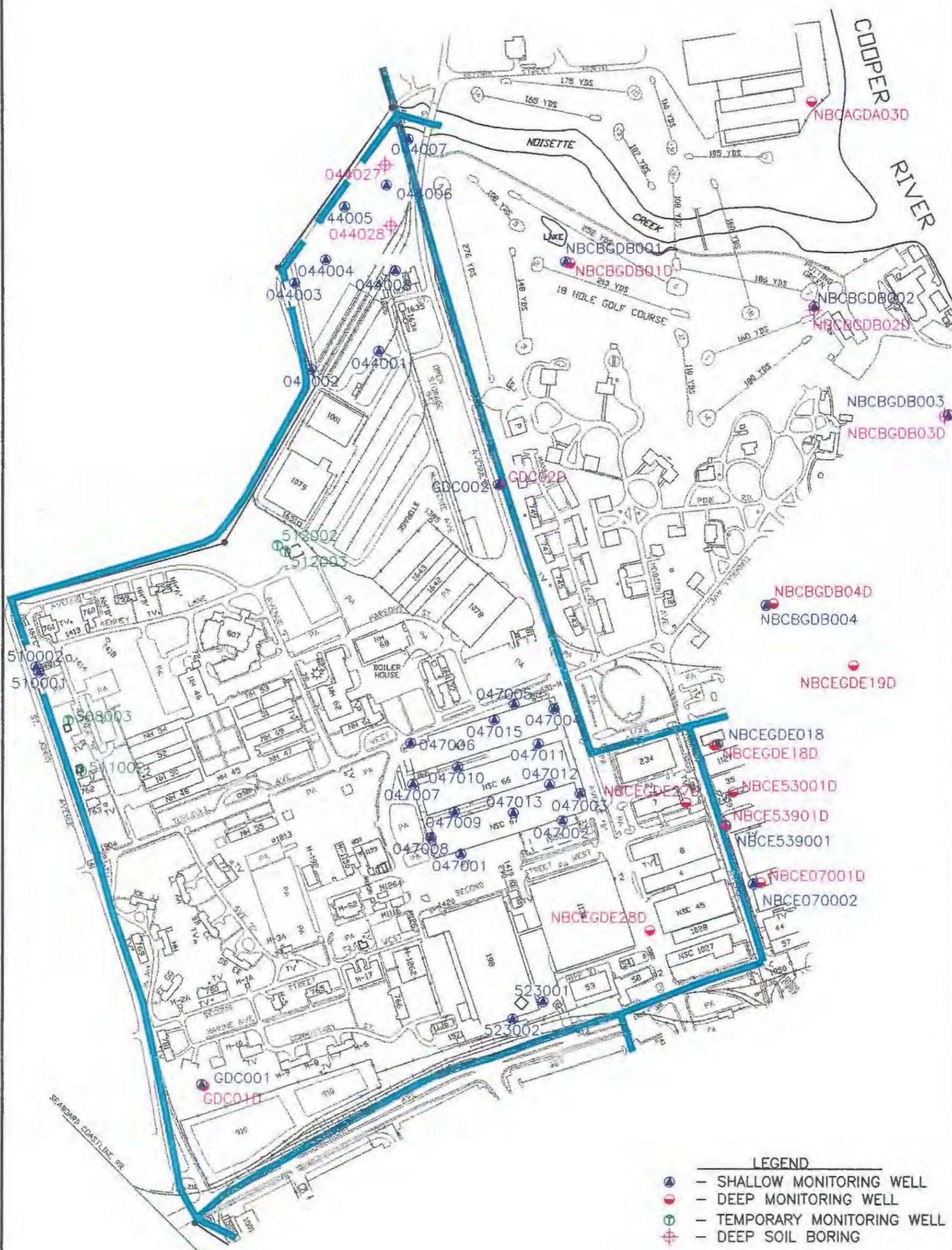
Monitoring Well ID	Date Installed	TOC Elev. (msl)	Grnd. Elev. (msl)	Drilled Data (feet bgs)			DTW (TOC)	GW Elev.* (msl)
				TOS	BOS	BOW		
Temporary Monitoring Wells								
NBCC508003	8/7/97	29.44	26.9	9.5	19.2	19.5	13.78	15.66
NBCC511002	8/6/97	29.09	26.6	10.0	19.7	20.0	12.34	16.75
NBCC512002	8/7/97	10.23	7.9	2.0	11.7	12.0	3.83	6.40
NBCC512003	8/7/97	12.38	10.0	3.0	12.7	13.0	5.21	7.17
Zone E RFI Monitoring Wells								
NBCEGDE027	9/11/96	10.19	7.2	3.0	12.0	13.0	6.98	3.21
NBCEGDE27D	9/12/96	9.79	7.2	28.2	37.2	38.0	6.59	3.20
NBCEGDE028	9/13/96	9.62	9.7	3.8	12.8	13.8	7.02	2.60
NBCEGDE28D	9/10/96	9.52	12.3	21.7	25.7	26.5	6.79	2.73

Notes:

- bgs = below ground surface
- msl = mean sea level
- TOC = Top of well casing
- TOS = Top of screened interval
- BOS = Bottom of screened interval
- DTW = Depth to water
- * = Depths to groundwater vary seasonally and diurnally. These depths should only be considered approximate (6/21/95 data presented for Zone C wells; 8/8/97 data presented for Zone C temporary wells; 10/16/96 data presented for Zone E wells).

Two shallow/deep well pairs, NBCEGDE027/27D and NBCEGDE028/28D, drilled during the Zone E RFI, and are located within the southeastern portion of Zone C. Lithologic data from these two borings as well as those within Zone B were considered in evaluating the subsurface geology of Zone C. Please refer to the *Final RFI Report CTO-0029 Zone B (E/A&H, November 1996)* and *Draft Zone E RFI Report (E/A&H, November 1997)* for boring log data for these additional locations.

Of the stratigraphic formations described in Section 2.1.1, the two most prominent formations encountered were the Wando and Ashley formations. The lowermost stratigraphic unit identified is the Ashley Formation of the Tertiary Cooper Group. The bulk of the sediments overlying the



LEGEND

- - SHALLOW MONITORING WELL
- - DEEP MONITORING WELL
- - TEMPORARY MONITORING WELL
- ⊕ - DEEP SOIL BORING

400 0 400
 SCALE FEET


ZONE C
 RCRA FACILITY
 INVESTIGATION REPORT
 NAVAL BASE CHARLESTON
 CHARLESTON, S.C.

FIGURE 2.1
 ZONE C
 GROUNDWATER MONITORING WELL
 LOCATION MAP
 DWG DATE: 10/09/97 DWG NAME: 2903GWMW

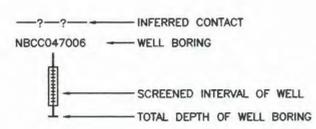
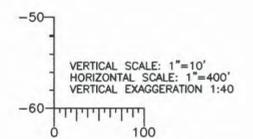
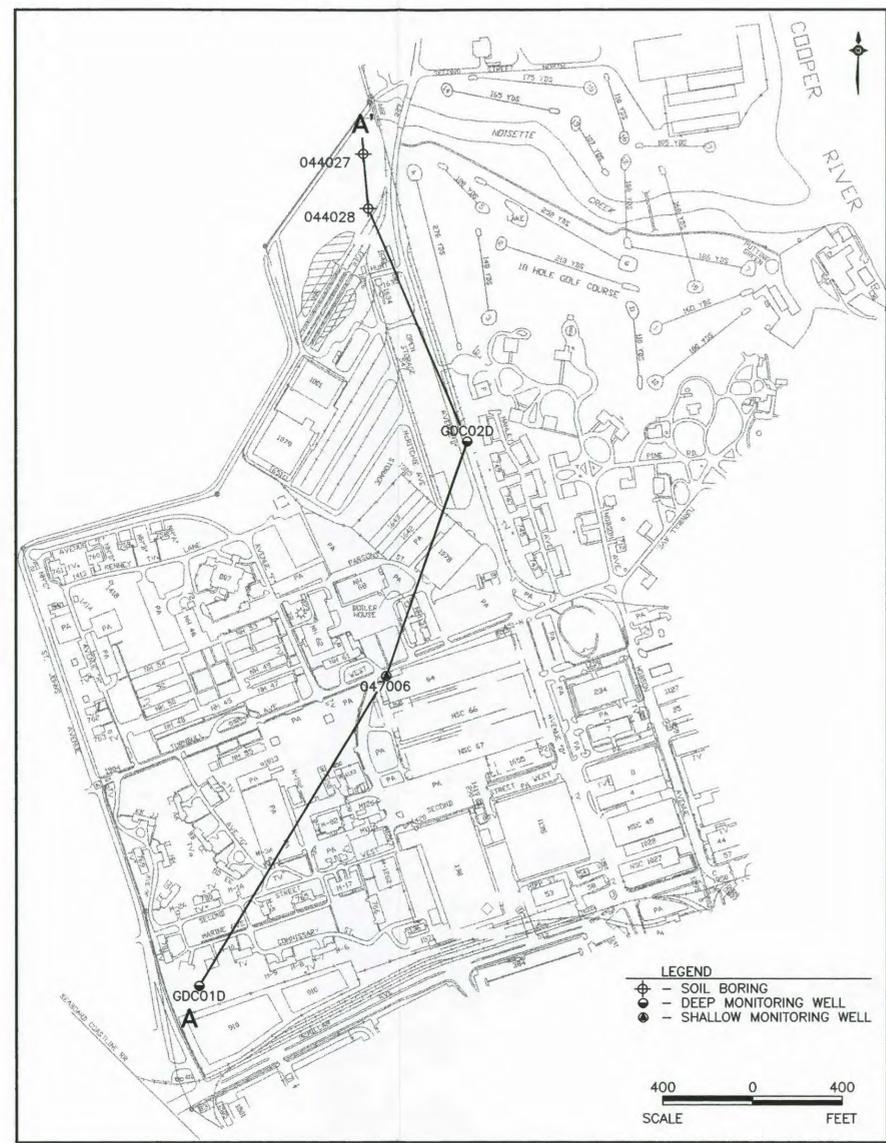
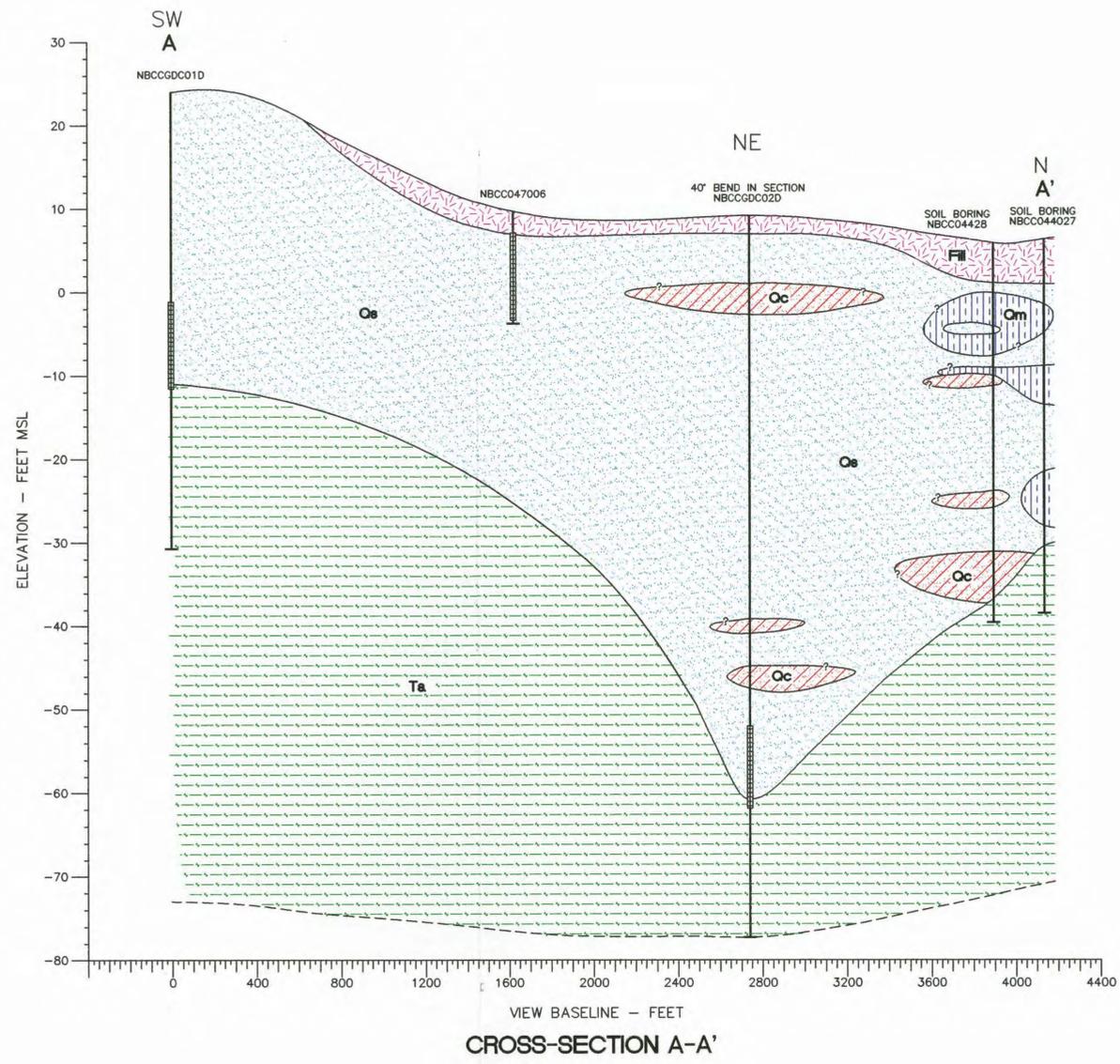
Ashley are thought to make up the Quaternary Wando Formation. However, several different Quaternary-age units are physically similar to the Wando and cannot be unequivocally identified in the field. There is also the possibility of Quaternary-age reworking of Tertiary sediments. As a result, the deposits encountered overlying the Ashley were lumped into Quaternary-age groupings.

Borehole lithologic information in Zone C is limited the information to the upper 85 feet of the subsurface. Boring data were used to construct a lithologic cross section A-A' across Zone C (Figure 2.2). Additional boring data from Zones A, B, and E deep well locations were used to construct a contour map of the elevation of the top of the confining unit, which is primarily the Ashley Formation for most of Zone C (Figure 2.3).

2.1.3 Ashley Formation (Ta)

The Ashley Formation was encountered in all Zone C deep borings. The top of this formation, which was the target of deep borings, was encountered from -6.1 feet msl and -60.7 feet msl at locations GDE28D and GDC02D, respectively. The significant relief of its surface is clearly evident in Figures 2.2 and 2.3. Shallow elevations of the Ashley exist in the southern portion of the zone and decrease towards the north. A depression in the Ashley is located in the vicinity of GDC02D.

The Ashley Formation is an olive-yellow to olive-brown, tight, calcareous, sandy and clayey silt often found dry in split-spoon samples. A sample collected for physical parameter analysis from the Ashley Formation at GDC02D was composed of 26% sand, 47% silt, and 27% clay. Five Ashley Formation samples collected in Zone H for grain-size analysis revealed an average silt, sand, and clay content of 49%, 27%, and 27%, respectively. Geotechnical information for the physical parameter samples collected in Zone C is presented in Appendix B.



LEGEND

Fill	Undifferentiated mixture of medium to high plasticity clays, fine sand, silt, gravel and ROC. Varies greatly with location.
Qc	QUATERNARY CLAY--light gray to green-gray with occasional mottling of orange or red; medium plasticity; typically stiff; some very fine to fine sand present usually in matrix; no organic material.
Qm	QUATERNARY MARSH CLAY--gray to black; highly organic; low to medium plasticity; soft; silty; occasional very fine to fine sand present as stringers and laminae; also occurs as older, more compacted and stiff marsh clay deposits at depth. AQUITARD
Qs	QUATERNARY SAND--light brown to gray; predominantly very fine to fine with occasional gradations of medium to coarse grain fractions; occasional shell hash and phosphate nodules. AQUIFER.
Ta	TERTIARY ASHLEY FORMATION--olive-green to olive-brown silt with varying amounts of clay and very fine sand; medium plasticity, firm to stiff, trace calcareous. CONFINING UNIT.

REVISION

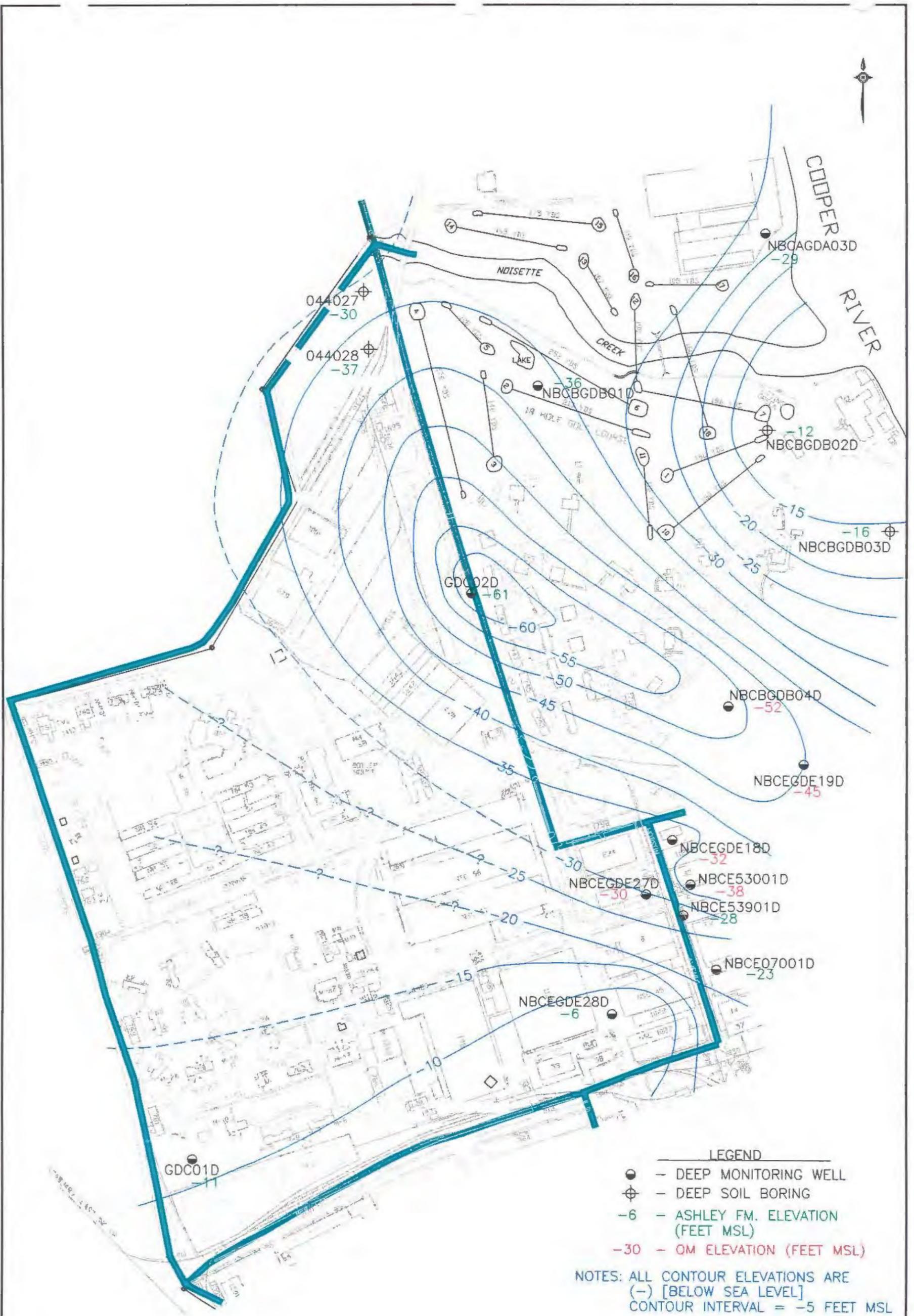
Rev Number:000	Rev Date:00/00/00	Rev By: NAME
Rev Number:000	Rev Date:00/00/00	Rev By: NAME
Rev Number:000	Rev Date:00/00/00	Rev By: NAME
Rev Number:000	Rev Date:00/00/00	Rev By: NAME
Rev Number:000	Rev Date:00/00/00	Rev By: NAME

**ZONE C
FINAL RCRA FACILITY
INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.**

**FIGURE 2.2
LITHOLOGIC CROSS SECTION
A-A'**

Dr by: E. ROGERS	Tr by: E. ROGERS
Ck by: T. KAFKA	App by: A. DENNEN
Date: 10/06/97	DWG Name: 2903LCSA

Sheet 1
Of 1



- LEGEND**
- - DEEP MONITORING WELL
 - ⊕ - DEEP SOIL BORING
 - 6 - ASHLEY FM. ELEVATION (FEET MSL)
 - 30 - OM ELEVATION (FEET MSL)

NOTES: ALL CONTOUR ELEVATIONS ARE (-) [BELOW SEA LEVEL]
 CONTOUR INTERVAL = -5 FEET MSL




ZONE C
 RCRA FACILITY
 INVESTIGATION REPORT
 NAVAL BASE CHARLESTON
 CHARLESTON, S.C.

FIGURE 2.3
 ZONE C
 TOP OF CONFINING UNIT
 ELEVATION CONTOUR MAP
 DWG DATE: 10/09/97 DWG NAME: 2903TCUE

2.1.4 Quaternary-Age Sediments

Overlying the Ashley Formation in Zone C and extending to ground surface (in areas not covered by fill materials) are Quaternary-age sediments which range in thickness from approximately 16 to 70 feet at GDE28D and GDC02D, respectively. Four Shelby tube samples were collected from the near surface (< 20 feet bgs) Quaternary-age sediments underlying Zone C. The average porosity for these samples was 35%. The grain-size distribution for these samples averaged 96% sand, 3% silt, and 1% clay.

The Quaternary-age deposits introduced in Figure 2.2 consisted of three lithologic units, which are briefly summarized as follows:

- **Quaternary-age clay (Qc):** Light gray to green-gray with occasional orange and red mottling; medium plasticity; typically stiff; some very fine to fine sand present usually in matrix; no organic material.
- **Quaternary-age marsh clay (Qm):** Gray to black; highly organic; low to medium plasticity; soft; silty; occasional very fine to fine sand present as stringers and laminae; also occurs as older, more compacted and stiff, dewatered marsh clay deposits at depth.
- **Quaternary-age sand (Qs):** Light brown to gray; predominantly very fine to fine with occasionally gradations of medium to coarse grain fractions; occasional shell hash and phosphate nodules.

The Qs unit is the most predominant of the Quaternary-age units found in Zone C. The Qm and Qc deposits have limited lateral continuity and are primarily localized. The greater concentration of Qm deposits to the north reflects the marsh environment associated with Noisette Creek.

The boring log for GDC01D illustrates the lithology encountered in the extreme southwestern portion of Zone C. Fine sand was present in this well from the surface to 15 feet bgs. From 15 to 26 feet bgs, the lithology is primarily sandy clay, although clay content decreases over the last 2 to 3 feet. A well-sorted, medium to coarse grained shell hash was present from 26 to 29 feet bgs, which was underlain by another 7 feet of fine sand to 36 feet bgs. The Ashley Formation was encountered at the base of this sand.

A significant variation in lithologic composition was encountered at GDE27D in the southeastern portion of the zone. Beneath the upper 5 feet of fill (clay and unconsolidated sand), a 20-foot section of very fine to fine sand (Qs) with some medium-grained lenses and silty sections was encountered. Rapidly interbedded fine-grained silty sand and clay laminae were present from 25 to 35 feet bgs, followed by more than 2 feet of poorly sorted, fine to coarse sand with shell fragments and black phosphate fragments to approximately 37 feet bgs. Older, compacted marsh clay (Qm) was present from 37 feet bgs to the top of the Ashley Formation at 40 feet bgs.

The boring log for GDC02D illustrates the lithology encountered along the Zone C and B boundary in the vicinity of the depression in the Ashley Formation shown in Figures 2-2 and 2-3. The interval between ground surface and the top of the Ashley Formation at GDC02D is primarily fine to medium-grained sand (Qs), except for three deposits of stiff, gray clay (Qc) present at 8 to 12 feet bgs, 49-50 feet bgs, and 54-57 feet bgs. From 57 feet bgs to the top of the Ashley Formation at 70 feet bgs, sand (Qs) with increased silt and clay content was present. A sample collected for physical parameter analysis from 54 to 70 feet bgs was composed of 78% sand, 10%

silt, and 12% clay. The depth of sand development at this location reflects the extensive erosion of the Ashley Formation during the Quaternary period.

2.1.5 Soil

The extent of fill materials in Zone C reflects topographical relief within the zone. Fill materials were not encountered along the southwestern and western portions of the zone, which are higher in elevation and are primarily residential. Lower elevations to the east, southeast, and northeast (near Noisette Creek) are closer in elevation to sea level and have a greater preponderance of fill materials in the upper 5 to 10 feet of the shallow subsurface.

2.2 NAVBASE Hydrogeology

2.2.1 Regional Hydrologic and Hydrogeologic Background

Parts of the southern portion of NAVBASE are drained by Shipyard Creek, while northern areas are drained by Noisette Creek. The drainage basins of both waterways include areas other than NAVBASE. These waterways are tributaries to the Cooper River. Surface drainage over the remainder of NAVBASE flows directly into the Cooper River, which discharges into Charleston Harbor.

Shipyard Creek, a small tidal tributary about 2 miles long, flows southeast along the southwestern boundary of NAVBASE to its confluence with the Cooper River opposite the southern tip of Daniel Island. Piers line the western shore of the channel's lower mile, while the entire length of the eastern shore is bounded by tidal marshland.

Noisette Creek, which transects the northern portion of NAVBASE, is a tidal tributary approximately 2.5 miles long. The creek flows nearly due east from its headwaters in the City of North Charleston and empties into the Cooper River.

Groundwater occurs under water table or poorly confined conditions within the Pleistocene deposits overlying the Ashley Formation. Transmissivities in the Pleistocene aquifer are generally less than 1,000 square feet per day (feet²/day) and well yields are variable, ranging from 0 to 200 gallons per minute (gpm). This groundwater contains high concentrations of iron and is commonly acidic at shallow depths (Park, 1985).

The Ashley Formation is hydrogeologically significant mainly because of its low permeability. In most locales, its sandy, finely granular limestones produce little or no water and act as confining material that produces artesian conditions in the underlying Santee Limestone (Park, 1985).

The Santee Limestone aquifer is typically artesian, except in outcrop areas. Yields from wells in the Santee are typically less than 300 gpm (Park, 1985).

2.2.2 NAVBASE Hydrogeologic Investigation

Hydrogeological information was obtained from slug test analysis and water level measurements conducted during the Zone C RFI. Vertical permeability, grain-size distribution, and porosity were estimated from analysis of Shelby tube samples collected during drilling.

2.2.3 Lower Confining Unit

The high clay and silt content, laterally consistent overall thickness, and very low vertical permeabilities of the Ashley Formation indicate that this formation behaves as a confining unit beneath much of Zone C. Zone H Shelby tube samples collected from the Ashley exhibited a very low average vertical hydraulic conductivity of 0.0027 feet per day. According to Fetter (1988), sediments with permeabilities of 10⁻⁵ centimeters per second (cm/sec) (0.03 feet/day) or less can be considered confining units. The low vertical permeability in the Ashley indicates an extremely low potential for groundwater movement downward through the unit. The fact that samples collected from this formation were dry to moist lends further credence to its designation as an

aquitard. As a confining unit, the Ashley behaves as a hydraulic barrier between the water-bearing Quaternary-age sediments and underlying formations.

As shown in Figure 2.3, the Ashley Formation was not encountered at several locations close to the Zone C boundary in Zone E (NBCEGDE18D and NBCE53001D) and Zone B (NBCBGDB04D); instead, older, compacted deposits of marsh clay (included as Qm deposits in the Zone C lithologic unit classification) were found. Samples of this unit from the Zone E RFI (classified as Qco in the *Draft Zone E RFI Report*) had an average vertical permeability of 2.16×10^{-6} cm/s (0.0061 feet/day) and averaged 4.5% sand and 95.4% silt and clay. These physical characteristics are similar to those of the Ashley, indicating that the older, compacted and dewatered Qm deposits also behave as a confining unit, although localized in extent. At GDE27D, 3 feet of Qm was found overlying the Ashley, indicating that the unit pinches out to the west. Therefore, it is thought that the confining unit beneath all but the extreme southeastern corner of Zone C is the Ashley Formation.

2.2.4 Surficial Aquifer

The high sand content (approximately 90%) and moderate vertical permeability of the Quaternary-age units found in Zone C indicate that this formation is an aquifer. Shelby tube samples collected from this formation exhibited a moderate average vertical hydraulic conductivity of 2.1 feet/day. According to Anderson (1990) and Fetter (1988), sediments with permeabilities between 1 and 10 feet per day and greater than 0.03 feet/day are defined as unconfined fine sand with water-transporting capabilities.

The surficial aquifer primarily behaves as an unconfined aquifer throughout Zone C. Shallow wells monitor fluctuations of the water table, which was generally encountered within 6 feet bgs. Deep wells, in the absence of any aquitards, monitor hydrostatic pressure of the unconfined aquifer for that portion of the aquifer immediately overlying the confining unit. The presence of

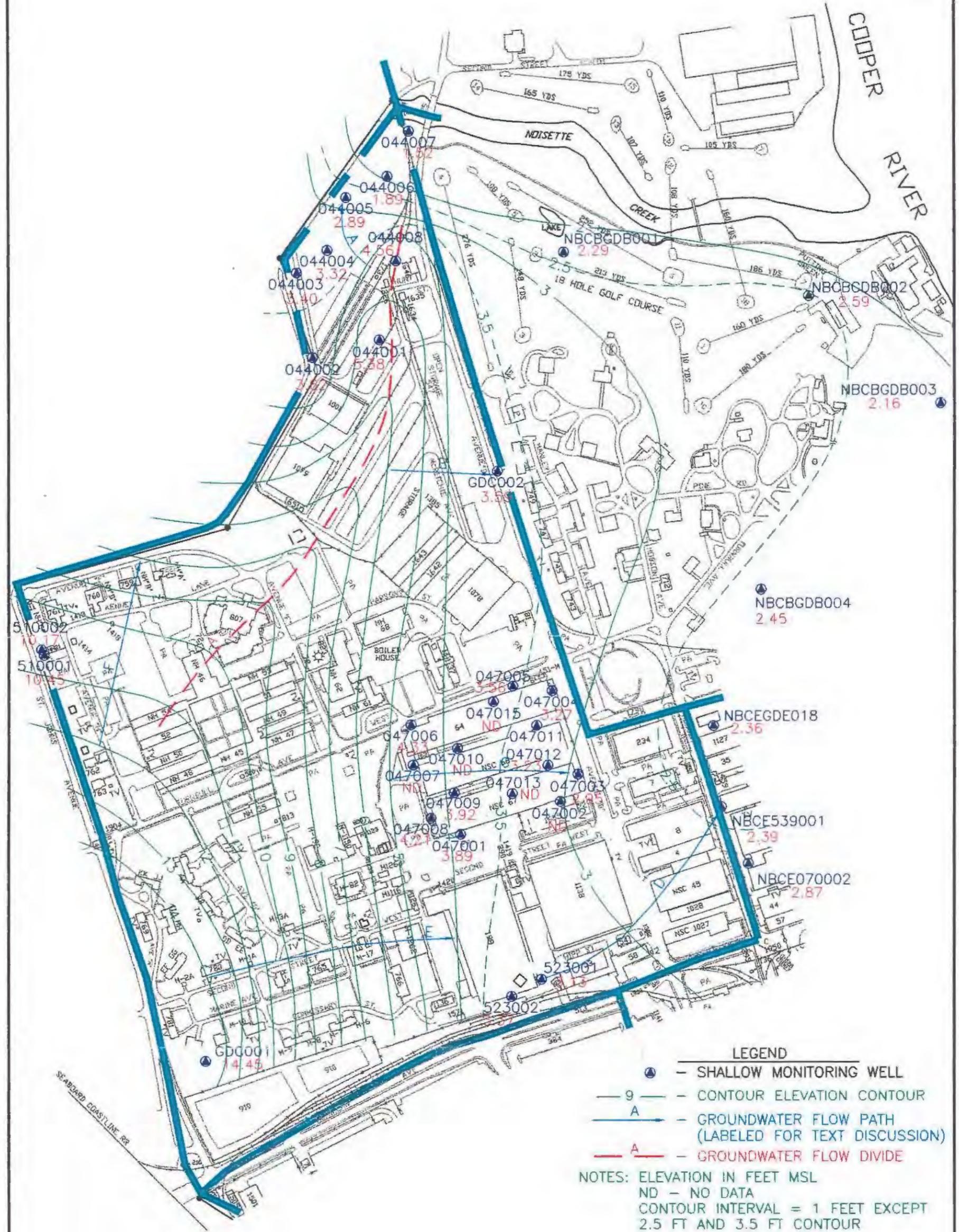
Qc and Qm deposits may result in locally semi-confining conditions in Zone C, primarily in areas of greater clay development (i.e., Noisette Creek and SWMU 44). Localized semi-confined conditions are probably prevalent at GDC02D based on the 3-foot thick Qc deposit located approximately 5 feet above the top of the well screen (Figure 2.2).

2.2.5 Groundwater Flow Direction

Groundwater levels in Zone C wells were measured as part of a base-wide water level measurement event on June 28, 1996. Since the shallow well screens intersect the water table, groundwater elevations measured in shallow wells represent the water table surface. A groundwater elevation map using the shallow well data is presented in Figure 2.4; it includes several Zone B and E wells to further define the geometry of the water table surface. Four wells at SWMU 47 were inaccessible during this event and are labeled "ND" for no data in Figure 2.4. Intermediate contours representing the 2.5 and 3.5-foot elevations were included to further define the hydraulic head domain.

Groundwater elevations are highest in the west and southwestern portion of Zone C. A groundwater divide (labeled "A" in Figure 2.4) trends roughly southwest to northeast and separates the northwestern and southeastern portion of the zone. Groundwater northwest of divide "A" either flows off NAVBASE property or toward SWMU 44. Southeast of divide "A" groundwater flows east toward Zones B and E.

A Zone C deep well groundwater elevation map was not constructed due to the limited number and spacing of deep wells. The deep wells will, however, be used in developing base-wide groundwater elevation maps.



- LEGEND**
- - SHALLOW MONITORING WELL
 - 9 — - CONTOUR ELEVATION CONTOUR
 - A — - GROUNDWATER FLOW PATH (LABELED FOR TEXT DISCUSSION)
 - A — - GROUNDWATER FLOW DIVIDE

NOTES: ELEVATION IN FEET MSL
 ND - NO DATA
 CONTOUR INTERVAL = 1 FEET EXCEPT
 2.5 FT AND 3.5 FT CONTOUR



ZONE C
 RCRA FACILITY
 INVESTIGATION REPORT
 NAVAL BASE CHARLESTON
 CHARLESTON, S.C.

FIGURE 2.4
 ZONE C
 SHALLOW GROUNDWATER ELEVATION
 MAP - JUNE 28, 1996
 DWG DATE: 10/03/97 DWG NAME: 2903SGEM

2.2.6 Vertical Hydraulic Gradient

When water levels at the two shallow/deep well pairs in Zone C are compared, one well pair exhibited a positive hydraulic gradient and the other a negative gradient. Positive gradients indicate a downward potential for vertical flow and negative gradients indicate potential for upward flow.

Table 2.2 presents the calculated vertical hydraulic gradients between the shallow/deep well pairs. The vertical gradients were calculated by dividing the differences between shallow and deep water level elevations by the vertical distance between the bottom of the well screens.

**Table 2.2
 Vertical Hydraulic Gradients**

Well Pair	Groundwater Elevation Difference (ft)	Vertical Distance (ft)	Vertical Hydraulic Gradient (ft/ft)
GDC001/GDC01D	0.3	22.5	0.01
GDC002/GDC02D	-0.8	59	(-)0.01

Note:
 (-) = upward potential

The well pair at GDC001/GDC01D has a downward hydraulic gradient (positive), indicating the potential for groundwater to flow from upper to lower portions of the aquifer. The well pair at GDC002/GDC02D exhibits a negative vertical gradient, indicating a potential for upward vertical flow of groundwater in the aquifer. This is probably a reflection of the presence of a Qc aquitard overlying the deep well screen and the fact that the well location coincides with an erosional scour in the Ashley Formation. A vertical hydraulic gradient map is provided in Figure 2.5.



LEGEND
 ● - DEEP MONITORING WELL
 0.01 - DOWNWARD GRADIENT
 -0.01 - UPWARD GRADIENT

400 0 400
 SCALE FEET

 ZONE C
 RCRA FACILITY
 INVESTIGATION REPORT
 NAVAL BASE CHARLESTON
 CHARLESTON, S.C.

FIGURE 2.5
 ZONE C
 VERTICAL HYDRAULIC GRADIENTS
 DWG DATE: 10/10/97 | DWG NAME: 2903VHGD

2.2.7 Horizontal Hydraulic Gradient

The shallow groundwater elevation map (Figure 2.4) was used to construct representative groundwater flowpaths across various portions of Zone C. Six flowpaths, labeled A-F in Figure 2.4, were drawn for gradient calculations. Flowpaths A and C provide gradient estimates across SWMUs 44 and 47, respectively. The remaining flowpaths estimate generalized gradients across the zone. At some locations, well locations coincided with flowpath endpoints, while at others, estimates from the contour lines were used. Table 2.3 presents horizontal hydraulic gradients computed along each flowpath.

Table 2.3
Horizontal Hydraulic Gradient

Flowpath	Δh (ft)	Δx (ft)	i (ft/ft)
A	1.11	310	0.0036
B	2.41	435	0.0055
C	2.05	785	0.0026
D (shallowest)	0.74	1035	0.0007
E (steepest)	10	1050	0.0095
F	4	790	0.0051

Notes:

- Δh = Change in hydraulic head
- Δx = Change in distance
- i = horizontal hydraulic gradient

The steepest gradient was calculated in the southwestern portion of Zone C. The shallowest was in the southeastern portion of the zone. The gradients across SWMUs 44 and 47 are similar in magnitude.

2.2.8 Hydraulic Conductivity (K_h)

Rising and falling head slug tests were conducted to determine the hydraulic conductivity of the aquifers. The hydraulic conductivities for shallow and deep aquifer depths are presented in Tables 2.4 and 2.5 and were plotted next to their respective wells to produce Figure 2.6. Injecting the slug produced falling head data and withdrawing the slug produced rising heads. Both rising and falling head slug tests were conducted on 30% of the wells installed in Zone C.

Table 2.4
Zone C
Shallow-Well Slug Test Hydraulic Conductivity Results in feet/day

Well	Rising Head K_h	Falling Head K_h	Geometric Mean*
044001	2.75	2.86	2.80
044006	1.22	1.50	1.35
047001	14.2	8.05	10.7
047003	5.18	Not Used	5.18
047006	5.67	2.90	4.06
510001	9.57	8.81	9.18
523001	5.40	2.89	3.95
GDC001	0.830	0.530	0.660
GDC002	6.78	3.45	4.84

Note:

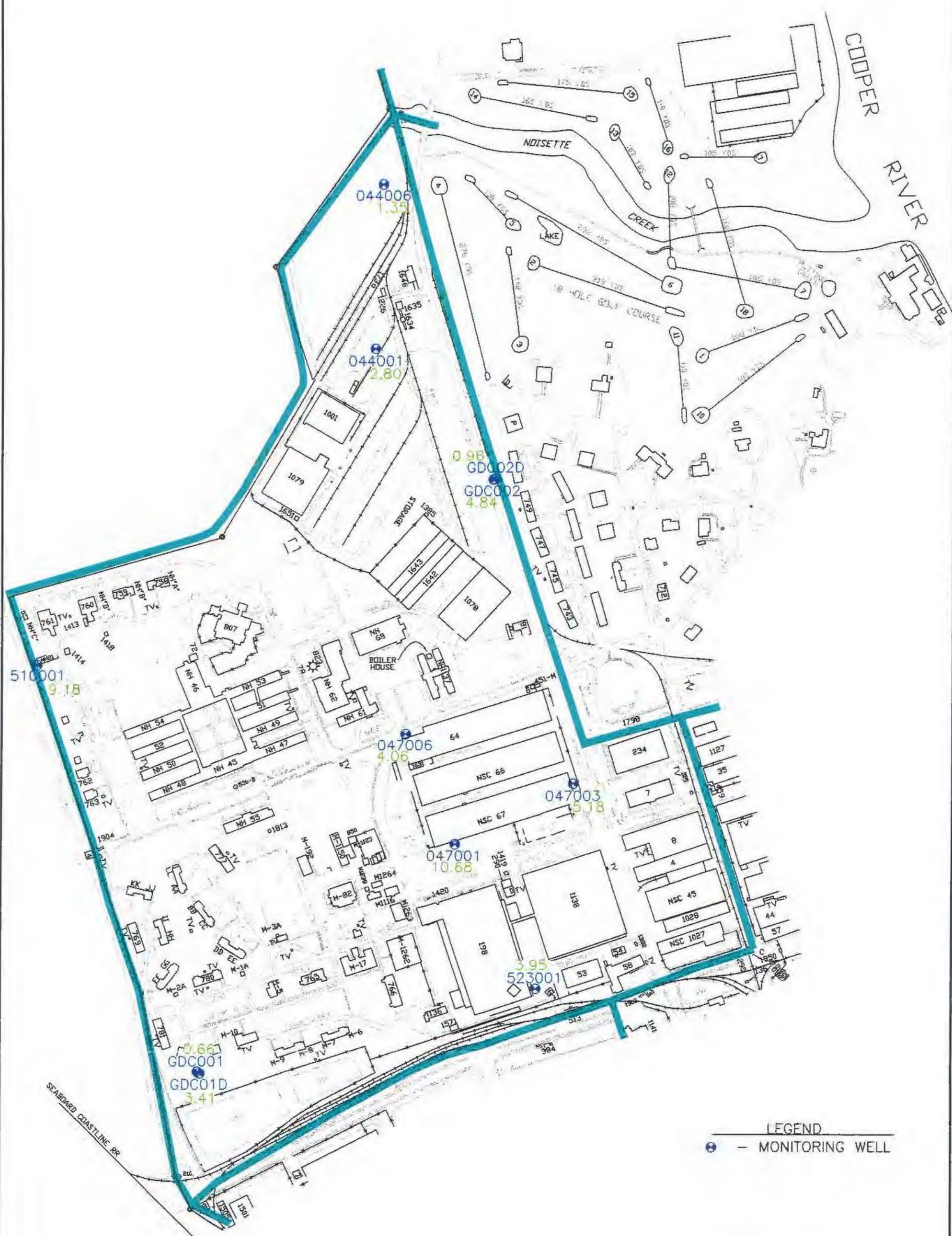
* = Average calculated using the falling and rising head values.

Table 2.5
Zone C
Deep-Well Slug Test Hydraulic Conductivity Results in feet/day

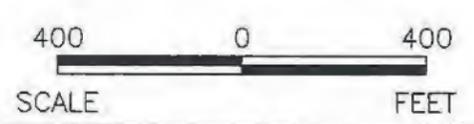
Well	Rising Head K_h	Falling Head K_h	Geometric Mean*
GDC01D	3.02	3.85	3.41
GDC02D	0.92	0.99	0.96

Note:

* = Average calculated using the falling and rising head values.



LEGEND
 - MONITORING WELL



NOTE: RESULTS ARE IN FEET/DAY



ZONE C
 RCRA FACILITY
 INVESTIGATION REPORT
 NAVAL BASE CHARLESTON
 CHARLESTON, S.C.

FIGURE 2.6
 ZONE C
 HYDRAULIC CONDUCTIVITY
 GEOMETRIC MEANS
 DWG DATE: 09/30/97 DWG NAME: 29ZNCMW2

Data from the slug tests were compiled using the computer program AQTESOLV (Aquifer Test Solver) by Geraghty and Miller Modeling Group (1989). Rising and falling head slug test data from the aquifer were plotted using an unconfined aquifer solution. For this solution, elapsed time versus displacement (change in water levels) was plotted on a semi-logarithmic graph. Hydraulic conductivity (K_h) was computed by the program using an equation developed by Bouwer and Rice (1976) for unconfined aquifers. The output from the program is included in Appendix C.

Because hydraulic conductivity data are lognormally distributed, the geometric mean is the best measure of central tendency. Therefore, the average hydraulic conductivity for each well is presented as the geometric mean of the falling and rising head values.

The range of shallow K_h values is 0.660 to 10.7 feet/day. The K_h value at GDE001 is anomalously low given its extensive sand development. Values at 044001 and 044006 are low due to the highly interbedded nature of sand and clay deposits associated with the marsh environment near Noisette Creek. Apart from SWMU 44, sand development within most of Zone C is extensive and fairly homogenous. An effective conductivity value (K_{eff}) of 4.38 feet/day was calculated as the geometric mean for all shallow well locations, except those at SWMU 44. A K_{eff} value for the two SWMU 44 locations was similarly calculated as 1.94 feet/day. These values will be used in Section 2.2.9 for horizontal groundwater velocity calculations.

The geometric mean from the deep well data is 1.81 feet/day.

2.2.9 Horizontal Groundwater Velocity

To estimate the rate at which groundwater and possibly dissolved contaminants are migrating, groundwater velocity was calculated using the following formula:

$$V = \frac{K * i}{n_e}$$

Where:

- V = horizontal groundwater velocity
- K = hydraulic conductivity
- i = horizontal hydraulic gradient
- n_e = effective porosity

The average porosity of 34.5% found in Quaternary sand (Qs) was used as the effective porosity in the equation. The horizontal hydraulic gradients presented in Section 2.2.7 and effective hydraulic conductivities (K_{eff}) determined in Section 2.2.8 were used in the above equation.

Table 2.6 presents estimated groundwater velocity along the six flowpaths previously presented in Figure 2.4. No velocity estimates were made for the deep aquifer since only two deep wells are in Zone C.

Table 2.6
Groundwater Velocity Results

Flowpath	K _{eff} (ft/day)	i (ft/ft)	Velocity (ft/day)
A	1.94	0.0036	0.0202
B	4.38	0.0055	0.0698
C	4.38	0.0026	0.0330
D	4.38	0.0007	0.0089
E	4.38	0.0095	0.1206
F	4.38	0.0051	0.0647

Notes:

- K_{eff} = effective hydraulic conductivity
- i = horizontal hydraulic gradient

2.3 Climate

The climate of the Charleston Harbor area is relatively mild compared to areas farther inland. The mountains in the northern portion of the state serve as a barrier to cold air masses from the northwest, and the Bermuda high-pressure system limits the progress of cold fronts into the area. These conditions produce relatively mild, temperate winters. Summers are hot and humid, but relatively moderate with regard to temperature extremes. Moderate summer temperatures are largely due to the influence of the Gulf Stream (S.C. SEA Grant Consortium, 1992).

The average monthly air temperatures for the Charleston area are presented in Table 2.7. The temperatures are generally moderated by marine influences and are often 2°C to 3°C lower in the summer and 3°C to 8°C higher in the winter than areas farther inland. Temperatures higher than 38°C and lower than -6.5°C are unusual for the area (S.C. SEA Grant Consortium, 1992).

Table 2.7
Mean Temperature and Wind Data
for Charleston Harbor between 1970 and 1985^a

Month	Daily Max (°C)	Daily Min (°C)	Mean Speed (km/hr)	Prevailing Direction
January	16.4	3.1	14.8	SW
February	16.8	4.5	16.6	NNE
March	20.0	7.3	16.7	SSW
April	24.9	11.5	16.1	SSW
May	28.8	16.6	14.3	S
June	31.6	20.6	13.7	S
July	31.6	22.2	13.0	SW
August	31.5	21.4	12.1	SW
September	29.2	18.8	13.0	NNE
October	25.1	12.7	13.2	NNE
November	19.9	6.6	13.2	N
December	16.1	3.5	14.0	NNE
Annual	24.3	12.4	14.2	NNE

^a Note: = S.C. SEA Grant Consortium, 1992

The wind direction and velocity in the Charleston area are highly variable, and rather evenly distributed in all directions. The inland portions of the region are subjected to a southwest-northeast wind regime. The prevailing winds are northerly in the fall and winter, and southerly in spring and summer. The monthly average wind velocities and directions for the area range from a low of 12.1 kilometers per hour (kph) in May to a high of 16.7 kph in March. The average monthly wind speeds and prevailing wind directions are also presented in Table 2.7 (S.C. SEA Grant Consortium, 1992).

The Charleston area averages 124.9 centimeters (cm) of precipitation annually, almost exclusively rainfall. Very little precipitation is recorded as snow, sleet, or hail. The greatest mean monthly precipitation is normally received in July while the smallest amount normally occurs in November (S.C. SEA Grant Consortium, 1992).

Relative humidity in the Charleston Harbor area is normally very high and fluctuates greatly. Generally, it is higher during the summer months than other times of the year, and the coastal areas exhibit a lower relative humidity than inland areas. The monthly mean relative humidity for four different times of day are presented in Table 2.8 (S.C. SEA Grant Consortium, 1992).

Cloud cover varies widely for Charleston, with annual averages of 101 clear days, 115 partly cloudy days, and 149 cloudy days. The mean monthly clear, partly cloudy, and cloudy days for the area are also presented in Table 2.8 (S.C. SEA Grant Consortium, 1992).

Table 2.8
Monthly and Annual Mean Precipitation, Relative Humidity, and Cloud Cover
for Charleston Harbor between 1960 and 1985^a

Month	Precipitation (cm)	Relative Humidity by Time (%)				Cloud Cover % Number of Days		
		0100	0700	1300	1900	Clear	Partly Cloudy	Cloudy
January	6.45	82	84	55	73	8	8	15
February	8.36	79	82	52	68	9	6	13
March	9.98	81	83	50	67	9	9	13
April	7.32	84	84	50	67	11	8	11
May	9.17	88	84	54	72	8	12	11
June	12.65	90	86	59	75	6	12	12
July	19.58	91	88	64	79	4	13	14
August	16.79	92	91	63	80	5	14	12
September	14.81	91	91	63	82	7	11	12
October	7.21	88	89	56	80	12	8	11
November	5.31	85	87	51	77	13	6	11
December	7.24	82	84	54	74	9	8	14
Annual	124.87	86	86	56	75	101	115	149

Note:
^a = (S.C. SEA Grant Consortium, 1992)

The primary concern as far as climate extremes are concerned is the occurrence of tropical cyclones or hurricanes. Hurricanes frequent the east coast of the United States and almost always have some effect on the weather around Charleston Harbor. Hurricanes normally occur between August and December. The last hurricane to make landfall in the Charleston area was Hurricane Hugo, a class IV hurricane which struck Charleston in September 1989 causing severe damage. Tornadoes are extremely rare in the vicinity but have occurred in the inland portions of Charleston County (S.C. SEA Grant Consortium, 1992).

3.0 FIELD INVESTIGATION 1

The following section lists the objectives of the field investigation and describes the technical sampling methodologies, procedures, and protocols implemented during data collection within Zone C. Fieldwork was conducted in accordance with the *Final Comprehensive Sampling and Analysis Plan* (E/A&H, August 1994) (CSAP) and the USEPA Region IV Environmental Services Division, *Standard Operating Procedures and Quality Assurance Manual* (USEPA, February 1991) (ESDSOPQAM). Sampling and investigatory methods used in the Zone C RFI investigation are summarized in this section. Any deviations from the approved work plans, such as the number of samples collected, modified locations, or procedures, etc., were documented in the field and are discussed in detail in Section 10, Site-Specific Evaluations. 2
3
4
5
6
7
8
9
10

3.1 Investigation Objectives 11

The sampling strategy for each AOC and SWMU in Zone C, as detailed in the *Final Zone C RFI Work Plan* (E/A&H, November 1995), was designed to collect sufficient environmental media data to accomplish the following: 12
13
14

- Characterize the facilities in Zone C. 15
- Define contaminant pathways and potential receptors (on and offsite, where applicable). 16
- Define the nature and extent of contamination, if any, at Zone C sites. 17
- Assess human health and ecological risk. 18
- Assess the need for corrective measures. 19

3.2 Sampling Procedures, Protocols, and Analyses 20

3.2.1 Sample Identification 21

All samples collected during this investigation were identified using the 10-character scheme from Section 11.4 of the CSAP. This scheme identifies the samples by site, sample matrix, location, and sample depth. The first three characters identify the site where the sample was collected. The 22
23
24

fourth character identifies the matrix or quality control (QC) code for the sample. The fifth through eighth characters identify the sample location. The ninth and tenth characters identify the soil sample depth or sample interval. For example: sample ID 044SB00402 is a second-interval soil sample from Boring B004 at SWMU 044. For the groundwater samples, the ninth and tenth characters identify the sampling sequence. For example, 523GW00101 is the first groundwater sample collected from monitoring well W001 at AOC 523, and 523GW00102 would indicate the second groundwater sample collected.

3.2.2 Soil Sampling

Section 4 of the CSAP describes soil sampling procedures and activities used in the RFI. The following subsections summarize site-specific procedures implemented in Zone C.

3.2.2.1 Soil Sample Locations

Soil samples were collected from locations proposed in the *Final Zone C RFI Work Plan* (E/A&H, November 1995), which were based on the investigation strategy outlined in Section 1.2 of that document. Each SWMU and AOC primary sampling pattern is justified in Sections 2.1 through 2.6 of the Work Plan. Some proposed sample locations were modified slightly due to utility locations. A few locations were inaccessible due to the thickness of concrete overlying the soil.

At some sites, additional samples were required to adequately characterize contaminant distribution. After the analytical data were interpreted for samples collected during the initial round of soil sampling, a second sampling round was proposed in some areas to define the extent of contamination. Typically, additional sample locations were justified due to relatively high contaminant concentrations identified on the previous sampling pattern's perimeter.

3.2.2.2 Soil Sample Collection

Composite soil samples were generally collected for laboratory analysis from 0 to 1 foot bgs and from 3 to 5 feet bgs. The 0- to 1-foot bgs interval is referred to in this report as the first or upper interval sample. At soil sample locations overlain by pavement, the upper interval was collected from the base of the pavement to 1 foot below the base of the pavement. The 3- to 5-foot bgs interval is referred to as the second or lower interval sample. No other intervals were sampled due to the relatively shallow depth to groundwater in Zone C, typically from 2 to 6 feet bgs. No saturated soil samples were retained for laboratory analysis.

Stainless-steel hand augers were used to collect soil samples. At sodded locations, the sod (generally less than 2 inches thick) overlying the soil sample at the upper interval was removed before augering to 1 foot bgs. As the auger filled with soil, it was removed from the hole, and its contents were placed in stainless-steel mixing bowls. This process was repeated until the entire interval had been collected. The lower interval sample was collected using a clean decontaminated stainless-steel auger, following the same procedures. A coring machine was used at numerous locations to gain access to soil covered by concrete and/or asphalt.

3.2.2.3 Soil Sample Preparation, Packaging, and Shipment

Section 11 of the CSAP details procedures for sample preparation, packaging, and shipment. Below is a brief overview of the procedures for soil samples.

Sample material was transferred from the stainless-steel bowl to a glass sample jar using a stainless-steel spoon. Samples collected for volatile organic analysis (VOA) were not homogenized, but were containerized immediately with zero headspace to minimize the possibility of volatilization. Soil for all other analyses was homogenized with a stainless-steel spoon and packed into appropriate containers. Any remaining soil was returned to the auger hole. Bentonite pellets, hydrated in place, were used to fill any remaining space.

Soil samples were identified as described in Section 3.2.1 of this document, and in accordance with Section 11.4 of the CSAP. From the moment of collection, labels were affixed to each sample container. Other pertinent information such as weather conditions, date and time of collection, sampling team, and a sketch of the location was included in a Zone C soil sampling logbook.

Soil sample containers were individually custody-sealed, encased in protective bubble wrap and a resealable plastic bag, and placed in a cooler for shipment. The samples were further packed with ice and double-bagged in waterproof resealable plastic bags to ensure proper preservation at 4°C. All samples were then entered onto an official chain-of-custody form, which was then affixed to the top, inside surface of the sample cooler.

After entering sample numbers, analyses, times, date, and an air-bill shipping number into an official shipping log, the coolers were shipped priority overnight via FedEx to the analytical laboratories.

3.2.2.4 Soil Sample Analysis

Soil samples were analyzed per USEPA SW-846 methods at Data Quality Objective (DQO) Level III unless otherwise noted, as follows:

- | | | |
|---|---|----------|
| • Volatile organic compounds (VOCs) | USEPA Method 8240 | 18 |
| • Semivolatile organic compounds (SVOCs) | USEPA Method 8270 | 19 |
| • Pesticides/polychlorinated biphenyls (PCBs) | USEPA Method 8080 | 20 |
| • Cyanide | USEPA Method 9010 | 21 |
| • Metals | Title 40 Code of Federal Regulations (CFR) Part 264 Appendix IX | 22
23 |
| • Total petroleum hydrocarbons (TPH) | USEPA Method 418.1 | 24 |

Approximately 10% of the soil samples collected in Zone C were duplicated and submitted for Appendix IX analytical parameters at DQO Level IV. These additional samples were collected to fulfill quality assurance/quality control (QA/QC) standards while cost-effectively analyzing additional parameters.

In addition to the analyses listed above, the following Appendix IX parameters were also analyzed for:

- Hexavalent chromium USEPA Method 218.4
- Dioxins USEPA Method 8290
- Herbicides USEPA Method 8150
- Organophosphate pesticides USEPA Method 8140

If contaminants were detected above risk-based screening levels, additional samples were collected for soil engineering parameter data to be used in the CMS and the contaminant fate and transport assessment of this report.

The engineering parameters were as follows:

- Cation Exchange Capacity (CEC) USEPA Methods 9080, 9081
- Total Organic Carbon (TOC) USEPA Method 9060
- pH USEPA Method 9045
- Nitrate USEPA Method 9056
- Nitrite USEPA Method 9056
- Ammonia USEPA Method 350
- Phosphorus (total) USEPA Method 365.4
- Sulfur (percent) ASTM* D-129-64

• Chlorides (percent)	ASTM D-2015-77	1
• Bulk Density	ASTM D-1587-83	2
• Soil Moisture	ASTM D-2216-80	3
• Unsaturated Hydraulic Conductivity	ASTM D-2434-68	4
• Grain-Size Analysis	ASTM D-422-63	5
• Hydrometer Analysis	ASTM D-422	6
• Synthetic Precipitation Leachate Procedure	USEPA Method 1312	7
• Porosity	Sowers and Sowers, 1951	8
<i>Note:</i> * American Society for Testing and Materials		9

3.2.3 Monitoring Well Installation and Development 10

Section 5 of the CSAP describes the methods used during monitoring well installation and development. All monitoring wells were installed in accordance with South Carolina Well Standards and Regulations after permits were acquired from the South Carolina Department of Health and Environmental Control (SCDHEC). The following subsections briefly describe the site-specific methods applied in Zone C. Appendix A includes all lithologic boring logs and monitoring well construction diagrams for Zone C. 11
12
13
14
15
16

3.2.3.1 Shallow Monitoring Well Installation 17

The shallow monitoring wells were installed so that groundwater samples could be collected from the shallow aquifer's upper portion. These monitoring wells were installed using the hollow-stem auger drilling method, which involved augering to the total depth of the borehole using hollow-stem auger flights tipped with a lead auger head. The total depth of the shallow wells depended primarily on depth to groundwater. Every effort was made to bracket the water table surface at each shallow monitoring well location. However, this was not always possible due to the shallow depth to groundwater. Because groundwater is encountered at approximately 2 to 6 feet bgs across NAVBASE, the typical depth shallow monitoring well was 11 to 13 feet bgs. 18
19
20
21
22
23
24
25

For each monitoring well borehole, a 2-foot split-
spoon was collected for lithologic characterization at 5-foot intervals. These soil samples were visually classified and screened for organic vapors by the onsite geologist, but were not retained for chemical analysis. Typical split-
spoon sample intervals in shallow monitoring well boreholes were collected between 3 to 5 feet bgs, 8 to 10 feet bgs, and 13 to 15 feet bgs. A sample representing the lithology of the typical screened interval for each SWMU/AOC was retained for grain-size analysis from one well boring at each site.

Typical shallow monitoring well construction involved placing a 10-foot section of 2-inch inside diameter (ID) polyvinyl chloride (PVC) screen with 0.010-inch slots attached to 10 feet of 2-inch ID PVC riser pipe down the inside of the hollow-stem auger, after having drilled to the desired depth. Filter pack material was then poured into the annular space between the hollow-stem auger and PVC to approximately 2 feet above the top of the screened section. As the sand was added, the level in the annulus borehole was measured with a weighted tape. The hollow-stem auger sections were gradually withdrawn while the sand was added to allow uniform placement of the filter pack and to avoid bridging and inadvertently raising the well screen and riser casing with the augers. Care was taken to never raise the hollow-stem auger sections higher than the filter pack level in the borehole, preventing the formation from collapsing on the well screen. Bentonite pellets were placed from the top of the filter pack to ground surface and hydrated with potable water. After allowing the bentonite to hydrate, for approximately 24 hours, the surface mount was constructed. An expansion locking well cap provided temporary groundwater protection before the surface mount was completed.

3.2.3.2 Deep Monitoring Well Installation

Review of regional geology identified the Ashley Formation of the Cooper Group as the shallowest formation most capable of retarding or preventing downward flow of water and/or contaminants. This formation is widely noted in the Charleston area for its low permeability and its effectiveness

as a confining layer over the underlying Santee Limestone. Deep monitoring wells were installed 1
to allow groundwater sampling at the shallow aquifer's base in contact with the underlying 2
Ashley Formation. 3

Rotosonic drilling methods were used to install the deep monitoring wells. Rotosonic drilling 4
combines standard rotary action with sonic vibration. The sonic vibration created at the surface 5
is directed to the subsurface through the drill string, displacing formation material rather than 6
forcing cuttings back to the surface as do more traditional drilling methods. The Rotosonic 7
method produces a continuous core sample that allows for extremely accurate lithologic 8
characterization. Soil samples were logged and classified as described in Section 3.2.1. Ten- 9
20-foot core sections were typically produced, depending on anticipated proximity to the target 10
formation. 11

Upon identification of the target depth, monitoring wells were constructed much as they were 12
through hollow-stem augers. A 10-foot section of 2-inch ID, 0.010-inch factory slot PVC screen 13
was installed with the base of the screen at the contact between the Ashley Formation and the 14
overlying Pleistocene sediments. Attached to the screen was an appropriate length of 2-inch ID 15
PVC riser pipe. Filter pack sand was placed to approximately 2 feet above the screened interval 16
and settled by activating the sonic vibration. A bentonite seal at least 3 feet thick was placed on 17
top of the filter pack, settled with vibratory action, and then hydrated. The remaining interval of 18
borehole was then tremied to the surface with a high solids bentonite grout. 19

3.2.3.3 Monitoring Well Protector Construction 20

The well protectors installed were either the flush-mount, manhole type, or above-grade protective 21
casing type, depending on the well location. Well protectors were installed in accordance with 22
Section 5.4 of the CSAP. 23

Flush-mount well protectors were installed in vehicle traffic areas such as parking lots. 1
Above-grade steel protective casings were installed at all other areas. In the case of flush mounts, 2
a 2-foot by 2-foot section of material, typically concrete or asphalt, was removed from around the 3
borehole to approximately 6 inches deep. An 8-inch ID, by 8-inch deep flush-mount cover with 4
a bolt-down access cover was then placed over the capped well. The top of the completed well 5
cover was generally 2 inches above adjacent surfaces. Concrete was added to fill the 2-foot by 6
2-foot excavated area and mounded to provide a sloped surface away from the cover. A monitoring 7
well identification tag listing the well number, date installed, drilling subcontractor, total well 8
depth, and depth to groundwater was mounted onto the sloped concrete surface of each flush- 9
mount pad. Expansion caps and keyed-alike locks were placed on each monitoring well with a 10
flush-mount cover. 11

Above-grade well protectors were prepared by installing a 3.5-foot long, 4-inch by 4-inch section 12
of steel protective surface casing approximately 1 to 1.5 feet down over the PVC riser pipe. Care 13
was taken not to compromise the integrity of the bentonite seal overlying the filter pack material. 14
The protective casings were hinged approximately 6 inches from the top to allow access to the top 15
of the PVC riser pipe. The hinged covers for each above-grade protective casing were designed 16
to allow for security locking. A 4-foot by 4-foot concrete pad approximately 6 to 8 inches thick 17
was then constructed around each protective casing. Weep holes were drilled through the well 18
protector at a height that would not allow water to rise above the top of the well. A 3-inch 19
diameter bumper post was set at each corner of the pad. A monitoring well identification tag 20
listing the well number, date installed, drilling subcontractor, total well depth, and depth to 21
groundwater was mounted onto the hinged cover of each above-grade well protector pad. Each 22
hinged cover was secured with a keyed-alike lock. 23

3.2.3.4 Monitoring Well Development

Monitoring well development consisted of initially stressing the filter pack by surging and pumping until turbidity was reduced as much as practical and specific conductance, pH, and temperature stabilized. Wells were developed according to Section 5.5 of the CSAP.

Surging Procedures:

1. Decontaminated PVC rods were attached to a surge block.
2. The surge block was lowered into the monitoring well screen section.
3. The surge block was then raised and lowered so groundwater would be surged in and out of the monitoring well screen.
4. Surging was conducted for approximately 10 to 15 minutes per well.
5. The surge block was removed from the well for decontamination.

Shallow Well Pumping Procedures:

1. Decontaminated polyethylene tubing was lowered into the well.
2. The tubing was attached to a centrifugal pump at the surface and pumping was begun.
3. If the productivity of the monitoring well was low, it would be alternately pumped then left idle to recover.
4. Monitoring wells were developed until the water column was as free of turbidity as possible, given the subsurface conditions and until the pH, temperature, and specific conductance were stabilized to satisfy the following criteria:

Temperature:	within $\pm 1.0^{\circ}\text{C}$	1
pH:	within ± 0.5 standard unit	2
Conductivity:	within $\pm 10\%$ from the duplicate	3
Turbidity:	generally between 10 and 30 nephelometric turbidity units (NTUs) or relatively stable (± 15 NTU)	4 5

At least three well volumes of groundwater were removed from each well during development. 6

3.2.4 Groundwater Sampling 7

Groundwater was sampled in accordance with Section 6 of the CSAP. The following subsections 8
briefly summarize the site-specific methods applied in Zone C. 9

3.2.4.1 Groundwater Sampling Locations 10

Groundwater samples were collected from well locations based on the approved locations 11
identified in the *Final Zone C RFI Work Plan* (E/A&H, November 1995). Some proposed 12
locations were adjusted for access and to avoid utilities. 13

Additional samples were required at some sites to adequately characterize contaminant 14
distribution. After analytical data were interpreted for samples collected during the initial soil 15
sampling rounds, a second round of samples was collected in some areas. Typically, additional 16
sample locations were justified due to relatively high concentrations of contaminants on the 17
perimeter of the previous sampling pattern. 18

3.2.4.2 Groundwater Sample Collection 19

Groundwater sample collection followed these steps: 20

1. Wells were allowed to recover for at least two weeks after being developed. 21

2. Decontaminated sampling equipment and supplies were transported to the monitoring well. 1
2

3. A temporary work area was established around each well by placing plastic sheeting on the sampling table and around the well. Personal protective equipment (PPE) was donned in accordance with the approved health and safety plan (HASP) for the monitoring well to be sampled. 3
4
5
6

4. The condition and security of the monitoring well were recorded in the field logbook. The security casing was unlocked and the well cap removed. Headspace was immediately measured for VOCs using an organic vapor analyzer (OVA), which was also used to monitor the breathing zone before and during sampling. 7
8
9
10

5. Depth to water and total depth of the well were measured using an oil-water interface probe if OVA readings exceeding background, odor, or other indicators suggested a light nonaqueous phase liquid (LNAPL) on the water surface. A water-level meter was used if no LNAPL was suspected. All measurements were recorded to the nearest 1/100th of a foot. Static water-level measurements were taken from the top of casing at a permanent datum point notched in the well casing. Well volumes were calculated and all measurements and observations recorded in the field logbook. All equipment was decontaminated before reuse. 11
12
13
14
15
16
17
18

6. New decontaminated Tygon tubing was installed in the well. The tubing extended into the well and, if water level was sufficient, positioned above the screened interval. A peristaltic pump was positioned at the surface, and the tubing mounted through the pump. Groundwater was purged into graduated buckets or containers to take volume measurements, which were recorded in the field logbook. 19
20
21
22
23

7. Each well was purged of at least three well casing volumes of water. Temperature, pH, specific conductance, and turbidity were measured after each volume of water was removed from the well casing. A well was considered stabilized for sampling once temperature, specific conductance, and pH readings varied less than 10% or less between the last two readings. Turbidity was monitored until the reading was less than 10 NTUs or turbidity was lowered as much as practical and no more than five well casing volumes of water were removed. Wells that were purged dry due to slow recovery were sampled after 12 hours of recovery. Purging of some wells to achieve turbidity of less than 10 NTUs was not possible due to lithologic variabilities. For example, wells installed in areas with increased silt content were typically more difficult to achieve a turbidity of less than 10 NTUs.

8. After purging, groundwater samples were collected according to the analytical parameters proposed for each groundwater sample. Sample containers for pesticide, herbicide, metals, sulfate, sulfide, sulfite, carbonate, bicarbonate, chloride, phosphate, and SVOC analyses were collected from the discharge side of the Tygon tubing. VOC analyses samples were obtained by capping the tubing and raising it from the well and then allowing the contents of the tube to drain into the sample containers.

Groundwater sample locations were identified according to Section 3.2.1 of this report and Section 11.4 of the CSAP.

3.2.4.3 Groundwater Sample Preparation, Packaging, and Shipment

Guidelines in Section 11 of the CSAP were followed for the preparation, packaging, and shipment of groundwater samples collected during the Zone C RFI. The following briefly summarizes those activities.

Groundwater samples were preserved according to laboratory criteria for parameters being collected. Appropriate labels and custody seals were completed and affixed to each sample bottle. Glass sample containers were encased with bubble wrap and enclosed in a resealable plastic bag to protect against breakage during shipment. Plastic sample containers were also placed in a resealable plastic bag prior to shipment. Immediately after sample collection and identification, sample containers were placed on ice in coolers. Records of sampling were entered into a dedicated field logbook and a master logbook placed in a fireproof safe in the site trailer.

Groundwater sample containers were individually custody-sealed, encased in protective bubble wrap and a resealable plastic bag, and placed in a cooler for shipment. The samples were then packed with ice and double-bagged in waterproof resealable plastic bags to ensure proper preservation at 4°C. All sample information was recorded on an official chain-of-custody form, which was then affixed to the top, inside surface of the sample cooler. Temperature blanks were included with each shipment to monitor sample temperature upon arrival. All samples were recorded into a chain-of-custody form affixed to the inside of the top of each cooler.

After entering sample numbers, analyses, times, and an air-bill shipping number into an official shipping log, the coolers were shipped priority overnight to the analytical laboratories.

3.2.4.4 Groundwater Sample Analysis

Groundwater samples were analyzed per USEPA SW-846 methods at DQO Level III unless otherwise noted, as follows:

- VOCs USEPA Method 8240
- SVOCs USEPA Method 8270
- Pesticides/PCBs USEPA Method 8080
- Cyanide USEPA Method 9010

- **Metals** 40 CFR Part 264 Appendix IX 1
- **TPH** USEPA Method 418.1 2

Approximately 10% of the groundwater samples collected at Zone C were duplicated and submitted for Appendix IX analytical parameters at DQO Level IV. These additional samples were collected to fulfill QA/QC standards while cost-effectively analyzing sites for additional parameters. 3
4
5
6

In addition to the analyses listed above, Appendix IX parameters include: 7

- **Hexavalent chromium** USEPA Method 218.4 8
- **Dioxins** USEPA Method 8290 9
- **Herbicides** USEPA Method 8150 10
- **Organophosphorous pesticides** USEPA Method 8140 11
12

Groundwater samples collected from several grid-based monitoring wells in Zone C were analyzed for engineering parameters relevant to the CMS. These parameters included: 13
14

- **Temperature** Measured during sample collection 15
- **pH** Measured during sample collection 16
- **Biochemical Oxygen Demand (BOD)** USEPA Method 405.1 17
- **Chemical Oxygen Demand (COD)** USEPA Methods 410.1, 410.2, or 410.3 18
- **Alkalinity** USEPA Method 310.2 19
- **Hardness** USEPA Method 130.2 20
- **Total Suspended Solids (TSS)** USEPA Method 160.2 21
- **Total Dissolved Solids (TDS)** USEPA Method 160.1 22
- **Total Organic Carbon (TOC)** USEPA Method 415.1 23

• Nitrate	USEPA Method 352.1	1
• Nitrite	USEPA Method 354.1	2
• Ammonia	USEPA Method 350.1	3
• Phosphorus (Total)	USEPA Method 365.1	4

The zone-wide second round of quarterly groundwater sampling was conducted in September 1995. Second-round sampling results are not included in this report.

3.2.5 Sediment and Surface Water Sampling

Sediment and surface water were sampled in accordance with Section 7 of the CSAP. The following subsections briefly summarize those methods as applied in Zone C.

3.2.5.1 Sediment and Surface Water Sample Locations

Sediment and surface water samples were collected from the approved locations identified in the *Final Zone C RFI Work Plan* (E/A&H, November 1995). All sediment and surface water sample locations were accessible by solid land, except those collected in Noisette Creek, for which a boat was used. Surface water samples were collected before any sediment samples to prevent increasing the turbidity in the water samples.

3.2.5.2 Sediment and Surface Water Sample Collection

Composite sediment samples were collected for laboratory analysis from 0 to 6 inches bgs using the scoop sampling method outlined in Section 7.2.3 of the CSAP. Surface water samples were collected in accordance with Section 7.3 of the CSAP.

Stainless-steel spoons and bowls were used to collect sediment samples. Upon identification of the sample location, a decontaminated stainless-steel spoon or spatula was used to expose a previously unexposed surface. Using a clean decontaminated stainless-steel spoon, the exposed

sediment was then scooped into a decontaminated stainless-steel bowl. For VOC samples, the sample containers were filled directly from the sampling device while filtering out twigs, large rocks, and grass. The rest was homogenized in the bowl and placed into the appropriate sample containers.

Surface water samples were collected by submerging the appropriate sample containers with the open end pointed upstream. Care was taken not to disturb bottom sediments during the sampling procedure. VOC samples were collected first.

3.2.5.3 Sediment and Surface Water Sample Preparation, Packaging, and Shipment

Guidelines in Section 11 of the CSAP were followed for the preparation, packaging, and shipment of sediment and surface water samples collected during the Zone C RFI. The following briefly summarizes those activities.

Sediment and surface water samples were identified at the time of collection in accordance with Section 11.4 of the CSAP and as stated in Section 3.2.1. Samples were stored on ice in a cooler until prepared for shipment. Date and time of sample collection, weather, sampling team, sketch map of sample location, tidal phase, and analytical parameters were recorded in the Zone C sampling logbook for individual or groups of samples.

At the close of each day of sampling, sediment and surface water samples were grouped by sample identification, individually custody-sealed and encased in bubble wrap, double-bagged in waterproof plastic bags, and placed in a sample cooler. Ice, double-bagged in waterproof, resealable plastic bags, was placed on top of the samples to preserve them at approximately 4°C. Prior to sealing the sample cooler for shipment, all sample data were entered onto an official chain-of-custody form which was then affixed to the top, inside surface of the sample cooler. The coolers were then secured and two custody seals were affixed prior to shipment.

Records of sampling were entered into a dedicated field logbook and a master logbook placed in a fireproof safe in the site trailer. Sample coolers were shipped by air for next-day delivery to the analytical laboratories.

3.2.5.4 Sediment and Surface Water Sample Analysis

Sediment samples were analyzed per USEPA SW-846 at DQO Level III unless otherwise noted, as follows:

- TOC USEPA Methods 415.1, 415.2
- Cyanide USEPA Method 9010
- Metals 40 CFR Part 264 Appendix IX

Approximately 10% of the sediment samples collected in Zone C were duplicated and analyzed at DQO Level IV.

Surface water samples were analyzed using the following methods:

- VOC USEPA Method 8240
- SVOC USEPA Method 8270
- Pesticides/PCBs USEPA Method 8080
- Cyanide USEPA Method 9010
- Metals 40 CFR Part 264 Appendix IX
- Organotins Per Triangle Laboratories, Research Triangle Park, North Carolina SOP*

Note: * Standard Operating Procedures

Approximately 10% of the surface water samples collected in Zone C were duplicated and analyzed at DQO Level IV. 1
2

3.2.6 Wipe Sampling 3

Wipe sampling was conducted in accordance with Section 9 of the CSAP. The following subsections briefly summarize those methods as applied in Zone C. 4
5

3.2.6.1 Wipe Sampling Locations 6

The sample locations were not based on any predetermined locations, but were collected from interior walls and ceilings in areas most likely to have been impacted (i.e., areas with air movement patterns, ledges, or vents). The wipes were supplied by the analytical laboratory in a pre-cleaned glass jar. A new pair of disposable gloves was worn to collect each individual wipe sample. 7
8
9
10
11

3.2.6.2 Wipe Sample Collection 12

Lead wipe samples were collected by swabbing or wiping the material or surface with No. 42 Whatman Filters that were dampened with deionized water. The wipes were supplied by the Wisconsin Occupational Health Laboratory of Madison, Wisconsin, in 8-ounce, pre-cleaned glass jars. The wipe filters were removed from the sample jar using tweezers or gloves. A clean set of gloves was used with each individual sample to prevent cross-contamination. The sample area was 6 inches square. To ensure a consistent sampling area, a 6-inch square template was used. The entire sampling area was wiped with firm strokes using only one side of the filter. The filter was folded with the exposed sides against each other, then folded again. The filter was then returned to the sample jar from which it was taken. Care was taken to tightly reseal the jar to prevent solvent evaporation. The area sampled in square inches was noted in the field logbook. One filter blank was dampened with deionized water, folded, and returned to the sample jar to serve as a media blank. 13
14
15
16
17
18
19
20
21
22
23
24

3.2.6.3 Wipe Sample Preparation, Packaging, and Shipment

The sample jar was labeled immediately in accordance with Section 11.4 of the CSAP. The jars were individually custody-sealed, encased in bubble wrap, and boxed for shipment. A chain-of-custody form was prepared and placed in the box. The samples were shipped overnight to WOHL. Air-bill information and sample labels were kept in a master sample log.

3.2.6.4 Wipe Sample Analysis

Wipe samples were analyzed for:

- Bulk lead Per laboratory SOP

One wipe sample was collected as a duplicate to fulfill QA/QC requirements.

3.2.7 Vertical and Horizontal Surveying

Monitoring well locations and elevations were determined by conventional plane surveying techniques. The horizontal and vertical control were established from existing monumentation on NAVBASE with horizontal datum of NAD 83 (North American Datum, 1983) and vertical datum of NGVD 29 (National Geodetic Vertical Datum, 1929). All traverse closures exceeded 1/20,000. No data corrections were required as part of the monitoring well survey. Soil boring and monitoring well locations were surveyed using Global Positioning System (GPS).

3.2.8 Aquifer Characterization

Rising and falling head slug tests were conducted on nine shallow and two deep monitoring wells to enhance aquifer characteristic estimates. Before a slug test was initiated, the static water level in each well was measured using an electronic water-level indicator. A slug was then introduced into the well, at which time the water level and the time "T₀" were recorded. Periodically, water level/elapsed-time measurements were recorded as the head returned to the original level.

Similarly, each rising head slug test was performed by removing the slug and recording water level/elapsed-time measurements as the head returned to normal. The time required for a slug test to be completed and the water level rate of change are functions of the hydraulic conductivity of the aquifer.

The slug consisted of 5-foot, and 6-foot, 1.5-inch diameter solid Teflon cylinders with stainless-steel eyebolts attached at one end. A nylon rope tethered to the eyebolt suspended the slug in the well just above or below the water level. At the beginning of each test, the data logger was activated the instant the slug was either lowered into or removed from the water.

For each slug test, In-Situ pressure transducers and 2-channel Hermit 1000C data loggers were used to record water level/elapsed-time measurements. To facilitate graphing the data, the data loggers were programmed to measure and record water level on a logarithmic time scale. Raw data from the data loggers were downloaded to a personal computer for data reduction and manipulation.

3.2.9 Decontamination Procedures

Decontamination procedures were performed in accordance with Section 15 of the CSAP and Appendix B, Section B-8 of the ESDSOPQAM for sampling equipment and in accordance with Appendix E, Section E-9 of the ESDSOPQAM for drilling equipment, with the following exceptions. The detergent used on this project was Liquinox, which contains powerful chelating agents to bind and remove trace metals from sampling equipment. When available, hot water was used for field decontamination. PVC well construction materials were not solvent-rinsed or washed with hot water. Field reagent-grade water was produced onsite to meet the specifications of ASTM Type III water (D 1193-77 re-approved 1983, federal test method 7916). The steam cleaner and/or high-pressure hot water washer was capable of generating adequate pressure and producing hot water and/or steam. All wastes generated during decontamination were

containerized in designated drums for disposal by the Navy in accordance with Section 16 of the CSAP. 1
2

3.2.9.1 Decontamination Area Setup 3

The decontamination area is a concrete pad sloped to direct wash runoff into a catch basin, from which liquids were pumped regularly into designated containers. Equipment was cleaned on sawhorses or auger racks above the concrete surface. When field cleaning was necessary, plastic sheeting was placed on the ground to contain any spills. 4
5
6
7

3.2.9.2 Cross-Contamination Prevention 8

The following procedures were implemented during sampling activities to reduce cross-contamination risk. 9
10

- Fresh disposable outer gloves were donned before handling sampling equipment. 11

- Only Teflon, glass, or stainless-steel spray bottles/pressurized containers were used to apply decontamination rinsates. Each solution was kept in a separate container. 12
13

- All necessary decontaminated field equipment was transported to the sampling location to minimize the need for field cleaning. 14
15

3.2.9.3 Nonsampling Equipment 16

Nonsampling equipment includes drill rigs, and backhoes. Nonsampling equipment was decontaminated using the following procedures: 17
18

1. Equipment was decontaminated with high-pressure steam. 19

2. Portions of the equipment which came in contact with sampled material were scrubbed with a laboratory-grade detergent and clean water wash solution. 1
2

3. Equipment was rinsed with clean water as necessary. 3

3.2.9.4 Sampling Equipment 4

Sampling equipment includes any downhole equipment (e.g., augers, drill pipe, and split-barrel samplers) and any sampling utensils (e.g., pumps and stainless-steel spoons, spatulas, bowls), not dedicated to the sample location. Hollow downhole equipment or equipment with holes potentially transmitting water or drilling fluids were cleaned on the inside and outside. The decontamination procedure is as follows: 5
6
7
8
9

1. Protective gloves were donned before decontaminating the equipment. 10

2. Items were washed and scrubbed with a laboratory-grade detergent and clean water wash solution or sprayed with high-pressure steam. 11
12

3. Rinsed with ASTM Type III water. 13

4. Rinsed with organic-free water. 14

5. Rinsed twice with pesticide-grade isopropyl alcohol. 15

6. Rinsed with ASTM Type III water. 16

7. Air dried. If weather prohibited air drying, the isopropyl alcohol rinse was repeated and the item was rinsed with ASTM Type III water twice. 17
18

- 8. Items were wrapped in aluminum foil or plastic sheeting if the sampling equipment was stored or transported. 1
2

- 9. Augers and drill rods were covered in clean plastic after decontamination. 3

4.0 DATA VALIDATION

4.1 Introduction

Data quality objectives are qualitative and quantitative statements specifying the quality of data required to support decisions during environmental response actions. The level of certainty regarding the precision of the data varies with the intended end use of the data. According to USEPA guidance, *Data Quality Objectives for Remedial Response Activities, Development Process*, EPA/540/G-87/003, March 1987, the levels of analytical data were as follows:

- Level I — Field screening or analysis using portable instruments. Results are often not compound-specific and not quantitative, but results are available in real-time. It is the least costly analytical option.
- Level II — Field analyses using more sophisticated portable analytical instruments: in some cases the instruments may be set up in a mobile laboratory onsite. There is a wide range in the quality of the data that can be generated. It depends on the use of suitable calibration standards, reference materials, and sample preparation equipment in addition to training of the operator. Results are available in real-time or in several hours.
- Level III — All analyses performed in an offsite analytical laboratory. Level III analyses may use Contract Laboratory Program (CLP) procedures, but do not usually use the validation or documentation procedures required of CLP Level IV analysis. The laboratory may not be a CLP laboratory.
- Level IV — CLP routine analytical services (RAS). All analyses are performed in an offsite analytical laboratory following CLP protocols. Level IV is characterized by rigorous Quality Assurance/Quality Control (QA/QC) protocols and documentation.

- Level V — Analysis by nonstandard methods. All analyses are performed by an offsite analytical laboratory which may not be a CLP laboratory. Method development or method modification may be required for specific constituents or detection limits. CLP special analytical services (SAS) are Level V.

For the RFI at NAVBASE Charleston, analytical Level III data with 10% analyses for Appendix IX at Level IV were deemed appropriate for the intended data uses: site characterization, risk assessment, and corrective measure determinations/design.

It should be noted that in September 1993, USEPA replaced this guidance with an updated manual, *Data Quality Objectives Process for Superfund, Interim Final Guidance*, EPA/540/G-93/071 which stated, "This guidance replaces the earlier guidance EPA 540/G-87/003, OSWER Directive 9355.0-7B and the five analytical levels introduced in that document." As a result, the five analytical data levels were reduced to two — screening data and definitive data.

Definitive data (formerly Level III and IV) are defined as analytical data generated using rigorous analytical methods, such as approved USEPA reference methods. These data are analyte-specific, with confirmation of analyte identity and concentration. These approved methods produce tangible raw data (e.g., chromatograms, spectra, digital values) in the form of paper printouts or computer-generated electronic files. Also for data to be definitive, analytical or total measurement error (precision) must be determined (EPA/540/G-93/071, September 1993). As a result, the data collected at NAVBASE Charleston are now defined as definitive data per the most recent USEPA guidance, but will still be referred to as Level III and Level IV throughout the report to avoid confusion.

4.2 Validation Summary

This section presents the QA/QC evaluation of the data that were produced from the analysis of environmental media samples collected within Zone C during the RFI. The purpose of this evaluation is to verify that the appropriate QA/QC elements were followed and/or completed (e.g., method requirements, documentation), to identify and/or characterize any problems with the data set, and ultimately to determine the usability of the analytical data with respect to site characterization, risk assessment, and corrective measure determinations.

Examples of definitive data (formerly Level III and IV) QA/QC elements are as follows:

- Sample documentation (verified time of sample receipt, extraction and holding times)
- Chain-of-custody
- Initial and continuing calibration
- Determination and documentation of detection limits
- Analyte(s) identification
- Analyte(s) quantification
- QC blanks (trip, method, rinsate)
- Matrix spike recoveries
- Performance Evaluation (PE) samples (when specified)
- Analytical method precision
- Total measurement error determination

As part of the RFI, environmental samples were collected at NAVBASE Charleston Zone C from February to September 1995. All samples were analyzed by CompuChem Laboratories except for the dioxin and organotin samples. Southwest Laboratory of Oklahoma, Inc. analyzed the samples for dioxins and dibenzofurans. Triangle Labs of Research Triangle Park, NC, analyzed the organotins samples. In accordance with the approved *RFI Comprehensive Sampling and*

Analysis Plan, (E/A&H, August 1994), sample analyses followed the guidance in the *USEPA Test Methods for Evaluating Solid Waste*, SW-846 and 40 CFR Part 264. The analytical methods and DQO laboratory deliverables are summarized on Table 4.1.

Table 4.1
NAVBASE Analytical Program

Full Scan/Appendix IX Analytical Methods	Data Quality Level	Method Reference
Volatile Organic Compounds	III/IV	SW-846 8240
Semivolatile Organic Compounds	III/IV	SW-846 8270
Pesticides/Polychlorinated Biphenyls	III/IV	SW-846 8080
Chlorinated Herbicides	III/IV	SW-846 8150
Organophosphorus Pesticides	III/IV	SW-846 8140
Total Petroleum Hydrocarbons (TPH)	III	USEPA 418.1/3550 & 5030
Metals	III/IV	40 CFR Part 264 Appendix IX (SW-846 6010/7060/7421/7471/7740/7740)
Hexavalent Chromium	III/IV	USEPA 218.4
Polychlorinated dibenzo-p-dioxins	III/IV	USEPA 8290
Organotins	III/IV	Triangle Laboratory SOP

Notes:

Full Scan parameters include: VOCs, SVOCs, Pest/PCBs, TPH, and Metals (Level III). Appendix IX parameters include: VOCs, SVOCs, Pest/PCBs, Herbicides, Organophosphorus Pesticides, Metals, Hexavalent Chromium and Dioxins (Level IV). Organotins were analyzed on a per-site basis.

The methods listed in Table 4.1 are from:

- USEPA Office of Solid Waste and Emergency Response (OSWER), *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (SW-846), Third Edition, revised July 1992.
- USEPA Environmental Monitoring and Support Laboratory, *Methods for Chemical Analysis of Water and Wastes* (EPA-600/4-79-020, revised March 1983).

- USEPA 40 Code of Federal Regulations Part 264, Appendix IX (52 Federal Register 25947, July 1987). 1
2

Third-party independent data validation of all analytical work performed under the CSAP was conducted by Validata Chemical Services based on the QC criteria, the *USEPA National Functional Guidelines for Organic and Inorganic Data Review*. The third-party validator's function was to assess and summarize the quality and reliability of the data to determine their usability and to document any factors affecting data usability such as compliance with methods, possible matrix interferences, and laboratory blank contamination. 3
4
5
6
7
8

4.2.1 Organic Evaluation Criteria 9

The USEPA methods in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, and *Methods for Chemical Analysis of Water and Wastes* define QC criteria that the laboratory must meet. However, the methods do not address data evaluation from a user's perspective. Data evaluation criteria for the user are available in *USEPA Contract Laboratory National Functional Guidelines for Organic Data Review* (Functional Guidelines), February 1994. For NAVBASE Zone C, these functional guidelines were used throughout the data evaluation process for this purpose. 10
11
12
13
14
15
16

Data evaluation included the following parameters: 17

- Holding times 18
- Gas Chromatography/Mass Spectroscopy (GC/MS) instrument performance checks 19
- Surrogate spike recoveries 20
- Instrument calibration 21
- Matrix spike and matrix spike duplicates (MS/MSD) 22

- Blank analysis 1
- Internal standard (IS) performance 2
- Compound quantitation 3
- Field duplicate precision 4
- Calculations 5

When the QC parameters do not fall within the specific method guidelines, the data evaluator annotated or flagged the corresponding compounds where deficiencies were found. The following validation flags were used to annotate data exhibiting laboratory and/or field deficiencies or problems: 9

U **Undetected** — The analyte was analyzed for but not detected or was also found in an associated blank, but at a concentration less than 10 times the blank concentration for common constituents (acetone, methylene chloride) or five times the blank concentration for other constituents (benzene, toluene). The associated value shown is the quantitation or reporting limit. 14

J **Estimated Value** — One or more QC parameters were outside control limits. 15

UJ **Undetected and Estimated** — The analyte was analyzed for but not detected above the estimated quantitation limit. The quantitation limit is estimated because one or more QC parameters were outside control limits. 18

R/UR **Unusable Data** — One or more QC parameters grossly exceeded control limits. 19

EMPC **Estimated Maximum Possible Concentration** — The dioxin analyte was analyzed 1
for, but due to possible instrument carryover that cannot be verified, results may 2
actually be lower. 3

These validation flags were applied to data where deficiencies were noted. The EMPC validation 4
flag used by the validator is unique to the dioxin validation reports. Appendix D includes the 5
complete analytical dataset for Zone C. 6

4.2.1.1 Holding Times 7

Acceptable technical holding times are specified in the CSAP. The sample holding time depends 8
on the type of analysis. For water and soil samples, the holding time for VOC analysis is 14 days 9
from the collection date. SVOC, pesticide/PCB, organophosphorus pesticide and chlorinated 10
herbicide water samples must be extracted within seven days from the collection date and analyzed 11
within 40 days after extraction. For soil, samples must be extracted within 14 days of sample 12
collection and analyzed within 40 days of collection. Dioxin water and soil samples require 13
extraction within 30 days of collection and analysis within 45 days of collection. 14

Holding times for total petroleum hydrocarbons (TPH) analyses are 28 days from the day of 16
collection for preserved and refrigerated samples. 17

4.2.1.2 GC/MS Instrument Performance Checks 19

Performance standards for VOC and SVOC analyses are analyzed to determine if the data 20
produced by the instrument may be correctly interpreted according to the requirements of the 21
method being used. Performance standards must be analyzed within 12 hours of sample analysis, 22
and the results must be within the established criteria. 23

4.2.1.3 Surrogate Spike Recoveries

Surrogate compounds are added to samples and laboratory blanks before extraction and sample preparation to evaluate the effect of the sample matrix on extraction and measurement procedures. Surrogates are organic compounds chemically similar to analytes of interest but those not normally found in environmental samples. Three surrogate compounds are added to samples for VOC analysis, eight are added to samples for SVOC analysis, two are added to pesticide/PCB and dioxin samples, and one is added to both organophosphorous pesticides and chlorinated herbicide samples. Percent recovery of the surrogates is calculated by comparing the amount of the compound recovered by the analysis to the amount added to the sample.

The surrogate compounds recommended by the SW-846 methods are listed in Table 4.2. Abbreviations for each compound are in parentheses when applicable.

**Table 4.2
 Surrogate Compound Summary**

VOC Surrogates	SVOC Surrogates	Pesticide/PCB Surrogates	Herbicide Surrogate	Organophosphorous Pesticide Surrogate
Toluene-d8	Nitrobenzene-d5 (NR2)	Tetrachloro-m-xylene (TCMX)	2,4-Dichloro- phenoxyacetic acid (DCAA)	4-Chloro-3- Nitrobenzothiazole (CNBT)
Bromochlorobenzene (BCB)	Triphenyl-4,4 (TPH)	Decachlorobiphenyl (DCB)		
1,2-Dichloroethane (DCE)	2,4,6-Trichlorophenol (TCP)			
	Phenol-d5 (PH2)			
	2-Chlorophenol-d4 (2CP)			
	1,2-Dichlorobenzene-d4 (DCB)			
	2-Fluorophenol (2FP)			

Dioxin Surrogates
¹³ C ₁₂ - 1,2,3,4-Tetrachlorodibenzo-p-dioxin (TCDD)
¹³ C ₁₂ - 1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin (HxCDD)

4.2.1.4 Instrument Calibration

Instruments are initially and continually calibrated with standard solutions to verify that they can produce acceptable quantitative data for the compounds.

Initial calibration (GC/MS): The instrument is initially calibrated at the beginning of the analytical run to check its performance and to establish a linear five-point calibration curve. The initial calibration is verified by calculating the relative response factor (RRF) and the percent relative standard deviation (%RSD) for each compound. An RRF less than 0.05 or a %RSD greater than 30% is outside the QC limits for the initial calibration.

Continuing calibration (GC/MS): Standard solutions are run periodically to check the daily performance of the instrument and to establish the 12-hour RRF on which the sample quantitations are based. The continuing calibration is verified by calculating the RRF and the percent difference (%D) for each compound. An RRF less than 0.05 or a %D greater than 25% is outside the QC limits for the continuing calibration.

Initial calibration (GC): For single-component pesticides five-point calibrations are analyzed, and calibration factors (CF) are established. The CF for single-component pesticides must be less than or equal to 20%.

The multi-component pesticide toxaphene and all PCBs (or Aroclors) are analyzed separately. Retention times and CFs are determined for three to five primary peaks. The only review criteria for multi-component compounds is to verify these steps were taken.

A five-point initial calibration is analyzed for herbicides, organophosphorous pesticides, and TPH. Two methods for calibration may be used: external or linear regression methods. For the external method, the initial calibration may be verified by calculating the RRF and the %RSD for each compound. An RRF less than 0.05 or a %RSD greater than 20% is outside the QC limits for the initial calibration. If linear regression is used, the correlation coefficient must meet or exceed 0.995 before samples can be analyzed.

Continuing calibration (GC): The calibration verification is to confirm the calibration and evaluate instrument performance for single-component pesticides. The calibration verification consists of an instrument blank, performance evaluation mixtures (PEMs), and the midpoint concentration of the two standard mixes. The continuing calibration is run on two GC columns (a primary and a secondary) for analyte confirmation. The %D between the calculated amount and the true amount must not exceed 15% on the primary column. Multi-component compounds do not require continuing calibration.

For herbicides and organophosphorous pesticides, the continuing calibration is verified by calculating the RRF and the %D for each compound. An RRF less than 0.05% or a %D greater than 15% is outside the QC limits for the continuing calibration.

For NAVBASE Charleston, only positive results were flagged when the %RSDs and %D were outside control limits but less than 50%. If the %RSD or %D exceeded 50%, both the positive and nondetected results were flagged. Based on professional judgment, the results were flagged in this manner because the risk would be in reporting results with a high bias rather than a low bias.

4.2.1.5 Matrix Spike/Matrix Spike Duplicate (MS/MSD)

An MS is used to determine the accuracy of the analysis for a given matrix. An MS consists of a known quantity of stock solution added to the sample before its preparation and analysis. Evaluating the MS data involves two calculations. First, the percent recovery (%R) is calculated by comparing the amount of the compound recovered by the analysis to the amount added to the sample. In addition, the relative percent difference between the MS and the MSD samples is calculated and assessed. No specific requirements have been established for qualifying MS/MSD data. However, guidelines to aid in applying professional judgment are discussed in *Functional Guidelines for Organic Review*.

4.2.1.6 Laboratory Control Samples and Laboratory Duplicates

Total petroleum hydrocarbons and other GC methods may require laboratory control samples (LCS) and laboratory duplicates with each Sample Delivery Group (SDG). The LCS monitors the overall performance of each step during analysis, including sample preparation. All aqueous LCS %R results must fall within the control limits established by the laboratory. Laboratory duplicate samples are used to demonstrate acceptable method precision at the time of analysis. The RPD between the sample and the duplicate sample is calculated. Although no guidelines are established for organic laboratory duplicates, sample qualification is left up to professional judgment.

4.2.1.7 Blank Analysis

Laboratory method blanks are used to assess the existence and magnitude of potential contamination introduced during analysis. Additionally, field blanks may be collected to assess any contamination introduced during sample collection. When chemicals are found both in samples and laboratory blanks analyzed within the same 12-hour period and/or field-derived blanks, the usability of the data depends on the reviewer's judgment and the blank's origin. According to the functional guidelines, a sample result should not be considered positive unless the concentration of the compound in the sample exceeds 10 times the amount in any blank for common laboratory contaminants (i.e., methylene chloride, acetone, 2-butanone, and phthalate esters), or five times the amount for other constituents. These amounts are referred to as *action levels* (ALs). Because blank samples may not be prepared using the same weight of sample, volume of sample, or dilution, these factors should be also taken into consideration when using these blank criteria. The specific actions to be taken are as follows:

- If a chemical is found in the blank but not the sample, no action is taken.
- If the sample concentration is less than the quantitation limit and less than the AL, the quantitation limit is reported.

- If the sample concentration is between the quantitation limit and the AL, the concentration is reported as nondetect *U*. 1
2

- If the sample concentration is greater than the AL, the concentration may be used unqualified. 3
4

4.2.1.8 Field-Derived Blanks

 5

For this project, four types of field-derived blanks were collected: the field blank, the rinsate blank, the equipment blank, and the trip blank. The field blank is a sample of the source water used onsite, primarily to decontaminate equipment. The rinsate blank is a sample of runoff water from one or more pieces of the decontaminated equipment used to collect samples. The equipment blank is a sample of each filter pack, grout, bentonite pellets, or powder used in well construction. The trip blank is a 40-milliliter (ml) VOA vial filled with certifiable water used to assess cross-contamination during VOC sample shipment. 6
7
8
9
10
11
12

The frequencies for collecting these QC samples were defined in Section 13 of the *NAVBASE CSAP* as follows: 13
14

- Field blank — one per sampling event (week) per source. 15
- Rinsate blank — one per week per media. 16
- Equipment blank — one sample of each well construction material per source. 17
- Trip blank — one per sample shipping cooler containing VOA samples. 18

For data validation purposes, each trip blank is associated only with the samples from the same shipment or cooler. The field blanks and the rinsate blanks apply to a larger number of samples because only one is collected per sampling event. Because field-derived blanks are used with method blanks to assess potential cross-contamination of field investigative samples, no action was 19
20
21
22

taken if the same contaminants were detected in the method blanks and the associated field-derived
 blanks, but not in the investigative samples.

4.2.1.9 Internal Standard Performance

GC/MS internal standards (IS) are added to samples to check the stability of the instrument's
 sensitivity and response during each analytical VOC and SVOC run. IS area counts for samples
 and blanks must not vary more than a factor of two (-50% to +100%) from the associated
 calibration standard. If IS concentration results are outside this window, the sample would be
 flagged as estimated. Listed below are the internal standard compounds recommended by the
 methods. Abbreviations for each compound are in parentheses.

VOC IS Compounds

- Bromochloromethane (BCM)
- 1,4-Difluorobenzene (DFB)
- Chlorobenzene-d5 (CBZ)

SVOC IS Compounds

- 1,4-Dichlorobenzene-d4 (DCB)
- Naphthalene-d8 (NPT)
- Acenaphthene-d10 (ANT)
- Phenanthrene-d10 (PHN)
- Chrysene-d12 (CRY)
- Perylene-d12 (PRY)

Dioxin

- ¹³C₁₂-2,3,7,8-TCDD
- ¹³C₁₂-2,3,7,8-TCDF
- ¹³C₁₂-1,2,3,7,8-PeCDD
- ¹³C₁₂-1,2,3,7,8-PeCDF
- ¹³C₁₂-1,2,3,6,7,8-HxCDD
- ¹³C₁₂-1,2,3,4,7,8-HxCDF
- ¹³C₁₂-1,2,3,4,6,7,8-HpCDD
- ¹³C₁₂-1,2,3,4,6,7,8-HpCDF
- ¹³C₁₂-OCDD
- TCDD (Tetrachlorodibenzo-p-dioxin)
- HpCDF (Heptachlorodibenzofuran)
- TCDF (Tetrachlorodibenzofuran)
- OCDD (Octachlorodibenzo-p-dioxin)
- PeCDF (Pentachlorodibenzofuran)
- HpCDD (Heptachlorodibenzo-p-dioxin)
- HxCDD (Hexachlorodibenzo-p-dioxin)
- HxCDF (Hexachlorodibenzofuran)

4.2.1.10 Diluted Samples

A special evaluation was performed of diluted samples to determine if method detection limits were sufficiently low to be compared with reference concentrations (e.g., Maximum Contaminant Levels, RBCs, etc.). Table 4.3 lists all diluted samples from Zone C.

4.2.2 Inorganic Evaluation Criteria

The USEPA methods described in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, and *40 Code of Federal Regulations Part 264, Appendix IX* define quality control criteria that the laboratory must meet, but the methods do not address data evaluation from a user's perspective. Evaluation criteria are available in *USEPA Contract Laboratory National Functional Guidelines for Inorganic Data Review*, February 1994. The guidelines were used throughout the data evaluation process to address data usability.

Data evaluation for samples collected at NAVBASE included:

- Holding times
- Instrument calibration
- MS results
- Laboratory duplicates
- Blank analysis
- Inductively Coupled Argon Plasma (ICAP) interference check samples

**Table 4.3
 Diluted Samples**

Sample ID	Sample Delivery Group	Parameter	Dilution Factor	Results ($\mu\text{g}/\text{kg}$)
047SB00501	00035	Fluoranthene	5	1,700
520SB00102	0005P	Chlordane	10	37 J
520SB00201	0005P	Chlordane	10	1,700 J
520SB00202	0005P	Chlordane	2	68 J
513CB00201	0010A	Famphur	0.4	9 J
047SB01601	0022S	Benzo(k)fluoranthene	2	8,700 J

- ICP serial dilutions 1
- Laboratory control sample results 2
- Atomic Absorption (AA) duplicate injections and post-digestion spike recoveries 3
- Field duplicate precision 4

According to the functional guidelines, when the QC parameters do not fall within the specific method guidelines, the data evaluator annotates or flags the corresponding compounds where deficiencies were found. The data from NAVBASE Charleston sites were evaluated using this approach. The following flags were used to annotate data exhibiting laboratory and/or field deficiencies or problems: 9

U Undetected — The analyte was analyzed for but not detected above the instrument detection limit (IDL) or was also found in an associated blank at a concentration less than 5 times the blank concentration. 12

J Estimated Value — One or more QC parameters were outside control limits. 13

UJ Undetected and Estimated — The analyte was analyzed for but not detected above the listed estimated IDL; the IDL is estimated because one or more QC parameters were outside control limits.

R/UR Unusable Data — One or more QC parameters grossly exceeded control limits.

4.2.2.1 Holding Times

Acceptable technical holding times are specified in the CSAP. For aqueous and soil samples, the holding time for metals analysis is six months, except for mercury, which is 28 days from the date of collection. For aqueous and soil samples, cyanide analysis has a sample holding time of 14 days from the date of collection.

4.2.2.2 Instrument Calibration

Instruments are initially and continually calibrated with standard solutions used to check that they are capable of producing acceptable qualitative and quantitative data for the analytes on the inorganics list.

An initial calibration is performed to check the performance of the instrument at the beginning of the analytical run and to establish a linear calibration curve. Calibration standard solutions are run periodically to check the performance of the instrument and confirm that the initial calibration curve is still valid. Calibrations are verified by calculating the %R and comparing the amount of the analyte recovered by analysis to the known amount of standard. The %R for metals, except mercury and cyanide, should fall between 90% and 110%. The %R for mercury and cyanide should fall between 80% and 120% and 85% and 115%, respectively.

4.2.2.3 Blank Analysis

Laboratory method blanks are used to assess the existence and magnitude of potential contamination introduced during analysis. Additionally, field blanks may be collected to assess the potential contamination introduced during sample collection. When chemicals are found in samples and laboratory blanks, the usability of the data depends on the reviewer's judgment and the blank's origin. According to the functional guidelines, a sample result should not be considered positive unless the sample concentration exceeds five times the amount in any blank. These also are referred to as ALs. Because blank samples may not be prepared using the same weight of sample, volume of sample, or dilution, these variables should also be considered when using these blank criteria. The specific actions to be taken are as follows:

- If a chemical is found in the blank but not the sample, no action is taken.
- If the sample concentration is between the IDL, and less than five times the amount found in any blank, the concentration is reported as *U*.
- If the sample concentration is greater than five times the amount in any blank, the concentration may be used unqualified.

4.2.2.4 ICAP Interference Check Samples

The ICAP interference check sample is used to confirm the laboratory instrument's inter-element and background correction factors. Interference samples should be analyzed at the beginning and end of each sample analysis or at least twice per eight-hour working shift. The %Rs for the interference check sample should fall between 80% and 120%.

4.2.2.5 Laboratory Control Samples (LCS)

LCS are used to monitor the overall performance of steps in the analysis, including the sample preparation. All aqueous LCS %R results must fall within the control limits of 80% to 120%, except for antimony and silver, for which control limits have not been established. Soil LCS standards are provided by the USEPA. Control limits are established for each soil LCS standard prepared.

4.2.2.6 Spike Sample Analysis

Samples are spiked with known quantities of analytes to evaluate the effect of the sample matrix on digestion and measurement procedures. The %R should be within 75% to 125%. However, when the sample concentration exceeds the spike concentration by a factor of four or more, spike recovery criteria are not applicable.

4.2.2.7 Laboratory Duplicates

Laboratory duplicate samples are analyzed to evaluate data precision, a measure of the reproducibility of the analysis. The RPD between the sample and the duplicate sample is calculated. A control limit of 20% RPD should not be exceeded for analyte values greater than 100 times the IDL.

4.2.2.8 Inductively Coupled Argon Plasma Serial Dilutions

ICAP serial dilutions assess the presence or absence of matrix interference. One sample from each set of similar matrix type is diluted by a factor of five. For an analyte concentration that is at least a factor of 100 times above the IDL, the measured concentrations of the undiluted sample and the diluted sample should agree within 10%.

4.2.2.9 Atomic Absorption (AA) Duplicate Injections and Post-Digestion Spike Recoveries 1
During AA analysis, duplicate injections and post-digestion spikes are used to assess precision and 2
accuracy of the laboratory analysis. The %RSD of duplicate injections must agree within 20%. 3
%R of the post-digestion spike sample should fall between 85% and 115%. 4

4.3 Zone C Data Validation Reports 5
The Zone C data validation reports are included as Appendix E for review. These reports are the 6
outcome of the evaluations described above and are specific to the analytical data collected from 7
the Zone C RFI. 8

5.0 DATA EVALUATION AND BACKGROUND COMPARISON

This section describes the approach and technical methodologies employed to determine types (nature) and areal extent of all chemicals present in site samples (CPSS) in soil and groundwater at Zone C SWMUs and AOCs. Nature and extent were evaluated to determine the overall distribution of constituents detected on a micro (site-specific) as well as a macro (zone-wide) scale. In addition, these data will be used to assess base-wide conditions and the relationship of contaminants between zones across NAVBASE.

Types of compounds detected in Zone C include: VOCs, SVOCs, pesticides, PCBs, dioxins, organotins, and inorganics. To evaluate the significance of detected compounds, to determine where additional sampling (if any) should be conducted, to define the extent, and to develop investigative endpoints, organic data were compared to the USEPA Region III *Risk-Based Concentration Table*, June 1996 (RBCs) and inorganic data were compared to background concentrations. The comparison pertains only to the protection of human health and does not address protection of ecological receptors. Risk to the ecosystem from the contaminants onsite is assessed in Section 8.

The site-specific nature and extent evaluations for each SWMU and AOC within Zone C are detailed in Section 10, Site-Specific Evaluations of this report.

5.1 Organic Compound Analytical Results Evaluation

Organic compounds detected in Zone C soil and groundwater were compared to RBCs. The RBCs listed in the site-specific evaluations in Section 10 are taken from the *USEPA Region III Risk-Based Concentration Table* (USEPA Region III, June 1996). Information such as the frequency of detection and the range of detections were also compiled (see Section 10).

Dioxin data reflect a summary of the tetrachlorodibenzo-p-dioxin (TCDD) equivalency quotient (TEQ) values as computed using the procedure identified in *Interim Procedures for Estimating*

Risks Associated with Exposures to Mixtures of Chlorinated dibenzo-p-dioxins and dibenzofurans (CDDs and CDFs) (USEPA, 1989), and the USEPA *Interim Supplemental Guidance to RAGS: Region IV Bulletins, Human Health Risk Assessment*, Bulletin No. 2, November 1995. For screening purposes, dioxin data were compared to the dioxin TEQ of 1.0 $\mu\text{g}/\text{kg}$ based on a peer-reviewed scientific paper (Kimbrough et al., 1984). This dioxin concentration was used as the cleanup level at the Times Beach Superfund Site.

In accordance with recent carcinogenic polynuclear aromatic hydrocarbons (cPAH) guidance, USEPA *Interim Supplemental Guidance to RAGS: Region IV Bulletins, Human Health Risk Assessment*, Bulletin No. 2, November 1995, benzo(a)pyrene equivalents (BEQs) were computed, where appropriate by multiplying the reported concentration of each cPAH by its corresponding toxicity equivalency factor (TEF). The BEQ values were then summed for each sample, and the total was compared to the benzo(a)pyrene RBC value during the screening process. The comparisons listed above pertain only to the protection of human health and do not address protection of ecological receptors. Risk to the ecosystem from the contaminants onsite is assessed in Section 8.

5.2 Inorganic Analytical Results Evaluation

Sample results for inorganics are more difficult to compare because inorganics are naturally occurring and ubiquitous in soil. Further compounding this difficulty is the fact that NAVBASE is predominantly dredge-fill material that has been artificially placed onsite. Background values for surface soil, subsurface soil, shallow groundwater and deep groundwater were calculated in accordance with established procedures for NAVBASE. The dataset for surface and subsurface soil consisted of 45 and 30 samples, respectively. The dataset for shallow and deep groundwater consisted of four sampling rounds from two monitoring wells at each depth. The background data were presented and approved by the project team in May 1997. The background values are presented in Table 5-1.

Table 5.1
Zone C Inorganic Background Reference Values for Soil and Groundwater

Inorganic	Surface soil [mg/kg] (n = 45)	Subsurface soil [mg/kg] (n = 30)	Shallow Groundwater [µg/L] (n = 8)	Deep Groundwater [µg/L] (n = 8)
Aluminum	9,990 P	23,700 P	410 M	22.2 M
Antimony	0.55 N	0.92 N	ND	ND
Arsenic	14.2 P	14.1 N	6.07 M	ND
Barium	77.2 P	68.5 P	16.7 M	52.2 M
Beryllium	X	0.98 N	0.33 M	0.32 M
Cadmium	0.65 N	0.28 N	ND	ND
Chromium	26.4 P	12.5* P	1.99 M	ND
Cobalt	3.22 P	7.1 N	1.33 M	ND
Copper	34.7 P	42.2 P	1.90 M	ND
Lead	330 P	73.2 P	3.27 M	ND
Manganese	92.5 P	106 P	608 M	147 M
Mercury	0.24 N	0.30 N	ND	ND
Nickel	12.3 P	16.7 P	3.59 M	ND
Selenium	1.44 P	2.90 N	ND	ND
Silver	X	ND	1.26 M	ND
Thallium	ND	X	ND	ND
Tin	2.95 P	2.37 P	ND	ND
Vanadium	23.4 P	56.9 N	1.96 M	0.54 M
Zinc	159 P	243 P	13.2 M	ND
Cyanide	ND	ND	ND	ND

Note:

- P = Parametric UTL
- N = Nonparametric UTL
- M = Twice the mean
- X = No UTL calculated (NDs > 90%)
- ND = Not detected
- * = Reference value for non-clay samples
- mg/kg = milligrams per kilogram
- µg/L = micrograms per liter

Many compounds, particularly carcinogenic metals such as arsenic and beryllium, are typically detected at much higher concentrations than their risk-based screening levels. It is usually necessary to supplement site-specific sampling efforts with an attempt to determine the non-site-related concentrations of these compounds. The problem is to determine these reference (or background) concentrations, and how much higher than this level a parameter must be at a site before it is of concern. USEPA Region IV guidance on this subject recommends the use of twice the mean level of the background samples as an upper bound and recommends considering any site-related sample higher than its upper bound to be contaminated. Although this method is appropriate with small datasets, it would be inappropriate to use with the large grid-based soil datasets developed at Zone C. E/A&H used a dual-testing procedure to compare AOC/SWMU inorganic parameters with this grid-based dataset. A combination of a parametric or nonparametric upper tolerance limit (UTL) or reference concentration and a Wilcoxon rank sum test was used.

5.2.1 Grid-Based Background Datasets

The background datasets for Zone C soil collected from the upper and lower intervals come from 45 sample locations labeled GDC (GDCSB001 to GDCSB045). Lower interval soil samples were not collected at many of the locations because of a shallow water table. The background datasets for shallow groundwater come from two sample locations labeled GDC001 and GDC002; background datasets for deep groundwater come from sample locations GDC01D and GDC02D. The available data values for each chemical were assembled into datasets for soil and for groundwater.

Descriptive statistics were obtained for the original data values, including frequency distribution histograms and normal probability plots. Results were examined and, where appropriate (i.e., histogram positively skewed, normal probability plot concave upward, high skewness, and

kurtosis), data were transformed into natural logarithms (LN) or square roots of their original values to provide a closer approximation to a normal distribution. Descriptive statistics of the transformed data were compared to those of the originals. All of the soil datasets for inorganics required transformation before parametric analysis. No transformation was needed on the much smaller groundwater datasets, since statistical analysis was not performed.

It has been suggested that lognormal data indicate the presence of contamination in the samples at the high end of the range. However, "EPA's experience with environmental concentration data ... suggests that a Lognormal distribution is generally more appropriate as a default statistical model than the Normal distribution, a conclusion shared by researchers at the United States Geological Survey" (USEPA, 1992b, p.2).

Most of the background datasets examined were more nearly lognormal than normal. It is more reasonable to assume that lognormal background distributions of chemical concentrations are the norm for the NAVBASE than to assume that the datasets document a background that is contaminated in comparable fashion by numerous chemicals at different depths in both soil and groundwater. Nevertheless, a few potential data outliers did appear at the high end of some of the datasets, and it was important to eliminate them to preserve the integrity and utility of the background data. Normally, outliers should be removed from a dataset only in unusual circumstances and with specific reasons for each removal. In lognormal or square-root distributions, even apparently extreme values may fit a straight line on a normal probability plot of transformed data. Statistical rules of thumb for outlier removal generally are based on the variance of the sample, and include methods such as the "rule of the huge error" (Taylor, 1990, p.88), in which all values greater than four standard deviations above the mean are discarded along with Rosner's test, Dixon's test, the Shapiro-Wilk test, and others (Gibbons, 1994, pp.246-257).

Because of concerns about inadvertently including contaminated samples in the background datasets, outliers were eliminated more readily than many standard statistical guidelines would suggest. After consultation with the project team, outliers were removed on a chemical-by-chemical basis, descriptive statistics were recalculated for each chemical's dataset, and the resulting modified datasets were used for all further comparisons with background. Outliers removed from the background dataset are listed below:

<i>Upper interval soil</i>			7
Antimony	GDCSB00501	1.4 mg/kg	8
Arsenic	GDCSB00201	39.4 mg/kg	9
	GDCSB02801	22.4 mg/kg	10
	GDCSB03101	22.3 mg/kg	11
Barium	GDCSB04001	193 mg/kg	12
Lead	GDCSB01501	588 mg/kg	13
Manganese	GDCSB04101	101 mg/kg	14
Mercury	GDCSB03601	0.75 mg/kg	15
Nickel	GDCSB00601	27.7 mg/kg	16
Tin	GDCSB00101	8.1 mg/kg	17
Zinc	GDCSB02901	414 mg/kg	18
	GDCSB04001	779 mg/kg	19
<i>Lower interval soil</i>			20
Arsenic	GDCSB03002	31.6 mg/kg	21
Manganese	GDCSB00402	502 mg/kg	22
	GDCSB01002	520 mg/kg	23
Mercury	GDCSB01002	8.5 mg/kg	24
<i>Shallow groundwater</i>			25
Arsenic	GDCGW00204	15U $\mu\text{g/L}$ (nondetect)	26
Cobalt	GDCGW00103	5.2U $\mu\text{g/L}$ (nondetect)	27
	GDCGW00104	5.2U $\mu\text{g/L}$ (nondetect)	28
	GDCGW00203	5.2U $\mu\text{g/L}$ (nondetect)	29
	GDCGW00204	5.2U $\mu\text{g/L}$ (nondetect)	30
Copper	GDCGW00104	4.75U $\mu\text{g/L}$ (nondetect)	31
Lead	GDCGW00101	9.1U $\mu\text{g/L}$ (nondetect)	32
Nickel	GDCGW00203	11.6U $\mu\text{g/L}$ (nondetect)	33
<i>Deep groundwater</i>			34
Aluminum	GDCGW01D01	54.3U $\mu\text{g/L}$ (nondetect)	35
Vanadium	GDCGW01D03	3.4U $\mu\text{g/L}$ (nondetect)	36
	GDCGW02D03	3.4U $\mu\text{g/L}$ (nondetect)	37

5.2.2 Nondetect Data

Following guidelines presented in various USEPA documents, one-half of the sample quantitation limit (SQL) was used to represent nondetect values. In practice, this meant using one-half of the *U* values reported by the analytical laboratory and confirmed by the validator. This differs from the method used to represent nondetect values for organic parameters, where the minimum of one-half the lowest *J* value or one-half the lowest *U* value is used.

5.2.3 Developing Datasets for Sites

Results of laboratory analyses of soil and groundwater samples from the AOCs and SWMUs were assembled into datasets for each chemical of interest from the upper interval soil and shallow groundwater, for comparison with background.

5.2.4 Comparing Site Values to Background

The comparison of site to background can best be understood within the context of statistical hypothesis testing. A hypothesis test involves the creation of two hypotheses, a *null* and an *alternative* hypothesis. "In the context of background contamination at hazardous waste sites, the null hypothesis can be expressed as 'there is no difference between contaminant concentrations in background areas and onsite,' and the alternative hypothesis can be expressed as 'concentrations are higher onsite'" (USEPA RAGS, 1989a, p.4-8). Under the assumption that there is no contamination, the likelihood of any observed difference between site and background can be calculated. If the probability of the observed difference is smaller than some predetermined level, a decision is made that since the observed site samples are not likely to be from the same population as the background samples, the site is considered contaminated for a particular chemical.

Two possible errors can be made in this situation. The first is that a site will be considered contaminated when in fact it is clean, which is called a false positive. The probability of this

error, α , is controlled by specifying the level at which the null hypothesis is considered unlikely. 1
 The other possible error, the false-negative rate, β , can be seen as the probability of concluding 2
 from a test that no difference exists when in reality such a difference does exist; the site will be 3
 considered clean when in fact it is contaminated. The "power" of the test ($1-\beta$), which is the 4
 complement of the false-negative rate, is a measure of the strength of the conclusion that a 5
 difference does exist; it can be thought of as the probability of correctly identifying a contaminated 6
 site (Table 5.2). The calculation of β and power is somewhat more difficult and depends upon the 7
 magnitude of the actual concentration differences, the size of the sample, and the form of the 8
 probability distribution for the measurement process. 9

Table 5.2
Probability of Possible Conclusions of a Hypothesis Test

Test	Reality	
	Same as Background (clean)	Greater than Background (contaminated)
Same as Background	$1-\alpha$	β
Greater than Background	α	$1-\beta$

There is a trade-off, in general, between the false-positive and false-negative rate, given a certain 10
 sample size. A test that rarely rejects the hypothesis of "no contamination" will be more prone 11
 to miss an actual difference. A test that frequently concludes contamination is present, on the 12
 other hand, will be more likely to make the mistake of concluding that a difference arising by 13
 chance is a real difference. The total amount of error can be minimized in two ways: by 14
 increasing the sample size or by using a test that is "most powerful." The choice of the form of 15
 the hypothesis test is crucial to minimizing the total error. 16

USEPA Region IV often suggests a "two-times background" test: If the maximum detected concentration of a chemical at a site exceeds twice the mean background level, the chemical should be considered a chemical of potential concern (COPC) and should be subjected to detailed risk analysis (i.e., the chemical is a contaminant at the site). What is often not recognized is that this procedure is a statistical one and is subject to the same errors as a hypothesis test. The problem with this approach is that background levels are never level; that is, the nature of the background data greatly affects the result of applying the "two-times background" criterion. For a normally distributed variable with a coefficient of variation (CV) of 0.25, less than 0.01% of the population is expected to be greater than twice the mean; if the CV is 1.00, 15.9% of the population is expected to exceed the standard. In the latter case, 15.9% of the presumably uncontaminated background population would be rated contaminated by the test (false positive rate = 15.9%). The "two-times background" test neglects the valuable information about variation that is present in the background samples and, therefore, cannot be the most statistically powerful test since it does not make the most effective use of the available data.

Hypothesis tests should be suited to the type of decision that needs to be made, as well as to the type of data available. Any method for comparing site to background must be capable of detecting two different kinds of site contamination. The first type involves localized "hot spots" within the site; for example, one or two site samples out of nine or 10 might test well above the highest background samples, while the rest are low or even nondetect. This situation was modeled as a mixture of two distributions — some of the samples from a given site come from a distribution similar to the background samples while others from the same site come from a second distribution with a higher mean/median. The other type of contamination occurs when most or all of the site samples are above the mean of background samples, but none is necessarily above the high end of the background range. This situation was modeled assuming that the distribution of site samples is similar to background, but with a higher mean/median. The first scenario is referred to as the mixture scenario and the second as the shift scenario. Two complementary tests were

employed for these two situations respectively — a tolerance- interval test and a Wilcoxon rank sum test.

5.2.5 Tolerance-Interval or Reference Concentration Test

Individual data values from a site can be compared to a high percentile (95th, 98th, 99th) of background values. This operation can be done parametrically by comparing to a specified percentile of the distribution of background values, obtained either from a normal probability chart of transformed values or by using standard methods of estimating quantities (e.g., Gilbert, 1987, p.175, Equation. 13.24). It can also be done nonparametrically by comparing to a percentile of the background data values themselves, rather than to an assumed distribution of the values.

Rather than comparing site values to specific percentiles of the background data, they can be compared to estimated reference concentrations that enclose a specified percentage of the background population. A one-sided tolerance interval with 95% coverage and 95% confidence signifies that approximately 95% of individual population values fall below the upper limit, with 95% confidence. Once the interval is constructed, each site sample is compared to the UTL or reference concentration (USEPA, 1992b, p.51). Any value that exceeds the limit is considered evidence of contamination at that point.

A roughly lognormal distribution of background values allows the use of parametric tolerance intervals, using LN-transformed values, when the nondetect percentage is low. Individual sample values are compared to a UTL or reference concentration that is calculated using the expression:

$$\exp[X + k (s)]$$

where:

X = mean of LN-transformed background values

s = standard deviation of LN-transformed values

k = tolerance factor

When a square-root data transformation is used, the comparable expression is:

$$[X + k (s)]^2$$

The tolerance factor, k , is obtained from tables with specified levels of α and P_0 , where $(1 - P_0)$ equals the proportion of the population contained within the tolerance intervals. For a given set of α and P_0 , k depends on the sample size, n . For $n = 44$ (the sample size for Level 1 of background for soils), $k = 2.0986$ when $\alpha = 0.05$ and $P_0 = 0.05$ (confidence = 95%, coverage = 95%). This value was generated by linearly extrapolating between tabled values of $n = 40$, $k = 2.125$ and $n = 45$, $k = 2.092$ producing the equation:

$$k = -0.0066 * n + 2.389 \text{ when } \{40 \leq n \leq 45\}$$

According to a USEPA statistical training course manual (USEPA, 1992c, p.29), "reference concentrations can be computed with as few as three data values; however, to have a passable estimate of the standard deviation, one should probably have at least eight to 10 samples." Outliers were first identified and removed from the datasets, as explained in Section 5.2.1. A UTL, or reference concentration, was then calculated for the revised dataset of each chemical in upper and lower interval soil and used for background comparisons. Shallow and deep groundwater background datasets for Zone C contain only eight samples apiece (four rounds of samples from each of two wells at each level). Reference concentrations were computed as twice the mean of each dataset.

Where a significant proportion of the soil samples were nondetect (> 50%), means and standard deviations could not be computed accurately, and it was necessary to employ nonparametric tolerance intervals. In these cases, the UTL or reference concentrations were taken directly from the sample sets, rather than from calculations based on the presumed data distributions. In

practice, this meant using either the largest or the second largest observed background value as the standard of comparison (USEPA, 1992b, p.54) when nondetects (ND) are greater than 50%. As with the parametric calculations, the method was applied to the datasets after removing outliers.

The following decision rule was applied to the background datasets for soil:

- Where $ND \leq 50\%$, use parametric UTL.
- Where $50\% < ND < 90\%$, use first or second highest value in dataset as the nonparametric UTL.
- Where $ND \geq 90\%$, no valid background value can be determined.

The power of these tolerance-limit tests varies based on several factors, such as the number of samples that are assumed to have come from the distribution with the larger mean, the magnitude of the shift in the mean, and the distribution of the background samples. It also depends upon the sample size at each site and the sample size of the background.

5.2.6 Wilcoxon Rank Sum Test

When values for the majority of a sites samples are higher than the mean background value, but none is dramatically higher, the site samples, as a group, must be shown to be significantly higher than the group of background samples for contamination to be identified at the site.

The most commonly prescribed method for comparing two populations is the *t*-test, which determines whether the two population means differ significantly. The *t*-test was not used in this report to compare site values to background because it is parametric. Although the background

data values are approximately normally distributed after being transformed (by LN or square root), there is no reason to expect that the site values will be. In addition, the presence of estimated values for the nondetects calls into question the accuracy of the calculated means that are compared within the *t*-test.

A nonparametric counterpart to the *t*-test is the Wilcoxon rank sum test, also known as the Mann-Whitney U test. Since it is nonparametric, the two datasets that are compared need not be drawn from normal or even symmetric distributions, and the test can accommodate a moderate number of nondetect values by treating them as ties (Gilbert, 1987, p.248). The method for handling nondetect and qualified values is important because it affects their ranks. Detected but not quantified values (Js) should receive higher ranks than nondetects (Us). Since the ranks of the data values are evaluated and compared rather than the values themselves, the test is not sensitive to minor inaccuracies in estimated values and does not require an estimate of the mean, nor do the data values need to be transformed. The Wilcoxon test is superior to some other nonparametric tests, such as the sign test or the test of proportions, because it takes into account differences in concentrations and, therefore, has more statistical power to detect differences in those concentrations.

The Wilcoxon rank sum test operates by combining the site and background data values and ranking them by concentration. The ranks of the site samples are then compared to the background ranks. If the site ranks, as a group, are significantly higher than those of the background, the null hypothesis that the site and background values came from the same population is rejected at a chosen confidence level (USEPA, 1992b, p.46). Each group should contain at least four data values.

The Wilcoxon test is very similar in power to the *t*-test when samples are normally distributed and it is more powerful when the distribution is skewed. The power of this test varies based on several

variables, such as the magnitude of the shift in the median, the distribution of the background 1
samples, the sample size at each site, and the sample size of the background. 2

5.2.7 Summary of Statistical Techniques Used 3

Techniques that allow the use of statistical inference were chosen. Methods must be capable of 4
detecting situations where: (a) a small number of site values are much higher than background 5
and (b) site values are generally higher than background. For situation (a), transform all data 6
values where appropriate to approximate normal distributions, then compare site values to a UTL, 7
mean plus k standard deviations, of the background data, where k depends on sample size. When 8
the percentage of nondetects is above 50%, use nonparametric tolerance limits; above 90% 9
nondetects, no reliable tolerance limits can be determined. For situation (b), apply the Wilcoxon 10
rank sum test to compare each group of site values to background. 11

5.2.8 Combined results of the UTL (Reference Concentration) and the Wilcoxon Rank 12 Sum Tests 13

Methods described in Section 5.2.5 identify individual samples with concentrations that are 14
significantly higher than background, while the method in Section 5.2.6 identifies entire sites. If 15
the results from either test were positive (i.e., significantly higher than background), the sample 16
and/or site values were compared to the corresponding USEPA RBCs for soils and, where 17
appropriate, carried forward into detailed risk assessment. 18

5.2.9 Conclusion 19

The overall approach documented here is conservative for a number of reasons: (1) the number 20
of background samples (especially for soil) is above the minimum recommended in various 21
guideline documents (USEPA RAGS, 1989a, p.4-9), producing greater confidence in the ability 22
to characterize background and to distinguish background concentrations from those at sites; 23
(2) following procedures described in Section 5.2.1, high values were removed from the 24

background datasets whether they were true outliers in the conventional sense, thereby lowering 1
the total background levels to which the sites were compared; and (3) the use of two 2
complementary tests increased the likelihood that any contamination would be identified and 3
addressed further, since a positive result from either test triggered a detailed risk assessment. 4

6.0 FATE AND TRANSPORT

The objective of fate and transport assessments is to evaluate what is known regarding the constituents in the environment based on inherent characteristics of both the constituents and the environmental media in which they are present. Specifically, fate and transport assessment evaluates a constituent's ability to become mobile or change in the environment. To accomplish this, a general understanding of the chemical and physical properties that govern the interaction of a constituent within environmental media is required. From a macroscopic viewpoint, the characteristics of the site, such as topography, weather, geography, and geology, play a role in the transport process. From a microscopic viewpoint, the characteristics of site soil, sediment, and water, as well as the chemical and physical properties of the constituent, play a role in evaluating the processes of advection, diffusion, and dispersion that move a constituent between media or place to place within a medium. A discussion of fate and transport will help to identify potential receptors that result from the constituent movement in the environment. Site-specific conclusions regarding fate and transport are detailed in Section 10.

After evaluating Zone C, for the above characteristics, four potential routes of constituent migration have been identified:

- Air emissions resulting from VOCs released from surface soil
- The leaching of constituents from soil to groundwater
- Surface soil erosion and runoff of constituents into adjacent zones of sediment deposition
- The migration of constituents from shallow groundwater into surface water bodies

As mentioned above, significant processes of constituent migration include erosion, advection, diffusion, and dispersion and are defined as follows:

Erosion 1
Erosion is the process by which particles are suspended and subsequently moved by the physical 2
action of water. Compounds adsorbed to particulate material are thereby moved along with the 3
particulates. 4

Advection 5
Advection is the process by which dissolved substances migrate with flowing groundwater. 6
Hydraulic conductivity, effective porosity, average linear velocity and hydraulic gradient are 7
medium characteristics that determine a chemical's rate of movement by advection. This 8
characteristic is significant for compounds associated with groundwater. 9

Diffusion 10
Diffusion is the hydrodynamic process by which solutes are transported from a region of high 11
concentration to a region of low concentration. In very fine sediments with very slow hydraulic 12
conductivities, diffusive transport may be the dominant mode of migration. 13

Dispersion 14
Dispersion is the hydrodynamic process by which solutes are mixed with uncontaminated water, 15
diluted, and transported preferentially due to anisotropic aquifer conditions. 16

6.1 Properties Affecting Fate and Transport 17
Numerous chemical and physical properties of both the constituent and the surrounding media are 18
used to evaluate fate and transport mechanisms. 19

6.1.1 Chemical and Physical Properties Affecting Fate and Transport 20
Chemical and physical properties used to evaluate fate and transport include vapor pressure, 21
density, solubility, half-life, Henry's law constant, organic carbon/water partitioning coefficient, 22

and molecular weight. Table 6.1 below provides an overview of chemical property behavior based on these properties.

**Table 6.1
 Chemical and Physical Properties**

Chemical Property	Critical Value	High (>)	Low (<)
Vapor Pressure (VP)	10 ⁻³ mm Hg	volatile	nonvolatile
Density ^a (D)	0.75 to 1.25 g/cm ³	sink/fall	float/rise
Solubility ^a (S)	0 to 100 mg/L	leaches from soil, mobile in water, does not readily volatilize from water	absorbs to soil, immobile in water, volatilizes from water
Henry's Law Constant (HL)	5x10 ⁻⁶ to 5x10 ⁻³ atm-m ³ /mole	resistance to mass transfer in the aqueous phase	resistance to mass transfer in the gas phase
Half life (T _{1/2})	biologically dependent	does not degrade readily	degrades readily
Organic Carbon/Water Partitioning Coefficient ^a (K _{oc})	10 to 10000 kg _{oc} /L _{water}	tends to adsorb to organic material in soil; immobile in the soil matrix	tends not to adsorb to organic material in soil; mobile in the soil matrix
Molecular Weight (MW)	400 g/mole	parts of the above may hold true, more detailed evaluation necessary	all of the above hold true

Note:

a = Determinations for the Critical Ranges were based on literature review and professional judgment.

Table 6.2 contains chemical and physical property data for each chemical detected in Zone C samples (soil, groundwater, surface water, and sediment). Section 10 discusses SWMU- or AOC-specific fate and transport, migration pathways and potential receptors.

Compounds with similar chemical and physical properties also display similar fate and transport mechanisms. This facilitates the general grouping of contaminants based on chemical and

Table 6-2
 Fate and Transport Properties and Screening Levels for Constituents Detected in Soil and Groundwater
 NAVBASE-Charleston, Zone C
 Charleston, South Carolina

Parameter	Vapor Pressure (mm Hg)	Density (g/cm ³)	Solubilit (mg/L)	Henry's Law Constant (atm-m ³ /mole)	Organic Carbon Water Part. Coeff. (L/kg)	Salt Water Chronic WQC ! (ug/L)	Tap Water RBC or UTL *	Water Units	Ground Water Protection SSL or UTL **	Soil Units
Acenaphthene	1.6E-03	1.024	3.47	1.70E-04	7.08E+03	NDA	220 UG/L	a	57000 SSL	UG/KG
Acenaphthylene	2.9E-02	0.899	3.93	2.00E-04	2.50E+03	NDA	220 UG/L	a	11000 CALC	UG/KG b
Acetone	2.7E+02	0.791	1E+06	3.97E-05	2.19E+00	NDA	370 UG/L		1600 SSL	UG/KG
Acetophenone	1	NDA	NDA	1.58E-01	3.50E+01	NDA	0.0042 UG/L		0.7 CALC	UG/KG b
Acrolein	220	0.847	200000	4.4E-06	4.90E-01	NDA	73 UG/L		290 CALC	UG/KG
Aldrin	6.0E-06	1.700	0.027	2.67E-05	4.07E+02	NDA	0.004 UG/L		500 SSL	UG/KG
Aluminum	NA	NA	NA	NA	NA	NDA	3700 UG/L		23700 REF	MG/KG c
Anthracene	2.0E-04	1.260	0.045	6.50E-05	2.60E+04	NDA	1100 UG/L		1200000 SSL	UG/KG
Antimony	NA	NA	NA	NA	NA	NDA	1.5 UG/L		5 SSL	MG/KG c
Aroclor-1254	4.1E-05	1.566	0.08	7.10E-03	4.31E+05	0.03	0.0087 UG/L		8600 CALC	UG/KG b
Aroclor-1260	4.1E-05	1.566	0.08	7.10E-03	8.22E+05	0.03	0.0087 UG/L		16000 CALC	UG/KG b
Arsenic	NA	NA	NA	NA	NA	36	6.07 UG/L		29 SSL	MG/KG c
Barium	NA	NA	NA	NA	NA	NDA	260 UG/L		1600 SSL	MG/KG c
Benzoic acid	1.0E+00	1.316	3400	7.02E-07	1.82E+02	NDA	15000 UG/L		40000 SSL	UG/KG
Benzo(g,h,i)perylene	1.0E-10	NDA	0.00026	1.40E-07	7.76E+06	NDA	150 UG/L	d	46000 CALC	UG/KG d
Benzo(a)pyrene Equivalents										
Benzo(a)anthracene	2.2E-08	1.274	0.012	2.3E-06	1.40E+06	NDA	0.092 UG/L		2000 SSL	UG/KG
Benzo(a)pyrene	5.6E-09	1.351	0.0039	2.40E-06	1.77E+06	NDA	0.0092 UG/L		8000 SSL	UG/KG
Benzo(b)fluoranthene	5E-07	NDA	0.0014	1.2E-05	5.50E+05	NDA	0.092 UG/L		5000 SSL	UG/KG
Benzo(k)fluoranthene	9.59E-11	NDA	0.00055	1.04E-03	4.37E+06	NDA	0.92 UG/L		49000 SSL	UG/KG
Chrysene	6.3E-09	1.274	0.0018	7.26E-20	9.52E+04	NDA	9.2 UG/L		160000 SSL	UG/KG
Dibenzo(a,h)anthracene	1E-10	1.282	0.005	7.33E-09	3.30E+06	NDA	0.0092 UG/L		2000 SSL	UG/KG
Indeno(1,2,3-cd)pyrene	1E-10	NDA	0.062	2.96E-20	1.60E+06	NDA	0.092 UG/L		14000 SSL	UG/KG
Beryllium	NA	NA	NA	NA	NA	NDA	0.33 UG/L		63 SSL	MG/KG
alpha-BHC	2.5E-05	1.870	1.63	5.30E-06	1.82E+03	NDA	0.011 UG/L		0.5 SSL	UG/KG
beta-BHC	2.8E-07	1.890	0.24	2.30E-07	2.48E+03	NDA	0.037 UG/L		3 SSL	UG/KG
delta-BHC	1.7E-05	1.870	0.314	2.50E-07	1.50E+03	NDA	0.037 UG/L	e	3 SSL	UG/KG e
gamma-BHC (Lindane)	6.7E-05	1.569	7.5	3.25E-06	1.21E+03	NDA	0.052 UG/L		9 SSL	UG/KG
4-Bromophenyl-phenylether	2.0E-03	1.000	NDA	1.00E-04	8.71E-04	NDA	210 UG/L		840 CALC	UG/KG b
Butylbenzylphthalate	8.6E-06	1.120	2.76	1.30E-06	1.51E+02	NDA	730 UG/L		930000 SSL	UG/KG
Cadmium	NA	NA	NA	NA	NA	9.3	1.8 UG/L		8 SSL	MG/KG
Carbon disulfide	3.0E+02	1.260	2100	1.33E-02	6.18E+01	NDA	2.1 UG/L		3200 SSL	UG/KG
Chlordane	1.0E-05	1.600	0.056	4.80E-05	4.95E+04	0.004	0.052 UG/L		10000 SSL	UG/KG
Chloroform	1.6E+02	1.489	8000	3.23E-03	4.60E+01	NDA	0.15 UG/L		600 SSL	UG/KG
Chromium	NA	NA	NA	NA	NA	50	3700 UG/L		38 SSL	MG/KG c
Chromium (hexavalent)	NA	NA	NA	NA	NA	50	18 UG/L		38 SSL	MG/KG
Cobalt	NA	NA	NA	NA	NA	NDA	220 UG/L		7.1 REF	MG/KG c
Copper	NA	NA	NA	NA	NA	2.9	150 UG/L		42.2 REF	MG/KG c
Cyanide	NA	NA	NA	NA	NA	5.2	73 UG/L		NDA	
2,4-D	1.1E-02	1.420	682	1.95E-02	5.37E+02	NDA	6.1 UG/L		1880 CALC	UG/KG b
4,4'-DDD	1.0E-06	1.476	0.02	2.16E-05	4.37E+04	NDA	0.28 UG/L		16000 SSL	UG/KG
4,4'-DDE	6.5E-06	NDA	0.04	2.34E-05	2.45E+05	NDA	0.2 UG/L		54000 SSL	UG/KG
4,4'-DDT	1.9E-07	1.560	0.005	4.89E-05	3.87E+05	0.001	0.2 UG/L		32000 SSL	UG/KG
Dibenzo(a,i)acridine	NDA	NDA	NDA	NDA	NDA	NDA	NDA		NDA	
Dibenzofuran	NDA	1.089	10	NDA	1.00E+04	NDA	15 UG/L			
Di-n-butylphthalate	1.0E-05	1.046	13	6.30E-05	1.38E+03	NDA	370 UG/L		2300000 SSL	UG/KG
Dibutyltin	NDA	NDA	NDA	NDA	NDA	NDA	0.11 UG/L	j	NDA	
Dieldrin	1.8E-07	1.750	0.2	2.00E-05	1.34E+04	0.0019	0.0042 UG/L		4 SSL	UG/KG b
Diethylphthalate	2.0E-03	1.118	896	8.46E-07	6.92E+01	NDA	29000 UG/L		47000 SSL	UG/KG
Dimethoate	5.06E-06	1.281	25	2.63E-11	9.12E+00	NDA	0.73 UG/L		3.2 CALC	UG/KG b
3,3'-Dimethylbenzidine	NDA	NDA	NDA	NDA	4.47E+02	NDA	0.0073 UG/L		0.2 SSL	UG/KG

Table 6-2
 Fate and Transport Properties and Screening Levels for Constituents Detected in Soil and Groundwater
 NAVBASE-Charleston, Zone C
 Charleston, South Carolina

Parameter	Vapor Pressure (mm Hg)	Density (g/cm3)	Solubilit (mg/L)	Henry's Law Constant (atm-m3/mole)	Organic Carbon Water Part. Coeff. (L/kg)	Salt Water Chronic WQC ! (ug/L)	Tap Water RBC or UTL * Units	Ground Water Protection SSL or UTL **	Soil Units
Dinoseb	NDA	1.265	52	5.00E-04	5.01E+02	NDA	3.7 UG/L	170 CALC	UG/KG b
Di-n-octylphthalate	0.0014	0.978	3	1.41E-12	977237221	NDA	73 UG/L	1E+08 SSL	UG/KG
Dioxin (TCDD TEQ)	NDA	NDA	NDA	NDA	3.30E+06	NDA	0.5 PG/L	4 CALC	UG/KG k
Diphenylamine	NDA	1.160	<i>Insolubl</i>	NDA	NDA	NDA	91 UG/L	NDA	
1,2-Diphenylhydrazine	NDA	1.158	NDA	NDA	9.47E+02	NDA	0.084 UG/L	3.5 CALC	UG/KG b
Disulfoton	1.8E-04	1.144	12	5.42E-06	7.76E+02	NDA	0.15 UG/L	5 CALC	UG/KG b
Endosulfan I	1.0E-05	1.745	0.53	1.01E-04	2.04E+03	0.0087	22 UG/L	1800 SSL	UG/KG
Endosulfan II	1.0E-05	1.745	0.28	1.91E-05	2.34E+03	0.0087	22 UG/L	1800 SSL	UG/KG
Endosulfan sulfate	NDA	NDA	0.117	NDA	2.34E+03	NDA	22 UG/L	1800 SSL	UG/KG f
Endrin	7.0E-07	1.650	0.23	5.00E-07	8.32E+03	0.0023	1.1 UG/L	1000 SSL	UG/KG
Endrin aldehyde	2.0E-07	NDA	0.26	3.86E-07	2.69E+04	NDA	1.1 UG/L	1000 SSL	UG/KG g
bis(2-Ethylhexyl)phthalate	2.0E-07	0.987	0.3	1.10E-05	2.00E+09	NDA	4.8 UG/L	3600000 SSL	UG/KG
Famphur	NDA	NDA	NDA	NDA	4.19E+02	NDA	22 UG/L	450 CALC	UG/KG l
Fluoranthene	5.0E-06	1.252	0.24	1.69E-02	3.80E+04	NDA	150 UG/L	430000 SSL	UG/KG
Fluorene	7.0E-04	1.203	1.69	2.10E-04	5.01E+03	NDA	150 UG/L	56000 SSL	UG/KG
Heptachlor	3.0E-04	1.660	0.18	2.30E-03	1.20E+04	0.0036	0.0023 UG/L	23000 SSL	UG/KG
Heptachlor epoxide	2.6E-06	NDA	0.35	3.20E-05	2.09E+04	0.0036	0.0012 UG/L	700 SSL	UG/KG
Lead	NA	NA	NA	NA	NA	8.5	15 UG/L	330 REF	MG/KG c
Manganese	NA	NA	NA	NA	NA	NDA	608 UG/L	106 REF	MG/KG c
Mercury	NA	NA	NA	NA	NA	0.025	2 UG/L		
Methoxychlor	1.4E-06	1.410	0.04	1.58E-05	7.94E+04	NDA	18 UG/L	160000 SSL	UG/KG
Methylene chloride	3.5E+02	1.327	20000	2.00E-03	2.30E+01	NDA	4.1 UG/L	20 SSL	UG/KG
1-Methylnaphthalene	NDA	1.006	24.6	4.11E-04	8.51E+03	NDA	150 UG/L	51000 CALC	UG/KG i
Methylnaphthalene	NDA	1.006	24.6	4.11E-04	8.51E+03	NDA	150 UG/L	51000 CALC	UG/KG i
Methylparathion	9.6E-06	NDA	50	1E-07	6.3E+01	NDA	0.91 UG/L	6 CALC	UG/KG
Monobutyltin	NDA	NDA	NDA	NDA	1.00E+06	NDA	0.11 UG/L	4400 CALC	UG/KG b
Naphthalene	5.4E-02	1.145	30	4.60E-04	9.40E+02	NDA	150 UG/L	8400 SSL	UG/KG
Nickel	NA	NA	NA	NA	NA	8.3	73 UG/L	130 SSL	MG/KG
N-Nitrosodiphenylamine	1.0E-01	1.230	0.004	NDA	1.20E+03	NDA	14 UG/L	1000 SSL	UG/KG
Parathion	9.7E-06	NDA	6.45	5.65E-07	1.00E+04	NDA	22 UG/L	8900 CALC	UG/KG
Pentachlorophenol	1.1E-04	1.978	20	2.10E-06	4.09E+02	7.9	0.56 UG/L	30 SSL	UG/KG
Phenanthrene	6.8E-04	1.179	1	3.90E-05	2.29E+04	NDA	150 UG/L	>1e+8 CALC	UG/KG d
Phenol	0.2	1.058	82000	2.7E-07	6	NDA	2200 UG/L	10000 SSL	UG/KG
Phorate	8.4E-04	1.156	20	6.40E-06	3.20E+03	NDA	0.73 UG/L	96 CALC	UG/KG b
Pyrene	2.5E-06	1.271	0.135	1.09E-05	6.46E+04	NDA	110 UG/L	420000 SSL	UG/KG
Safrole	NDA	1.096	47	NDA	661	NDA	NDA	NDA	
Selenium	NA	NA	NA	NA	NA	71	18 UG/L	5 SSL	MG/KG
Silver	NA	NA	NA	NA	NA	NDA	18 UG/L	34 SSL	MG/KG
Sulfotepp	1.7E-04	1.196	25	2.88E-06	6.61E+02	NDA	1.8 UG/L	55 CALC	UG/KG
2,4,5-T	7.5E-07	1.420	278	8.68E-09	2.04E+02	NDA	37 UG/L	450 CALC	UG/KG b
2,4,5-TP (Silvex)	5.2E-06	NDA	140	1.31E-07	2.57E+03	NDA	29 UG/L	5300 CALC	UG/KG b
Thallium	NA	NA	NA	NA	NA	NDA	0.29 UG/L	0.7 SSL	MG/KG
Tin	NA	NA	NA	NA	NA	NDA	2200 UG/L	2.95 REF	MG/KG c
Toluene	2.2E+01	0.867	515	6.70E-03	1.29E+02	NDA	75 UG/L	12000 SSL	UG/KG
Total Petroleum Hydrocarbo	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	
Trichlorofluoromethane	6.9E+02	1.487	1100	1.10E-01	1.58E+02	NDA	130 UG/L	2300 CALC	UG/KG
Vanadium	NA	NA	NA	NA	NA	NDA	26 UG/L	600 SSL	MG/KG c
Vinyl acetate	NDA	NDA	NDA	NDA	NDA	NDA	3700 UG/L	17000 SSL	UG/KG
Zinc	NA	NA	NA	NA	NA	86	1100 UG/L	1200 SSL	MG/KG

FOOTNOTES TO TABLE 6-2

* - Ground water screening concentration which is the greater of:

1. Tap water risk-based concentration as presented in EPA Region III tables (June 1996)
2. Grid-based background upper tolerance limits for shallow ground water; Navbase Charleston - Zone C (Risk based screening concentrations assume a target risk of 1E-06 and a target hazard index of 0.1)

** - Soil screening concentration selected by the following order of preference:

Table 6-2
 Fate and Transport Properties and Screening Levels for Constituents Detected in Soil and Groundwater
 NAVBASE-Charleston, Zone C
 Charleston, South Carolina

Parameter	Vapor Pressure (mm Hg)	Density (g/cm ³)	Solubility (mg/L)	Henry's Law Constant (atm-m ³ /mole)	Organic Carbon Water Part. Coeff. (L/kg)	Salt Water Chronic WQC ! (ug/L)	Tap Water RBC or UTL * Units	Ground Water Protection SSL or UTL **	Soil Units
-----------	------------------------	------------------------------	-------------------	---	--	---------------------------------	------------------------------	---------------------------------------	------------

1. Groundwater protection soil screening levels as presented in USEPA Soil Screening Guidance: Technical Background Document. USEPA., EPA/540/R-95/128, May 1996; DAF = 20. Where appropriate, values were adjusted to correlate with a hazard quotient of 0.1
 2. Grid-based background upper tolerance limits - maximum of surface or subsurface soil; Navbase Charleston - Zone C
 3. Generic SSL calculated in accordance with the Soil Screening Guidance using default assumptions and USEPA MCLs as the target soil leachate concentration. The DAF was set equal to 20.
 4. Generic SSL calculated in accordance with the Soil Screening Guidance using default assumptions and tap water RBCs as the target soil leachate concentration. Tap water RBCs were selected to equate with an ILCR of 1E-6 or HQ of 0.1.
- (The USEPA SSG formula for calculating the generic groundwater protection soil SSL is provided below.)

! - Salt water chronic water quality criteria as provided in EPA (1993)

NA - Not applicable

NDA - No data available

SSL means the value was obtained from the USEPA SSG Technical Guidance Document.

REF means the value represents the background reference concentration.

CALC indicates the value was calculated in accordance with USEPA SSG methods.

a - Acenaphthene used as a surrogate

b - Calculated using Soil Screening Guidance (USEPA May 1996)

c - grid-based background upper tolerance limit

d - Fluoranthene used as a surrogate

e - gamma-BHC used as a surrogate

f - endosulfan used as a surrogate

g - endrin used as a surrogate

h - Treatment technique action level for lead

i - naphthalene used as a surrogate

j - Tributyltin oxide used as a surrogate

k - Dioxin (TCDD TEQ) soil screening value based on the tap water RBC

l - Parathion used as a surrogate

UG/L or ug/L - Micrograms per liter

UG/KG - Micrograms per kilogram

MG/KG - Milligrams per kilogram

mmHg - Millimeters of mercury

g/cm³ - Grams per cubic centimeter

mg/L - Milligrams per liter

atm-m³/mole - Atmosphere cubic meters per mole

L/kg - Liters per kilogram

Generic Groundwater Protection Soil SSL formula

$$C_t = C_w * ((K_{oc} * f_{oc}) + [(P_w + P_a * H')/d])$$

Where:

- | | | |
|-----------------|---|---|
| C _t | - | soil screening level (mg/kg) |
| C _w | - | target soil leachate concentration (mg/l) |
| K _{oc} | - | organic carbon partition coefficient (L/kg) -chemical specific |
| f _{oc} | - | fraction organic carbon (0.002 or 2%) - conservative default |
| P _w | - | water filled soil porosity (0.3 unitless) - default |
| P _a | - | air filled soil porosity (0.13 unitless) - default |
| H' | - | dimensionless Henry's Law constant (H * 41) - chemical specific |
| d | - | soil bulk density (kg/L; 1.5) - default |

physical properties into these categories: VOCs, SVOCs, pesticides/PCBs, chlorinated herbicides, 1
chlorinated dibenzodioxins/dibenzofurans, and inorganics. 2

VOCs 3

The chemical and physical properties with the greatest influence on the fate and transport of VOCs 4
are solubility, Henry's law constant, and vapor pressure. Typical fate and transport characteristics 5
are: 6

- VOCs can leach from soils into groundwater. 7
- VOCs tend to be highly mobile in both soil and groundwater. 8
- VOCs tend to volatilize from both soil and groundwater. 9
- VOCs tend to dissipate relatively quickly. 10

The VOCs have low molecular weights, moderate densities, and Henry's law constants, varying 11
organic carbon/water partitioning coefficients, and high solubilities and vapor pressures. Overall, 12
VOCs are expected to be moderately to highly mobile in the environment and to be relatively 13
quick in attenuating from soil and groundwater. 14

SVOCs 15

The chemical and physical properties with the greatest influence on the fate and transport of 16
SVOCs are solubility, vapor pressure, and organic carbon/water partitioning coefficient. Typical 17
fate and transport characteristics are: 18

- SVOCs tend to adsorb to soil particles. 19
- SVOCs tend to be immobile in the environment. 20
- SVOC movement tends to occur more often by colloidal suspension than by diffusion (i.e., 21
greater mobility occurs when coupled with "carrier" compounds). 22

SVOCs have high molecular weights; wide-ranging vapor pressures, solubilities, and Henry's law constants; moderate to high densities; and generally high organic carbon/water partitioning coefficients. Overall, SVOCs are expected to be relatively immobile in soils and diffuse only slightly to groundwater. The most notable exception to the anticipated SVOC immobility in the environment are the phenols and substituted phenols, which have higher solubilities.

Pesticides/PCBs

The chemical and physical properties with the greatest influence on the fate and transport of pesticides/PCBs are solubility, Henry's law constant, and organic carbon/water partitioning coefficient. Typical fate and transport characteristics are:

- Pesticides/PCBs tend to adsorb to soil particles.
- Pesticides/PCBs tend to be hydrophobic (avoid water).
- Pesticides/PCBs tend to be immobile in the environment.
- Pesticides/PCBs tend to degrade relatively slowly.

Pesticides/PCBs have moderate molecular weights, generally high densities and organic carbon/water partitioning coefficients, and generally low solubilities, vapor pressures, and Henry's law constants. Overall, pesticides/PCBs are anticipated to be immobile and persistent in the environment, not readily diffusing into groundwater.

Chlorinated Herbicides

Solubility has the greatest influence on the fate and transport of chlorinated herbicides. Typical fate and transport characteristics are:

- Chlorinated herbicides can leach from soil particles to groundwater.
- Chlorinated herbicides tend to be mobile in both soil and groundwater.
- Chlorinated herbicides tend to degrade relatively slowly.

Chlorinated herbicides have low Henry's law constants and vapor pressures, and moderate molecular weights, organic carbon/water partitioning coefficients, and solubilities. Overall, chlorinated herbicides are expected to be moderately mobile in groundwater with some retention in soil.

Chlorinated Dibenzodioxins/Dibenzofurans

The chemical and physical properties with the greatest influence on the fate and transport of chlorinated dibenzodioxins/dibenzofurans are solubility, Henry's law constant, and organic carbon/water partitioning coefficient. Typical fate and transport characteristics are:

- Chlorinated dibenzodioxins/dibenzofurans tend to adsorb to soil particles.
- Chlorinated dibenzodioxins/dibenzofurans tend to be hydrophobic (avoid water).
- Chlorinated dibenzodioxins/dibenzofurans tend to be immobile in the environment.
- Chlorinated dibenzodioxins/dibenzofurans tend to degrade relatively slowly.

Chlorinated dibenzodioxins/dibenzofurans exhibit limited mobility in most environmental settings, have a strong affinity for soil particles and organic matter, and are not expected to leach to groundwater.

Inorganics

Solubility has the greatest influence on the fate and transport of inorganics. Typical fate and transport characteristics are:

- Inorganics tend to adsorb to soil particles.
- Inorganics are not degradable.
- Inorganics tend to have moderate to low mobility, however, in environments where there is a low pH (i.e., acidic conditions [pH <5]), inorganics can become mobile.

Properties of the surrounding environmental media tend to dictate the fate and transport mechanisms of inorganic elements. Overall, inorganics are anticipated to be immobile and to remain adsorbed to soil particles, not readily diffusing into groundwater.

6.1.2 Media Properties Affecting Fate and Transport

The properties of environmental media used to evaluate fate and transport are TOC, normalized partition coefficient, CEC, redox conditions, pH, soil type, and retardation rate. The following briefly discusses these properties.

Total Organic Carbon

TOC indicates the soil's adsorptive capabilities. The higher the TOC, the higher the potential for a chemical to adsorb to soil particles.

Normalized Partition Coefficient (K_d)

K_d is used to predict the capacity for a constituent to partition between soil and water. To estimate K_d , the constituent's organic carbon/water partitioning coefficient (k_{oc}) is adjusted by the soil's TOC. Higher K_d s have a higher potential to adsorb organic compounds.

Cation Exchange Capacity

CEC reflects the soil's capacity to adsorb ions neutralizing an ionic deficiency on its surface. Generally, trivalent ions are preferentially adsorbed to soil over divalent ions, and divalent ions are preferentially adsorbed over monovalent ions. Although this is generally the case, the process also depends on soil pH. Soils with high CEC values have the potential to adsorb inorganic ions, although organic compounds with dipole moments also are affected by CEC.

Redox Conditions

Redox is the process which includes oxidation (the loss of electrons), and reduction (the gain of electrons). The resultant change in oxidation state generates products that are different from the reactants in their solubilities, toxicities, reactivities, and mobilities. Primarily, redox reactions influence the mobility of inorganic chemicals. Extreme redox conditions tend to mobilize chemicals, especially inorganics.

pH

The pH value is a logarithmic measure of hydrogen ions in the soil or groundwater, indicating the acidity or alkalinity of the medium. Chemicals react significantly different under changing pHs. Low pH conditions tend to mobilize chemicals, especially inorganics, while high pH conditions may lead to the formation of immobile metal hydroxides.

Soil Type

The mineralogical composition, particle-size distribution, and organic content of soil influence chemical fate and transport. Soil type dictates hydraulic conductivity, effective porosity, average linear velocity, and hydraulic gradient which, in turn, affect groundwater flow.

Retardation Factor (R)

The retardation factor is used to evaluate the ability for a soil or groundwater to inhibit the movement of a chemical by preferentially binding to contaminants with high organic carbon/water partitioning coefficients.

Table 6.3 summarizes the chemical and physical parameters of Zone C soil used to evaluate fate and transport. The average CEC for Zone C surface soil is 10.1 milliequivalent per liter (meq/L). Ranges for CEC were from 3.6 to 52 meq/L for surface soil. The average value for pH in Zone C soil samples (included as part of the pesticide analysis) is 6.64. The range of pH values for

Zone C soil is 4.0 to 8.3. These soil conditions indicate limited mobility for inorganics by the processes of advection, diffusion, and dispersion. The average TOC concentration for Zone C surface soil samples was 6,246 mg/kg. TOC measurements indicate a relatively high organic content that will inhibit the movement of contaminants, particularly those with high K_{oc} values, due to increased soil adsorption. The average porosity of the upper sand interval in Zone C, as determined through Shelby tube analysis, was 35%. Hydraulic conductivity for Zone C, as determined by analysis of four Shelby tube samples, is 2.07 feet/day; median hydraulic conductivity, based on slug tests in eleven wells in Zone C, is 6.71 feet/day.

Table 6.3
Soil Parameters Used to Evaluate Fate and Transport

Parameter	Zone C	Upper Sand	Zone C	Units
	Minimum Value	Zone C Maximum Value	Average Value	
Cation Exchange Capacity	3.6	52	10.1	(meq/L)
Total Organic Carbon	919	22,200	6,246	(mg/kg)
pH ^a	4	8.3	6.64	(--)
Total Porosity	0.293	0.395	0.35	(--)
Bulk Density ^b	1.43	1.73	1.59	(kg/m ³)

Notes:

- ^a = pH values compiled from pesticide analysis pre-screening by the laboratory
- ^b = Bulk density values are based on Zone C Shelby Tube data

Table 6.4 lists the approximate time of travel for groundwater flow from each AOC or SWMU to the Cooper River or Noisette Creek, depending on direction of flow, local groundwater gradient, and local hydraulic conductivity. Calculation of travel times was based on an assumption of zero elevation for water in the Cooper River and Noisette Creek. A river gauging station at the Army Depot in North Charleston at mile 10.5 of the Cooper River reported a mean river stage of

1.06 feet for the year 10/92 - 9/93. If mean river stage at Zone C is actually between zero and 1.06 feet, as indicated, then the calculations were based on a somewhat exaggerated horizontal hydraulic gradient. Consequently, results can be considered conservative.

Table 6.4
Travel Time Analysis

AOC/SWMU	Hydraulic Conductivity (feet/day) ^a	Vertical/Horizontal Gradient (-)	Total Porosity (-) ^b	Horizontal Velocity (feet/year)	Horizontal Distance (feet) ^c	Travel Time (years)
SWMU 44	1.35	0.00957	0.35	13,472	230	17
SWMU 47 (Includes AOC 516)	5.18	0.00221	0.35	11,939	1,500	126
AOC 508	7.054	0.00522	0.35	38,402	2,125	55
AOC 523	3.95	0.00194	0.35	7,99	1,750	219

Notes:

- ^a = Based on slug test data from adjacent monitoring wells
- ^b = Total porosity is based on the average of four Shelby tube samples collected in the upper sand.
- ^c = Horizontal distance is based on the potentiometric path of groundwater flow.

6.2 Fate and Transport Approach for Zone C

Fate and transport discussion for each SWMU/AOC begins with a description of site characteristics that can affect constituent migration. As presented earlier in this section, four potential routes of constituent migration have been identified for Zone C. Each SWMU and AOC has been evaluated as to site conditions that promote these migration pathways. In some cases, it is logical to evaluate fate and transport for a combination of SWMUs/AOCs based on their proximity.

An evaluation of individual constituent's ability to migrate is based on four cross-media transfer mechanisms: soil to groundwater, groundwater to surface water, surface soil to air, and/or surface soil to sediment. Cases have been made for each of these transfer mechanisms based on empirical data available for each environmental medium sampled. For example, if a constituent is found in

surface soil as well as in groundwater, it is reasonable to conclude that surface soil constituents may be leaching to the groundwater. The chemical and physical properties of the constituent and the media were evaluated, where necessary, in support of such conclusions. Zone C fate and transport were evaluated using constituent-specific chemical and physical properties and risk-based screening concentrations or grid-based background UTLs (Table 6.2).

The following discussions describe the methods used to evaluate the potential migration of constituents identified at each SWMU/AOC. In some cases, specific migration pathways do not exist for a site. When a particular pathway was not identified for a site, no screening or formal assessment was performed. Fate and transport were not evaluated for essential nutrients (calcium, iron, magnesium, potassium, and sodium), chlorides, or sulfur, which are abundant in shallow coastal/estuarine environments.

6.2.1 Soil-to-Groundwater Cross Media Transport

A phased screening approach was used to evaluate the potential for soil-to-groundwater migration of constituents, focusing attention on chemicals that have the greatest potential for impacting the shallow water-bearing zone. The screening process may be summarized as follows:

- *Qualitative* — The CPSS lists (excluding essential nutrients, chloride, and sulfur) for soil (all depths) and shallow groundwater were compared to determine which chemicals were present in both media.

Due to the nature and age of most SWMU/AOC operations, it was assumed that any impacts associated with compounds having the potential to migrate from soil would be currently manifested in the shallow aquifer. This approach is also supported by the thin, relatively permeable soil layer across Zone C. As a result, the qualitative comparison was used to identify those chemicals with reported concentrations in both media.

- *Quantitative* — Chemicals present in both media were compared to appropriate screening values. Maximum soil concentrations for each SWMU/AOC (or group thereof) were compared to the greater of leachability-based soil to groundwater screening levels, assuming a dilution attenuation factor of 10, as presented in the USEPA Region III RBC tables, June 1996 (or USEPA Soil Screening Guidance assuming a dilution attenuation factor of 10), and grid-based background UTL concentrations for soil in Zone C. Maximum groundwater analytical results for each SWMU/AOC (or group thereof) were compared to the greater of tap water RBCs and grid-based background UTL concentrations for the shallow aquifer in Zone C. For AOCs or SWMUs with available SPLP data, a quantitative comparison of SPLP concentrations (assuming a dilution attenuation of 10) to the tap water RBC was used for the quantitative assessment.

The quantitative assessment further refines the list of chemicals under consideration for formal fate and transport evaluation. It was assumed that if soil concentrations do not exceed leachability-based screening levels or background, no significant migration potential exists. Likewise, if current groundwater or SPLP concentrations do not exceed risk-based screening values, the conclusion was made that existing soil/groundwater equilibria are sufficiently protective of human health relative to potential groundwater ingestion exposure pathways.

- *Detailed Assessment* — Upon completion of the qualitative and quantitative screening processes, detailed analyses were performed to delineate the areal extent of soil impacts potentially affecting groundwater.

The outcome of the detailed assessment was used to determine the significance of soil impacts relative to the shallow aquifer. In some instances, isolated areas of soil contamination above leachability-based concentrations may have the potential for localized shallow groundwater impacts, but not of a magnitude that would pose a long-term or widespread threat to the aquifer.

The detailed assessment was used to identify these cases, as well as to make conclusions as to what areas of soil contamination may require supplemental investigation and/or modeling applications during the CMS as part of the remedial alternatives development process.

6.2.2 Groundwater-to-Surface Water Cross Media Transport

The principal focus of this evaluation was determining whether constituents identified in groundwater have the potential to extend their impacts or discharge to surface water. The screening process may be summarized as follows:

- *Qualitative* — The CPSS list for shallow groundwater was examined to identify the following: all constituents detected in both groundwater and surface water and all constituents that were detected in groundwater that can increase the area of impact in the shallow aquifer or to adjacent surface water bodies.

Many SWMUs/AOCs investigated at NAVBASE have no surface water onsite for a qualitative assessment. As a result, qualitative comparisons of shallow groundwater and surface water data are supported for only a few SWMUs/AOCs. Potential impact on ecological receptors was qualitative/semiquantitatively evaluated for sites with constituents detected in groundwater at concentrations above USEPAs saltwater chronic Ambient Water Quality Criteria (AWQC) protective of aquatic organisms.

- *Quantitative* — Chemicals present in groundwater and/or surface water were compared to appropriate screening values. Relative to human health evaluation, maximum shallow groundwater results for each SWMU/AOC (or group thereof) were compared to the greater of the tap water risk-based screening levels presented in the USEPA Region III RBC tables (June 1996), and grid-based background UTL concentrations for the shallow aquifer in

Zone C. Maximum surface water analytical results for each SWMU/AOC were compared 1
to AWQC (SCDHEC and/or USEPA) to address potential ecological concerns. 2

The quantitative assessment identifies chemicals detected in groundwater with the potential to 3
disperse within the aquifer, increasing the areal extent of groundwater concentrations that exceed 4
human health-based standards, or impact surface water via groundwater migration and discharge. 5
If groundwater concentrations do not exceed tap water risk-based screening levels and grid-based 6
background UTLs, no significant threat relative to migration potential exists. If no constituents 7
with published AWQC values are present in groundwater, no threat exists relative to ecological 8
impacts resulting from groundwater discharge to surface water. This assessment does not consider 9
potential dilution/attenuation factors affecting transport between the affected well and the surface 10
water discharge point, or the dilution capacity of the receiving water body. Omitting these factors 11
from the quantitative screening ensures that a conservative list of potential groundwater to surface 12
water concerns is developed. 13

- *Detailed Assessment* — Upon completion of the qualitative and quantitative screening 14
processes, detailed analyses were performed to delineate the areal extent of groundwater 15
and/or surface water impacts that may adversely affect human or ecological receptors. 16

The outcome of the detailed assessments was used to determine the significance of shallow 17
groundwater and surface water impacts. In addition, in areas where no surface water data were 18
collected as part of the Zone C RFI, the potential for significant surface water impacts was 19
determined preliminarily. These assessments were based on data collected from wells near surface 20
water bodies, and in some instances, incorporated conservative estimates of the dilutional 21
influences of the receiving stream or water body, plus travel time analysis, which assists in 22
predicting mass flux to the receiving stream. The Zone J RFI results will be used to confirm or 23
refute preliminary conclusions. The detailed assessment was used to identify these cases as well 24

as to render conclusions regarding what areas of shallow groundwater and/or surface water 1
contamination may require supplemental investigation and/or modeling applications during the 2
CMS as part of the remedial alternatives development process. 3

6.2.3 Soil-to-Air Cross-Media Transport 4

To evaluate the potential for soil to air migration of volatile contaminants, a screening approach 5
was used to focus attention on chemicals that have the greatest potential to volatilize in sufficient 6
quantities to create a human health threat in ambient air. The screening process may be 7
summarized as follows: 8

- *Quantitative* — The maximum concentrations of volatile CPSS detected in surface soil at 9
each SWMU/AOC were compared to soil-to-air screening concentrations as presented in 10
the USEPA Region III RBC tables (June 1996). 11

The quantitative assessment further refines the list of chemicals under consideration for formal fate 12
and transport evaluation. If soil concentrations do not exceed soil-to-air volatilization screening 13
concentrations, no significant migration potential exists, and current soil conditions are protective 14
of human health relative to potential inhalation exposure pathways. 15

- *Detailed Assessment* — After completing the quantitative screening process, detailed 16
analyses were performed to delineate the areal extent of surface soil impacts potentially 17
affecting ambient air. 18

The outcome of the detailed assessments was used to determine the significance of soil impacts 19
relative to ambient air. In some instances, isolated areas of soil contamination above soil-to-air 20
volatilization-based concentration may have the potential for localized ambient air impacts but not 21
be of a magnitude to pose a long-term or widespread threat through inhalation pathways. The 22

detailed assessment was used to identify these cases as well as to make conclusions as to what areas of soil contamination may require supplemental investigation and/or modeling applications during the CMS as part of the remedial alternatives development process.

6.2.4 Surface Soil-to-Sediment Cross-Media Transport

To evaluate surface soil to sediment erosional migration, a phased screening approach was used to identify chemicals having the potential to form contaminated sediments following surface soil erosion. The screening process may be summarized as follows:

- *Qualitative* — The CPSS lists (excluding essential nutrients, chloride and sulfur) for surface soil and sediment were compared to determine which chemicals were present in both media.

The most influential process by which sediments are formed involves the erosion of surface soil which collects in depositional areas. Site topography was used to identify areas with erosional potential and the expected area of deposition. Qualitative screening was used to identify constituents common to both media. Because erosional/depositional processes within Zone C are expected to be localized based on limited relief and soil conditions, screening focused on these localized units. Sediment results were compared to data for proximate surface soil representing the most likely point of sediment contaminant origination.

- *Semiquantitative* — Constituents present in both media, were compared to the maximum concentration in surface soil to the maximum concentration in related sediment.

The purpose of the semiquantitative assessment was to provide additional evidence in support of this migration pathway. Any impacts to ecological receptors with regard to contaminated sediments have been addressed for Zone C in Section 8 or will be addressed in the Zone J RFI dependant upon their specific location.

7.0 HUMAN HEALTH RISK ASSESSMENT

7.1 Introduction

A BRA analyzes the potential adverse effects on actual or hypothetical human and ecological receptors that could arise from exposures to hazardous substances released from a site if no remedial actions are taken to reduce the extent of present environmental contamination. Generally, a BRA is divided into two subsections; one addresses the human health risk, and the second assesses ecological risk. Data management and analysis methods used to reach the conclusions of this human health risk assessment are discussed in the following text. Ecological concerns are discussed in Section 8, Ecological Risk Assessment.

The succeeding subsections describe general methods, procedures, considerations, toxicological information, and related uncertainties affecting each SWMU- or AOC-specific BRA. Sections 7.1.1 through 7.1.8 provide a general risk assessment framework/outline to avoid presenting redundant information in subsequent site-specific assessments. As a result, the BRAs in Section 10, Site-Specific Evaluations, include only the basic mechanistic and evaluative elements applicable to evaluating risk and/or hazard at a particular SWMU or AOC.

The BRAs within Section 10 were prepared generally in accordance with the guidelines set forth in:

- *Risk Assessment Guidance for Superfund (RAGS), Volume I – Human Health Evaluation Manual (Part A)*, (USEPA, 1989a), (RAGS Part A).

- *RAGS, Volume I – Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals)*, (USEPA, 1991a), (RAGS Part B).

- *RAGS, Volume I – Human Health Evaluation Manual, Supplemental Guidance – Standard Default Exposure Factors – Interim Final*, (USEPA, 1991b), (RAGS Supplement). 1
2

- *RAGS, Volume I – Human Health Evaluation Manual, Supplemental Guidance – Dermal Risk Assessment – Interim Guidance*, (USEPA, 1992d), (Supplemental Dermal Guidance). 3
4

- Supplemental Guidance to RAGS: Region IV Bulletin, *Human Health Risk Assessment – Interim*, (USEPA IV, 1995a). 5
6

- Supplemental Guidance to RAGS: Region IV Bulletin, *Development of Health-Based Preliminary Remediation Goals, Remedial Goal Options (RGO) and Remediation Levels* (Supplemental RGO Guidance), (USEPA Region IV, 1994).. 7
8
9

- Supplemental Guidance to RAGS: Region IV Bulletin, *Provisional Guidance of Quantitative Risk Assessment of PAHs*, (USEPA Region IV, 1993), (PAH Guidance). 10
11

- *Exposure Factors Handbook*, (USEPA, 1989d). 12

- USEPA Region III *Risk-Based Concentration Table, January-June 1996*, (USEPA Region III, June 1996), (RBC Screening Tables). 13
14

- *Technical Memorandum Guidance on Estimating Exposure to VOCs During Showering*, (USEPA, 1991c). 15
16

These references are identified fully in Section 12, References. 17

7.2 Objectives

The objectives of the BRA are to:

- Characterize the source media and determine the chemicals of potential concern (COPCs) for affected environmental media.
- Identify potential receptors and quantify potential exposures for those receptors under current and future conditions for all affected environmental media.
- Qualitatively and quantitatively evaluate the adverse effects associated with the site-specific COPCs in each medium.
- Characterize the potential baseline carcinogenic risk and noncarcinogenic hazards associated with exposure to impacted environmental media at Zone C under current and future conditions.
- Evaluate the uncertainties related to exposure predictions, toxicological data, and resultant carcinogenic risk and noncarcinogenic hazard predictions.
- Establish RGOs for chemicals of concern (COCs) in each environmental medium based on risk/hazard to facilitate risk management decision-making.

Chemical contamination at the site must be characterized adequately before risk assessment can determine whether detected concentrations have the potential for toxic effects or increased cancer incidences and before it can serve as a basis for making remedial decisions. Variables considered in characterizing the study area are the amount, type, and location of contaminant sources. Variables considered for risk characterization are the pathways of exposure (media type and

migration routes); the type, sensitivities, exposure duration, and dynamics of the exposed populations (receptors); and the toxicological properties of identified contaminants.

The focus of each SWMU and/or AOC investigation is detailed in the Site Background and Investigative Approach section for each site. Comprehensive tables show the sample identification numbers and analytical methods applied for each sample. At most SWMUs and AOCs, sampling activities consisted of collecting surface (upper interval) and subsurface (lower interval) soil samples, in addition to groundwater samples from monitoring wells installed in the shallow and deep aquifers underlying the zone. Analytical results from surface soils, shallow groundwater, and deep groundwater were used to assess possible exposure to environmental contaminants.

Organization

A human health risk assessment, as defined by RAGS Part A, includes the following steps:

- ***Site characterization:*** Evaluation of data regarding site geography, geology, hydrogeology, climate, and demographics.
- ***Data collection:*** Analysis of environmental media samples, including background/reference samples.
- ***Data evaluation:*** Statistical analysis of analytical data to identify the nature and extent of contamination and to establish a preliminary list of COPCs based on risk-based and background screening. This list will subsequently be refined to identify COCs.
- ***Exposure assessment:*** Identification of potential receptors under current and predicted conditions and potential exposure pathways, and calculation/quantitation of exposure point concentrations (EPCs) and chemical intakes.

- *Toxicity assessment:* Qualitative evaluation of the adverse effects of the COPCs, and quantitative estimate of the relationship between exposure and severity or probability of effect. 1
2
3

- *Risk characterization:* A combination of the outputs of the exposure assessment and the toxicity assessment to quantify the total noncancer and cancer risk to the hypothetical receptors. 4
5
6

- *Uncertainty:* Discussion and evaluation of the areas of recognized uncertainty in human health risk assessments in addition to medium- and exposure pathway-specific influences. 7
8

- *Risk/Hazard Summary:* Presentation and discussion of the results of the quantification of exposure (risk and hazard) for the potential receptors and their exposure pathways identified under the current and future conditions. 9
10
11

- *Remedial Goal Options:* Computation of exposure concentrations corresponding to risk projections within the USEPA target risk range of 10^{-6} to 10^{-4} for carcinogenic COCs and HQ goals of 0.1, 1, and 3 for noncarcinogenic COCs. 12
13
14

This general process was followed in preparing the BRA for each Zone C SWMU and AOC at NAVBASE. 15
16

7.3 Site Characterization 17

When performing a BRA, environmental media data are compiled to determine potential site-related chemicals and exposures for each medium as outlined in RAGS Part A. The steps identifying COPCs are discussed below. 18
19
20

7.3.1 Data Sources

As part of each investigation, soil, groundwater, surface water, sediment, air, and/or other environmental media samples were collected and analyzed to delineate the sources, nature, magnitude, and extent of any contamination associated with current or past site operations. The data used in the BRA for each SWMU or AOC were obtained from the results of the RFI and associated sampling activities.

7.3.2 Data Validation

Data validation is an after-the-fact, independent, systematic process of evaluating data and comparing them to established criteria to confirm that they are of the technical quality necessary to support the RFI decisions. Parameters specific to the data are reviewed to determine whether they meet the stipulated DQOs. The quality objectives address five principal parameters: precision, accuracy, completeness, comparability, and representativeness. To verify that these objectives are met, field measurements, sampling and handling procedures, laboratory analysis and reporting, and nonconformances and discrepancies in the data are examined to determine compliance with appropriate and applicable procedures.

Data for Zone C were validated in accordance with the USEPA CLP Functional Guidelines and are discussed in Section 4, Data Validation, of this report. Complete data validation reports for the Zone C dataset are included in Appendix E. In its validated form, the Zone C dataset was deemed usable for assessing risk. Chlorinated dibenzodioxin and dibenzofuran data were closely scrutinized because the analytical laboratory departed from standard analytical methods. Although each SDG was not similarly affected, some chlorinated dibenzodioxin and dibenzofuran data were qualified as EMPC during data validation. Projected human health or ecological risk estimates based on these EMPC-qualified results are likely representative of the absolute maximum potential exposure and should be considered highly conservative.

7.3.3 Management of Site-Related Data

All environmental sampling data were evaluated for suitability of use in the quantitative BRA. Data obtained via the following methods were not appropriate for the quantitative BRA:

- Analytical methods that are not specific to a particular chemical, such as TOC or total organic halogen.
- Field screening instruments, including total organic vapor monitoring units and organic vapor analyzers.

Because duplicate samples were collected for QA/QC, in some instances more than one analytical result existed for a single sample location. One objective of data management was to provide one result per sample location per analyte. The mean of duplicate sample results was used as the applicable value, unless the analyte was detected in only one duplicate sample. In such cases, the detection results were used.

In addition, the BRAs addressed limitations of analytical results by including estimated concentrations for nondetected parameters. A nondetect indicates that the analyte did not exceed the quantitation limit of the sample (*U*-qualified results), which is determined by the analytical method, the instrument used, and possible matrix interferences. However, a nondetected analyte could be present at any concentration between zero and the quantitation limit. For this reason, one-half the *U* value could serve as an unbiased estimate of the nondetect. Because the estimated values of *J*-qualified hits were frequently much lower than the sample quantitation limits of *U*-qualified nondetects for organic compounds, one-half of each *U* value was compared to one-half of the lowest hit (normally *J*-qualified) at the same site. The lesser of these two values was used as the best estimate of the concentration that was potentially present below the sample quantitation limit, and was inserted into the adjusted dataset.

For inorganic chemicals, the decision rule was less complex: one-half of each *U* value represented the concentration of the corresponding sample when compiling the adjusted dataset. If two nondetects were reported for any one location (a result of QA/QC samples), one-half the lesser of the *U* values was compared to the lowest hit at the site (for organics, as above) or applied directly (for inorganics) to estimate a concentration value to be used in the Zone C RFI risk calculations. If a parameter was not detected at a SWMU/AOC, neither data management method was applied, and the parameter was not considered in screening or formal assessment.

Once the dataset was complete (i.e., after elimination of faulty data, consolidation of duplicate data values, and quantification of censored values), statistical methods were used to evaluate the RFI analytical results to: (1) identify COPCs and (2) establish EPCs at potential receptor locations. The statistical methods used in data evaluation are discussed below. The rationale used to develop this methodology and the statistical techniques to implement it are based on the following sources:

- RAGS Part A
- *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987)
- *Supplemental Guidance to RAGS: Calculating the Concentration Term* (USEPA, 1992e)

Microsoft FoxPro, Borland Quattro Pro, and Minitab for Windows¹ were used to manage data and calculate statistics. For each set of data describing the concentration of chemicals in a contaminated area, the following information was tabulated: frequency of detection, range of detected values, average of detected concentrations, and the calculated 95th percentile upper confidence limit (UCL) on the mean of log transformed values of the concentration. In accordance

¹ Reference to specific software products are not to be construed as an endorsement by the U.S. Navy or E/A&H.

with RAGS, the lesser of either the maximum concentration detected or the UCL was used to quantify potential exposure. This procedure is detailed in Section 7.3.6 of this document.

7.3.4 Selection of Chemicals of Potential Concern

The objective of this section of the BRA was to screen the available information on the substances detected (CPSSs) at each SWMU or AOC to develop a list or group of COPCs. COPCs are those chemicals selected by comparison with screening concentrations (risk-based and reference), intrinsic toxicological properties, persistence, fate and transport characteristics, and cross-media transport potential. For any COPC to be considered a COC, thus warranting assessment relative to corrective measures, it must meet two criteria. First, the COPC must contribute to an exposure pathway with an incremental lifetime excess cancer risk (ILCR) in excess of 10^{-6} or hazard index (HI) greater than 1 for any of the exposure scenarios evaluated in the risk assessment. Secondly, the COPC must have an individual risk projection greater than 10^{-6} or an HQ greater than 0.1. ILCR, HQ, and HI are detailed in Sections 7.3.7 and 7.3.8 of this report.

Before evaluating the potential risks/hazards associated with site media, it was first necessary to delineate the contamination onsite. This was accomplished by noting the chemicals detected in environmental media. These chemicals represent the CPSSs for each SWMU or AOC. The nature and general extent of CPSSs at each site are discussed in detail in Section 10 of the RFI. Because human health risk and hazard will ultimately direct remedial action, detailed discussions of COC extent were deferred to site-specific BRAs. The Risk Characterization section of each BRA provides risk and hazard maps for COCs (where data support such depictions) to provide visual aids in interpreting the risk assessment outputs. Where data do not support development of relevant visual presentations, affected locations are discussed for each medium. To reduce the list of CPSSs and thereby focus the risk assessment on COPCs, two comparisons were performed as described below.

7.3.4.1 Comparison of Site-Related Data to Risk-Based Screening Concentrations

The maximum concentrations of CPSSs detected in samples were compared to risk-based screening values. These values were obtained from *Determination of COCs by Risk-Based Screening, USEPA Region III*, March 18, 1994, and subsequent versions. As stated in the USEPA Region III document, a target HQ of 0.1 and a risk goal of 10^6 were used by USEPA to calculate screening concentrations for noncarcinogens and carcinogens, respectively. In instances where use of a more recent version of USEPA Region III's RBC tables was necessary, noncarcinogenic chemical values were adjusted to equate with an HQ of 0.1.

Groundwater (and surface water, where applicable) results were compared to tap water screening values, and reported soil (and sediment, where applicable) concentrations were compared to residential soil ingestion screening values. The soil screening value for lead was set equal to 400 mg/kg, consistent with recent OSWER directives considering protection of a hypothetical child resident; the lead groundwater screening value used was the USEPA Office of Water treatment technique action level (TTAL) of 15 $\mu\text{g/L}$.

A soil screening value of 1 $\mu\text{g/kg}$ (1,000 pg/g as 2,3,7,8-TCDD TEQs) was applied to chlorinated dibenzodioxine and dibenzofurans, based on a worker/industrial scenario and the target risk of $1\text{E-}4$. USEPA Region IV has determined this to be an appropriate cleanup level although typically a residential scenario and a target risk of $1\text{E-}6$ serve as the basis for screening values. For 2,3,7,8-TCDD TEQs, USEPA Region IV supports this approach in light of the high level of uncertainty associated with dioxin exposure. For groundwater, the TEQ value computed for each sample was compared to the 2,3,7,8-TCDD tap water screening level. In accordance with recent cPAH guidance (USEPA Region IV, 1993), benzo(a)pyrene equivalents (BEQs) were computed, where appropriate, by multiplying the reported concentration of each cPAH by its corresponding TEF. The BEQ values were then summed for each sample, and the total was compared to the benzo(a)pyrene RBC value during the screening process. Subsequent exposure quantification and

risk/hazard projections for cPAHs in soil and groundwater were performed using total BEQ values for each sampling location rather than individual compound concentrations.

CPSSs with maximum detected concentrations exceeding their corresponding concentrations, goals, levels, and/or standards were retained for further evaluation and reference screening in the risk assessment. Screening values based on surrogate compounds were used if no screening values were available in USEPA's table. Surrogate compounds were selected based on structural, chemical, or toxicological similarities.

The relevance of groundwater RBC screening is discussed in Sections 7.3.6 and 7.3.8. Because shallow and deep groundwater beneath most areas of Zone C contains chlorides and/or total dissolved solids (TDS) above South Carolina potable source criteria, water from these aquifers is not appropriate for domestic use. Consequently, screening the concentrations of compounds detected in groundwater against tap water RBCs provides a highly conservative assessment of the significance of groundwater impacts.

For CPSSs found in both soil (all depths) and shallow groundwater, an additional risk-based screening process was performed as part of the fate and transport assessment. Maximum soil concentrations were compared to the soil-to-groundwater cross-media protection values provided in the USEPA *Soil Screening Guidance: Technical Background Document*, May 1996 and *Risk-Based Concentration Table*, January-June 1996, (USEPA Region III, June 1996). The general approach was described in Section 6 and site-specific evaluations are presented in Section 10.

7.3.4.2 Comparison of Site-Related Data to Background Concentrations

Soil and groundwater background concentrations were determined on a zone-wide basis in Zone C, using results from the grid-based soil and groundwater background sampling locations. Surface

soil, subsurface soil, and shallow and deep groundwater were all addressed separately as discussed in Section 5. Statistical methods and rationale for determining background concentrations and comparing site data to background were also outlined in Section 5. After risk- and hazard-based screening values were compared, COPCs whose maximum detected concentrations exceeded corresponding background reference concentrations, or whose overall site concentrations were significantly greater than corresponding overall background concentrations as determined by Wilcoxon rank sum test procedures, were retained for further consideration as COCs in the BRA on a SWMU- or AOC-specific basis. The two statistical background comparisons were conducted as parallel analyses. If either method suggested that site-specific concentrations deviated from naturally occurring levels, the chemical was retained for formal risk assessment. These comparisons help account for chemicals that are common in nature, such as aluminum, manganese, and arsenic. By virtue of this process, risk and/or hazard associated with naturally occurring chemicals is not addressed where their concentrations are not above corresponding background.

The background reference concentration (UTL) is a fixed value determined to represent the upper bound of naturally occurring levels for a chemical in a specific matrix. Comparisons using reference concentrations are most effective in identifying "hot spots" or limited areas with pronounced impacts. Population tests, in this case performed using the Wilcoxon rank sum method, are used to determine whether values from one population (the site samples) are consistently higher or lower than those from another (the entire background dataset). Ideally, population tests identify general elevations in chemical concentrations absent definable hot spots. A detailed discussion of statistical methods, UTL calculations, Wilcoxon rank sum test outputs and general background sample information is provided in Section 5. In the RFI, if the maximum concentration of a CPSS was determined to be less than either background (via reference concentration comparison *and* population test) or the risk-based screening value, the CPSS was not considered further in the risk assessments unless deemed appropriate based on chemical-specific characteristics (e.g. degradation product with greater toxicity).

7.3.4.3 Elimination of Essential Elements: Calcium, Iron, Magnesium, Potassium, and Sodium 1
2

In accordance with RAGS Part A, essential elements that are potentially toxic only at extremely 3
high concentrations may be eliminated from further consideration as COPCs in a risk assessment. 4
Specifically, an essential nutrient may be screened out of a risk assessment if it is present at 5
concentrations that are not associated with adverse health effects. Based on RAGS, the lack of 6
risk-related data, and USEPA Region IV's recommendations, the following essential nutrients 7
were eliminated from the human health risk assessment: calcium, iron, magnesium, potassium, 8
and sodium. 9

7.3.4.4 Summary of COPCs 10

The results of the screening evaluations are presented on a medium-specific basis in each BRA in 11
Section 10. In summary, the risk information usually obtained from the Integrated Risk 12
Information System (IRIS) or Health Effects Assessment Summary Tables (HEAST) is necessary 13
to calculate risk and hazard estimates (and risk-based screening values). This information is based 14
on toxicological and epidemiological data which are critiqued and approved by the scientific and 15
regulatory community (i.e., listed in IRIS and/or HEAST). Risk information was not available 16
for some CPSSs; therefore, it was not possible to calculate risk and/or hazard for those chemicals. 17
For each environmental medium sampled at a SWMU or AOC, the data were screened using risk- 18
based and background values. The results of the screening process are presented in tabular format 19
in each BRA. Those chemicals determined to be COPCs through the screening process are 20
designated with an asterisk. Total isomer concentrations reported for chlorinated dibenzodioxins 21
and dibenzofurans (e.g., "Total HxCDD") were not specifically used in formal assessment per 22
USEPA protocol. Instead, exposure was estimated for each individually quantitated congener 23
(e.g., "123478-HxCDD"). No risk-based screening values are available for the generic group, 24
TPH. As a result, TPH assessment was handled consistent with state underground storage tank 25
(UST) regulations and the NAVBASE soil action level of 100 mg/kg. If no groundwater impacts 26

were identified, the existing soil concentrations were considered sufficiently protective of the underlying aquifer. 1
2

7.3.5 Calculation of Risk and Hazard 3

As previously discussed, CPSSs that exceed their respective screening values are considered COPCs. The subsequent identification of COCs is a two-phase process. First, exposure pathways exceeding the screening criteria established by USEPA and SCDHEC are identified. Identifying COCs from the refined list of COPCs involves calculating chemical-specific cancer risks and HQs for COPCs, estimating exposure-pathway risk/hazard, evaluating frequency and consistency of detection and relative chemical toxicity, and comparing them to background concentrations. In the next step, COPCs which individually exceed 10^6 ILCR or an HQ greater than 0.1 in a pathway of concern (i.e., an exposure pathway having ILCR greater than 10^6 or HI greater than 1 are retained as COCs. Section 7.3.7 discusses cancer risk thresholds and noncancer toxicity. 4
5
6
7
8
9
10
11
12
13

7.3.6 Exposure Assessment 14

This section of the BRA determines the magnitude of contact that a potential receptor may have with site-related COPCs. Exposure assessment involves four stages: 15
16

- Characterizing the physical setting and land use of the site 17

- Identifying COPC release and migration pathway(s) 18

- Identifying the potential receptors, under various land use or site condition scenarios, and the pathways through which they might be exposed 19
20

- Quantifying the intake rates, or contact rates, of COPCs 21

7.3.6.1 Exposure Setting and Land Use

This section of each BRA describes the basic layout of the SWMU or AOC as well as the suspected source(s) of contamination. Where multiple SWMUs and AOCs were combined for the RFI, the rationale for grouping is discussed. In addition, the projected future use of the site is discussed if information was available. Present land use in Zone C is comparable to commercial office and residential uses. Current base reuse plans call for continued office/training settings, with small portions of the property set aside as open space/buffer and housing.

At some SWMUs/AOCs, existing site features such as asphalt surfaces, buildings, and fences would prevent and/or minimize exposure to impacted media if they are maintained under base reuse plans. As part of each site-specific BRA, the potential influences of existing site features on exposure was evaluated. Where current site features affect how an individual might be exposed, detailed analyses were performed to calculate alternate EPCs and to derive factors to account for fraction ingested/contacted from the contaminated source. The assessments performed in consideration of existing features are presented as an additional exposure scenario within the quantification of exposure and risk characterization sections of the site-specific BRAs.

7.3.6.2 Potentially Exposed Populations

In each site-specific BRA, this section describes who may be exposed to contaminants in environmental media. For the Zone C BRAs, the potentially exposed populations addressed were current and future site workers, as well as hypothetical future site residents. Because current site workers at most sites within Zone C would be expected to have limited contact with contaminated media, worker-related exposure was addressed exclusively for maximally exposed future site workers. This approach, while providing a reasonably conservative assessment of future site worker risk/hazard, also renders a highly conservative approximation of risk/hazard for current site workers. It also accounts for the fact that the specific nature of future industrial users cannot be definitively stated.

7.3.6.3 Exposure Pathways

This section of each BRA summarizes how potential receptors (site workers, residents, etc.) may be exposed to contaminated media. In general, soil matrix-related pathways include incidental ingestion and dermal contact. For groundwater, ingestion and inhalation of volatilized contaminants were the primary pathways of exposure evaluated. Soil-to-groundwater and soil-to-air cross-media protection factors are also discussed where appropriate.

7.3.6.4 Exposure Point Concentrations

The EPC is the concentration of a contaminant in an exposure medium that will be contacted by a real or hypothetical receptor. Determining the EPC depends on factors such as:

- Availability of data
- Amount of data available to perform statistical analysis
- Reference concentrations not attributed to site impacts
- Location of the potential receptor

USEPA Region IV guidance calls for assuming lognormal distributions for environmental data and calculating the 95th percentile UCL on the mean to quantify exposure. Applying the UCL is generally inappropriate with fewer than 10 samples. The maximum concentrations detected were used for all datasets with fewer than 10 samples. In general, outliers have been included when calculating the UCL because high values seldom appear as outliers for a lognormal distribution. Including outliers increases the overall uncertainty of the calculated risks and conservatively increases the estimate of the human health threat.

For sample sets of 10 and greater, the UCL was calculated for a lognormal distribution as follows: 1

$$UCL = e^{\left(\bar{a} + 0.5s_a^2 + \frac{H_{0.95} x s_a}{\sqrt{n-1}} \right)}$$

2
3

where: 4

- \bar{a} = $\Sigma a/n$ = sample arithmetic mean of the log-transformed data, $a = \ln(x)$ 5
- s_a = sample standard deviation of the log-transformed data 7
- n = number of samples in the dataset 8
- $H_{0.95}$ = value for computing the one-sided upper 95% confidence limit on a lognormal mean from standard statistical tables (Gilbert, 1987) 9-10

The calculated values for the 95% UCL are presented in tabular format (where applicable) in each BRA. The tables statistically summarize COPCs identified in each environmental medium. Included for each COPC are the number of samples analyzed, mean and standard deviation of the natural log-transformed data (including the nondetect values), the *H*-statistic, the maximum of detected concentrations, and background concentrations (where available). For media from which fewer than 10 samples were collected, the maximum of positive detections of each COPC identified was used as the EPC to compute exposure.

Modified or alternate EPCs were calculated for some SWMUs/AOCs because existing features or skewed contaminant distributions had to be considered in quantifying exposure potential. The modified EPCs were derived to account for the fraction of impacted areas covered with asphalt surface, buildings, and the like. Should existing features be maintained under the future industrial site use, direct exposure to affected areas (surface soil) would be effectively precluded. In some

instances, factors were derived to modify the EPC to account for the fraction ingested/contacted (FI/FC) from the contaminated source. This approach was used where impacts were found to be extremely limited in areal extent (hot spots). Where this approach was taken, the basis for the decision is discussed in the site-specific BRA.

As previously discussed in the data management subsection (Section 7.3.3) of this document, analytical results are presented as "nondetects" whenever chemical concentrations in samples do not exceed the detection or quantitation limits for the analytical procedures as applied to each sample. Generally, the quantitation limit is the lowest concentration of a chemical that can be reliably quantified above the normal, random noise of an analytical instrument or method. To apply the above-mentioned statistical procedures to a dataset with reported nondetects for organic compounds, the lesser of one-half of the nondetect value for the sample or the lowest *J*-qualified value at the site was assumed to be the applicable default concentration. For inorganic chemicals, one-half of the nondetect value was assumed to be the applicable concentration. Using this method is a reasonable compromise between use of zero and the sample quantitation limit to reduce the bias (positive or negative) in the calculated UCL.

7.3.6.5 Quantification of Exposure

This section describes the models, equations, and input parameter values used to quantify doses or intakes of the COPCs for the surface soil and groundwater exposure pathways. The models are designed to estimate route- and medium-specific factors, which are multiplied by the EPC to estimate chronic daily doses. The intake model variables generally reflect 50th or 95th percentile values which, when applied to the EPC, ensure that the estimated intakes represent the reasonable maximum exposure (RME). Formulae were derived from RAGS, Part A unless otherwise indicated. Table 7.1 lists input parameters used to compute chronic daily intake (CDI) for potential receptors exposed to surface soil and/or groundwater contaminants. These soil and groundwater pathway assumptions were applied for each SWMU and AOC in Zone C. Where

other exposure routes/pathways were found (or predicted) to exist, additional exposure quantification formulae are presented. Because NAVBASE is currently part of BRAC III and final plans for reuse of all areas are not available, the future condition and use of Zone C cannot be assumed with much certainty. Therefore, the conservative assumptions were used to account for any reasonable future use. Current plans call for mixed use including open space, offices, light industrial, and a limited amount of residential area. Zone C media analytical results and exposure methods have been formatted to fine tune exposure estimates based on actual conditions as base reuse plans materialize. Age-adjusted ingestion factors were derived for the potential future residential receptors (resident adult and resident child combined) for carcinogenic endpoints. These factors consider the difference in daily ingestion rates for soil and drinking water, body weights, and exposure durations for children (ages 1 to 6) and adults (ages 7 to 31). The exposure frequency is assumed to be identical for the adult and child exposure groups.

Table 7.1
Parameters Used to Estimate CDI at RME

Pathway Parameters	Resident Adult	Resident Child	Adult Worker	Units
Surface Soil Ingestion and Dermal Contact				
Ingestion Rate (soil)	100 ^a	200 ^a	50 ^a	mg/day
Ingestion Rate (water)	2	1	1	L/day
Exposure Frequency	350 ^b	350 ^b	250 ^b	days/year
Exposure Duration	24 ^c	6 ^c	25 ^c	years
Dermal Contact Area	4,100 ^d	2,900 ^d	4,100 ^d	cm ²
Skin Adherence Factor	1	1	1	mg/cm ²
Absorbance Factor	0.01 (organics) 0.001 (inorganics)	0.01 (organics) 0.001 (inorganics)	0.01 (organics) 0.001 (inorganics)	unitless
Dermal Adjustment Factor	0.8 (VOCs) 0.5 (other organic compounds) 0.2 (inorganics)	0.8 (VOCs) 0.5 (other organic compounds) 0.2 (inorganics)	0.8 (VOCs) 0.5 (other organic compounds) 0.2 (inorganics)	unitless
Conversion Factor	1E-6	1E-6	1E-6	kg/mg
Body Weight	70 ^a	15 ^a	70 ^a	kg

Table 7.1
Parameters Used to Estimate CDI at RME

Pathway Parameters	Resident Adult	Resident Child	Adult Worker	Units
Averaging Time, Non-cancer	8,766 ^a	2,190 ^a	9125 ^a	days
Averaging Time, Cancer	25,550 ^f	25,550 ^f	25,550 ^f	days

Notes:

- a = USEPA (1989a) "Risk Assessment Guidance for Superfund Vol. I, Human Health Evaluation Manual (Part A)."
- b = USEPA (1991b) "Risk Assessment Guidance for Superfund Vol. I: Human Health Evaluation Manual Supplemental Guidance, Standard Default Exposure Factors," Interim Final, OSWER Directive: 9285.6-03.EPA/600/8-89/043.
- c = USEPA (1991a), "Risk Assessment Guidance for Superfund: Vol. I – Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)," OSWER Directive 9285.7-01B.
- d = Resident Adult accounts for head, hands, and forearms at 90th percentile values from Table 4B.1, Exposure Factors Handbook; assumes individual is clothed with shoes, long pants, and short sleeves; rounded up from 4,090 cm². Resident Child accounts for head, hands, forearms, lower leg, and feet using 90th percentile total body surface area values for male children 1 to 6 year olds (6,000 cm² assumed for 1 to 2 years old); because individual body part information is not available for 5 to 6 year olds, mean of other groups was assumed. Forearm surface area set equal to 46% of full arm; lower leg set equal to 41% of full leg measurement.
- e = Calculated as the product of exposure duration (years) x 365 days/year.
- f = Calculated as the product of 70 years (assumed lifetime) x 365 days per year.
- NA = Not applicable.

Surface Soil Pathway Exposure 1

Ingestion of COPCs in Surface Soil 2

The following equation is used to estimate the ingestion of COPCs in soil: 3

$$CDI_s = (C_s)(IR)(EF)(ED)(F)(FI)/(BW)(AT)$$
4

where: 5

- CDI_s = ingested dose (mg/kg-day) 6
- C_s = concentration of contaminant in soil (mg/kg) 7
- IR = ingestion rate (mg/day) 8
- EF = exposure frequency (days/year) 9
- ED = exposure duration (years) 10
- F = conversion factor (10⁻⁶ kg/mg) 11
- FI = fraction ingested from contaminated source (unitless) 12
- BW = body weight (kg) 13
- AT = averaging time (days) 14

Dermal Contact with COPCs in Surface Soil

1

The following equation is used to estimate intake due to dermal contact with COPCs in soil:

2

$$CDI_{sd} = (C_s)(CF)(EF)(ED)(F)(FC)(ABS)(AF)/(BW)(AT)$$

3

where:

4

- | | | | |
|------------|---|--|----------|
| CDI_{sd} | = | dermal dose (mg/kg-day) | 5 |
| C_s | = | concentration of contaminant in soil (mg/kg) | 6 |
| CF | = | contact factor (cm ²) | 7 |
| EF | = | exposure frequency (days/year) | 8 |
| ED | = | exposure duration (years) | 9 |
| F | = | conversion factor (10 ⁻⁶ kg/mg) | 10 |
| FC | = | fraction contacted from contaminated source (unitless) | 11 |
| ABS | = | absorption factor (unitless value, specific to organic versus inorganic compounds) | 12
13 |
| AF | = | adherence factor (mg/cm ²) | 14 |
| BW | = | body weight (kg) | 15 |
| AT | = | averaging time (days) | 16 |

Groundwater Pathway Exposure

17

Ingestion and Inhalation of COPCs in Groundwater

18

The following equation is used to estimate the ingestion and/or inhalation of COPCs in groundwater:

19

20

$$CDI_w = (C_w)(IR)(EF)(ED)(FI)/(BW)(AT)$$

21

where:

22

- | | | | |
|---------|---|---|----|
| CDI_w | = | ingested/inhaled dose (mg/kg-day) | 23 |
| C_w | = | concentration of contaminant in water (mg/L) | 24 |
| IR | = | ingestion rate (L/day) | 25 |
| EF | = | exposure frequency (days/year) | 26 |
| ED | = | exposure duration (years) | 27 |
| FI | = | fraction ingested from contaminated source (unitless) | 28 |
| BW | = | body weight (kg) | 29 |
| AT | = | averaging time (days) | 30 |

Figures 7.1 and 7.2 provide the formulae for calculating the CDI for soil and groundwater, respectively. Tables provided in each SWMU or AOC BRA quantify exposure to environmental media through all applicable pathways. Future site worker and hypothetical site resident exposure projections are provided separately. In accordance with USEPA guidance, the potential exposure to volatiles originating from groundwater during showering and domestic use has been estimated to be equivalent to that ingested through consumption of 2 liters/day of contaminated groundwater. Although the inhalation CDI computed on this basis is equal to that for ingestion exposures, risk and/or hazard associated with inhaled volatile contaminants are characterized using toxicological values specific to the inhalation pathway (e.g., inhalation slope factors [SFs] and reference doses [RfDs]).

Figure 7.1
Formulae for Calculating CDI for Soil

SOIL INGESTION PATHWAY

Residential Scenario:

Noncarcinogens — Child — Residential Scenario:

$$CDI_{NC-C} = \frac{C_s \times IR_{soil/child} \times EF_{res} \times F \times FI \times ED_{child}}{AT_{NC-C} \times BW_{child}}$$

Noncarcinogens — Adult — Residential Scenario:

$$CDI_{NC-A} = \frac{C_s \times IR_{soil/adult} \times EF_{res} \times F \times FI \times ED_{adult}}{AT_{NC-A} \times BW_{adult}}$$

Carcinogens (based on a lifetime weighted average):

$$CDI_C = \frac{C_s}{AT_C} \left[\frac{IR_{soil/child} \times EF_{res} \times F \times FI \times ED_{child}}{BW_{child}} + \frac{IR_{soil/adult} \times EF_{res} \times F \times FI \times ED_{adult}}{BW_{adult}} \right]$$

Figure 7.1 (continued)

SOIL DERMAL CONTACT PATHWAY

Residential Scenario:

Noncarcinogens — Child — Residential Scenario:

$$CDI_{NC-C} = \frac{C_s \times CF_{soil/child} \times EF_{res} \times F \times FC \times AF \times ABS \times ADJ \times ED_{child}}{AT_{NC-C} \times BW_{child}}$$

Noncarcinogens — Adult — Residential Scenario:

$$CDI_{NC-A} = \frac{C_s \times CF_{soil/adult} \times EF_{res} \times F \times FC \times AF \times ABS \times ADJ \times ED_{adult}}{AT_{NC-A} \times BW_{adult}}$$

Carcinogens (based on a lifetime weighted average):

$$CDI_C = \frac{C_s}{AT_C} \times \left[\frac{CF_{soil/child} \times EF_{res} \times F \times FC \times AF \times ABS \times ADJ \times ED_{child}}{BW_{child}} + \frac{CF_{soil/adult} \times EF_{res} \times F \times FC \times AF \times ABS \times ADJ \times ED_{adult}}{BW_{adult}} \right]$$

Figure 7.1 (continued)

Formulae for Calculating CDI for Surface Soil

Variable	Description
BW_{child}	average child body weight (ages 1-6) (kg)
BW_{adult}	average adult body weight (kg)
ABS	absorbance factor (unitless value specific to organic versus inorganic compounds)
ADJ	dermal to absorbed dose adjustment factor (unitless value specific to VOCs, SVOCs, and inorganic compounds)
AF	adherence factor (1 mg/cm ²)
ED_{child}	child exposure duration during (ages 1-6) (yr)
ED_{adult}	adult exposure duration during (ages 7-31) (yr)
$ED_{adult-w}$	adult worker exposure duration during (yr)
EF_{res}	residential exposure frequency (days/year)
EF_w	worker exposure frequency (days/year)
$IR_{soil/child}$	child soil intake rate (mg/day)
$IR_{soil/adult}$	adult soil intake rate (mg/day)
FC	fraction contacted from contaminated source (unitless)
$CF_{soil/child}$	child soil dermal contact factor (mg/day)
$CF_{soil/adult}$	adult soil dermal contact factor (mg/day)
AT_C	averaging time (carcinogen)
AT_{NC-A}	averaging time (noncarcinogen adult)
AT_{NC-C}	averaging time (noncarcinogen child)
C_s	chemical concentration in surface soil (mg/kg)
FI	fraction ingested from contaminated source (unitless)
F	conversion factor (10 ⁻⁶ kg/mg)

Notes:

CDI indicates Chronic Daily Intake

The worker scenario risk and hazard were calculated by substituting worker-specific assumptions into the adult portions of the formulae and then deleting the child portions of the formulae.

Figure 7.2

Formulae for Calculating CDI for Groundwater

GROUNDWATER INGESTION PATHWAY

Residential Scenario:

Noncarcinogens — Child — Residential Scenario:

$$CDI_{NC-C} = \frac{C_w \times IR_{\text{water/child}} \times EF_{\text{res}} \times ED_{\text{child}} \times FI}{AT_{NC-C} \times BW_{\text{child}}}$$

Noncarcinogens — Adult — Residential Scenario:

$$CDI_{NC-A} = \frac{C_w \times IR_{\text{water/adult}} \times EF_{\text{res}} \times ED_{\text{adult}} \times FI}{AT_{NC-A} \times BW_{\text{adult}}}$$

Carcinogens (based on a lifetime weighted average):

$$CDI_C = \frac{C_w}{AT_C} \left[\frac{IR_{\text{water/child}} \times EF_{\text{res}} \times ED_{\text{child}} \times FI}{BW_{\text{child}}} + \frac{IR_{\text{water/adult}} \times EF_{\text{res}} \times ED_{\text{adult}} \times FI}{BW_{\text{adult}}} \right]$$

Figure 7.2 (continued)

Formulae for Calculating CDI for Groundwater

PATHWAY: GROUNDWATER INHALATION WHILE SHOWERING

Residential Scenario:

In accordance with *Technical Memorandum Guidance on Estimating Exposure to VOCs During Showering*, USEPA/ORD, July 10, 1991:

$$CDI_{\text{ingestion}} = CDI_{\text{inhalation}}$$

Variable	Description
BW_{child}	average child body weight (ages 1-6) (kg)
BW_{adult}	average adult body weight (kg)
ED_{child}	child exposure duration during (ages 1-6) (yr)
ED_{adult}	adult exposure duration during (ages 7-31) (yr)
$ED_{\text{adult-w}}$	adult worker exposure duration during (yr)
EF_{res}	residential exposure frequency (days/year)
EF_{w}	worker exposure frequency (days/year)
$IR_{\text{water/child}}$	child water intake rate (mg/day)
$IR_{\text{water/adult}}$	adult water intake rate (mg/day)
FI	fraction ingested from contaminated source (unitless)
AT_{C}	averaging time (carcinogen)
$AT_{\text{NC-A}}$	averaging time (noncarcinogen adult)
$AT_{\text{NC-C}}$	averaging time (noncarcinogen child)
C_{w}	chemical concentration in groundwater (mg/L)

Notes:

CDI indicates Chronic Daily Intake

The worker scenario risk and hazard were calculated by substituting worker-specific assumptions into the adult portions of the formulae and then deleting the child portions of the formulae.

7.3.7 Toxicity Assessment

7.3.7.1 Carcinogenicity and Noncancer Effects

The USEPA has established a classification system for rating the potential carcinogenicity of environmental contaminants based on the weight of scientific evidence. The cancer classes are described below. Cancer weight-of-evidence class "A" (human carcinogens) means that human toxicological data have shown a proven correlation between exposure and the onset of cancer (in varying forms). The "B1" classification indicates some human exposure studies have implicated the compound as a probable carcinogen. Weight-of-evidence class "B2" indicates a possible human carcinogen, a description based on positive laboratory animal data (for carcinogenicity) in the absence of human data. Weight-of-evidence class "C" identifies possible human carcinogens, and class "D" indicates a compound not classifiable for its carcinogenic potential. The USEPA has established SFs for carcinogenic compounds. The SF is defined as a "plausible upper-bound estimate of the probability of a response (cancer) per unit intake of a chemical over a lifetime" (RAGS, Part A).

In addition to potential carcinogenic effects, most substances can also produce other toxic responses at doses greater than experimentally derived threshold concentrations. The USEPA has derived RfD values for these substances. A chronic RfD is defined as *an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure concentration for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime.* These toxicological values are used in risk formulae to assess the upper-bound level of cancer risk and noncancer hazard associated with exposure to a given contaminant concentration.

For carcinogens, the potential risk posed by a chemical is computed by multiplying the CDI (as mg/kg-day) by the SF (in reciprocal mg/kg-day). The HQ (for noncarcinogens) is computed by dividing the CDI by the RfD. The USEPA has set standard limits (or points of departure) for

carcinogens and noncarcinogens to evaluate whether significant risk is posed by a chemical (or combination of chemicals). For carcinogens, the point-of-departure range is 10^6 , with a generally accepted range of 10^6 to 10^4 . These risk values correlate with a 1 in 10,000 and a 1 in 1,000,000 excess incidence of cancer resulting from exposure to xenobiotics (all pathways).

For noncarcinogens, other toxic effects are generally considered possible if the HQ (or sum of HQs for a pathway, HI) exceeds unity (a value of 1). Although both cancer risk and noncancer hazard are generally additive (within each group) only if the target organ is common to multiple chemicals, a most conservative estimate of each may be obtained by summing the individual risks or hazards, regardless of target organ. The following BRAs have taken the universal summation approach for each class of toxicant. Additional details regarding the risk formulae applied to site data are provided in the Risk Characterization section of this document.

Critical studies used in establishing toxicity classifications by USEPA are shown in the IRIS database (primary source) and/or HEAST, Fiscal Year 1995 (secondary source). If toxicological information is unavailable in IRIS or HEAST, values were obtained from reports issued by the Environmental Criteria and Assessment Office (ECAO)/National Center for Environmental Assessment (NCEA). Where applicable, these values were also included in the database for these BRAs. The BRA for each site with identified COPCs includes a table summarizing toxicological data in the form of RfDs and SFs obtained for the relevant COPCs, as well as uncertainty/modifying factors, target organs, and cancer classes (where available).

7.3.7.2 Toxicity Profiles for COPCs

In accordance with RAGS, the BRAs include brief toxicological profiles for all COPCs. Most information for the profiles was gleaned from IRIS and HEAST, as mentioned in the preceding text, and toxicological database information table. Any additional references are noted specifically

in the profiles. The profiles summarize adverse effects of COPCs and the amounts associated with such effects.

7.3.8 Risk Characterization

Risk characterization combines the results of the exposure assessment and toxicity assessment to yield qualitative and quantitative expressions of risk and/or hazard for the exposed receptors. The quantitative component expresses the probability of developing cancer, or a nonprobabalistic comparison of the estimated dose with a reference dose for noncancer effects. These quantitative estimates are developed for individual chemicals, exposure pathways, transfer media, and source media, and for each receptor for all media to which one may be exposed. The qualitative component usually involves comparing COC concentrations in media with established criteria or standards for chemicals for which there are no corresponding toxicity values. The risk characterization is used to guide risk management decisions.

Generally, the risk characterization follows the methodology prescribed by RAGS Part A, as modified by more recent information and supplemental guidance cited earlier. The USEPA methods are, appropriately, designed to be health-protective, and tend to overestimate, rather than underestimate, risk. The risk results, therefore, are generally overly conservative, because risk characterization involves multiplying the conservative assumptions built into the exposure and toxicity assessments.

This section of each BRA characterizes the potential health risks associated with the intake of chemicals originating from the respective site. The USEPA methods used to estimate the types and magnitudes of health effects associated with exposure to chemicals have been supplemented, where appropriate, by graphical representations of risk and hazard. The objective of presenting this supplemental information is to more clearly depict the problem areas at the relevant sites on scales specific to individual sampling points.

Risk Characterization Methodology

Potential risks to humans following exposure to COPCs are estimated using methods established by USEPA, when available. These health-protective methods are likely to overestimate risk. Risks from hazardous chemicals are calculated for either carcinogenic or noncarcinogenic effects. Some carcinogenic chemicals may also pose a noncarcinogenic hazard. The potential human health effects associated with chemicals that produce systemic toxic and carcinogenic influences are characterized for both types of health effects. As mentioned in Section 7.3.6.5, inhalation exposure-related risk and hazard were computed using appropriate route-specific (inhalation) SFs and RfDs (where available).

Unlike the methods for estimating inhaled or ingested dose of COPCs, which quantify the dose presented to the barrier membranes (the pulmonary or gastrointestinal mucosa, respectively), dermal dose is estimated as the dose that crosses the skin and is systemically absorbed. For this reason, oral toxicity values must be adjusted to reflect the dermally absorbed dose.

Dermal RfD values and SFs are derived from the corresponding oral values. In deriving a dermal RfD, the oral RfD is multiplied by an oral absorption factor (ABF), expressed as a decimal fraction. The resulting dermal RfD is based on the absorbed dose, the appropriate value to which a dermal dose should be compared, because dermal doses are expressed as absorbed rather than administered (intake) doses. For the same reasons, a dermal SF is derived by dividing the oral SF by the ABF. The oral SF is divided rather than multiplied because SFs are expressed as reciprocal doses.

Appendix A of RAGS, Part A, states that in the absence of specific data, an assumption of 5% oral absorption efficiency would be relatively conservative. Supplemental Guidance to RAGS: Region IV Bulletin indicates that in the absence of specific data, USEPA Region IV suggests an oral to dermal absorption factor of 80% for VOCs, 50% for SVOCs, and 20% for inorganics. These

percentages (or associated fractions) were used in the BRA and are reflected in the applicable risk/hazard results.

Carcinogenic Effects of Chemicals

The risk attributed to exposure to carcinogens is estimated as the probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen. In the low-dose range, which would be expected for most environmental exposures, cancer risk is estimated from the following linear equation (RAGS, part A):

$$ILCR = (CDI)(SF)$$

where:

ILCR = incremental lifetime excess cancer risk, a unitless expression of the probability of developing cancer, adjusted for reference incidence

CDI = chronic daily intake, averaged over 70 years (mg/kg-day)

SF = cancer slope factor (mg/kg-day)⁻¹

For a given pathway with simultaneous exposure of a receptor to several carcinogens, the following equation is used to sum cancer risks:

$$Risk_p = ILCR(chem_1) + ILCR(chem_2) + \dots + ILCR(chem_i)$$

where:

Risk_p = total pathway risk of cancer incidence

ILCR(chem_i) = incremental lifetime excess cancer risk for a specific chemical

Cancer risk for a given receptor across pathways and across media is summed in the same manner.

Noncarcinogenic Effects of Chemicals

The risks associated with the noncarcinogenic effects of chemicals are evaluated by comparing an exposure level or intake with a reference dose. The HQ, defined as the ratio of intake to RfD is defined as (RAGS, Part A):

$$HQ = CDI/RfD$$

where:

HQ = hazard quotient (unitless)

CDI = intake of chemical (mg/kg-day)

RfD = reference dose (mg/kg-day)

Chemical noncarcinogenic effects are evaluated on a chronic basis, using chronic RfD values. An HQ of unity or 1 indicates that the estimated intake equals the RfD. If the HQ is greater than unity, there may be a concern for potential adverse health effects.

For simultaneous exposure of a receptor to several chemicals, an HI will be calculated as the sum of the HQs by:

$$HI = HQ_1 + HQ_2 + \dots HQ_i$$

where:

HI = hazard index (unitless)

HQ = hazard quotient (unitless)

Risk and hazard projections are summarized in tabular format for each medium following the general discussions of risk and hazard quantification methods. For most SWMUs and AOCs, the following subsections are included.

7.3.8.1 Surface Soil Pathways

This section of each BRA summarizes estimated surface soil risk/hazard for each receptor group. In addition, the primary contributors to carcinogenic risk and/or noncarcinogenic hazard are discussed.

7.3.8.2 Groundwater Pathways

This section of each BRA summarizes estimated groundwater risk/hazard for each receptor group. In addition, the primary contributors to carcinogenic risk and/or noncarcinogenic hazard are discussed.

7.3.8.3 Other Applicable Pathways

This section appears in BRAs for sites where pathways other than soil and groundwater were identified. It summarizes estimated risk/hazard for each receptor group and discusses the primary contributors to carcinogenic risk and/or noncarcinogenic hazard.

7.3.8.4 COCs Identified

This section summarizes the outcome of risk/hazard projections by identifying COCs for each impacted environmental medium. COCs are identified for each medium based on cumulative (all pathway) risk and hazard projected for each site, and are shown in tabular form (where necessary). USEPA has established a generally acceptable risk range of 10^{-4} to 10^{-6} , and an HI threshold of 1.0 (unity). In Zone C BRAs, a COC was considered to be any chemical contributing to a cumulative risk level of 10^{-6} or greater and/or a cumulative HI above 1.0, if its individual ILCR exceeds 10^{-6} or whose HQ exceeds 0.1. For carcinogens, this approach is relatively conservative,

as a cumulative risk of 10^4 (and individual ILCR of 10^6) is generally recognized by USEPA Region IV as the actionable trigger for establishing COCs. The COC selection method presented was used to provide a more comprehensive evaluation of chemicals contributing to carcinogenic risk or noncarcinogenic hazard during the RGO's development process.

Under the traditional risk-based COC trigger provisions, no carcinogenic COCs would be identified for a particular receptor group/pathway combination if the overall cumulative site risk is less than 10^4 . However, as described in Section 7.3.7.1 of this report, the cumulative risk threshold used to identify COCs in the following BRAs is two orders of magnitude more conservative, 10^6 .

7.3.8.5 Risk/Hazard Maps

In addition to the standard tabular presentation of risk/hazard, summary risk and hazard contour maps were plotted (where appropriate) for applicable environmental media to provide a visual supplement. When they are used in an RFI, contour maps are generally developed to show the distribution and concentration of individual chemicals or groups of chemicals, or the risk/hazard associated with potential exposure through applicable pathways.

As an extension of conventional risk/hazard determinations, risk and hazard were calculated based on each COC's concentration at each sample location. Maps were constructed for each combination of SWMU/AOC, medium, and pathway for which sufficient data were available to produce relevant contours. Maps and other graphics were prepared only when they were considered a useful aid in data interpretation and/or CMS decision-making. Narratives are provided where graphical presentations were inappropriate. If COCs were not identified in the BRA for a specific site or an adequate narrative explanation could be provided, risk contours were not developed for that site.

Surfer for Windows and ArcView, standard graphical data presentation and geographic information system packages, were used to plot the risk/hazard projections on SWMU/AOC maps. Section 7.3.9.7 describes the interpolation method used to locate the contours, and discusses the uncertainties involved in the mapping process. The contour maps illustrate risk or hazard associated with COCs in the subject medium. The risk/hazard for individual locations were based exclusively on chemicals detected. For shallow groundwater (where applicable), maps address first-quarter analytical results. Tables summarize the data used to generate graphical presentations. This information allows the reviewer to make determinations regarding the nature of the contaminants identified, and also facilitates remedial alternatives screening as part of the CMS.

7.3.9 Risk Uncertainty

This section of the BRAs presents and discusses the uncertainty and/or variability inherent in the risk assessment process in addition to medium-specific and exposure pathway-specific influences. Risk assessment sections are discussed separately below, and specific examples of uncertainty sources are included where appropriate.

7.3.9.1 General

Uncertainty is a factor in each step of the exposure and toxicity assessments summarized above. Overall, uncertainties associated with the initial stages of the risk assessment process become magnified when they are combined with other uncertainties. Together, the use of high-end estimates of potential exposure concentrations, frequencies, durations, and rates leads to conservative estimates of CDI. Toxicological values for chemicals derived from USEPA databases and other sources are generally derived from animal studies. Uncertainty and modifying factors are applied to extrapolate the results of these studies to predict potential human responses, providing a margin of safety based upon confidence in the studies. During the risk characterization process, individual chemical risk is added to determine the incremental excess

cancer risk for each exposure pathway. If the individual exposure predictions were calculated based on the upper limit estimates of exposure to each chemical, the margin of safety of the cumulative incremental risk is the sum of all the individual safety margins applied throughout the process. Use of these safety margins during all exposure and risk/hazard computations provides an extremely conservative means of predicting potential human health effects. The margins of safety or "conservatisms" inherent in each step of the human health risk assessment are addressed in the Risk Uncertainty discussion. It is not possible to eliminate all uncertainties or potential variability in the risk assessment process; however, recognizing the influences of these factors is fundamental to understanding and subsequently using risk assessment results.

The Risk Uncertainty section of each BRA presents the uncertainty and/or variability of site-specific and medium/pathway-specific factors introduced as part of the risk assessment process, in addition to other factors influencing the uncertainty of the calculated incremental excess cancer risks and hazard quotients/indices. Calculated risk/hazard levels reflect the underlying variability of the analytical results that they are based on; they also embody uncertainty about potentially unsampled maxima and minima in the analytes. The exposure pathways considered for selection in the Exposure Assessment Section of the BRA are extremely conservative.

Assumptions are made as part of the risk assessment process based on population studies and USEPA guidance. This guidance divides the assumptions into two basic categories: the upper bound (90 to 95th percentile) and the mean or 50th percentile central tendency (CT) exposure assumptions. As discussed in the Exposure Assessment section, the RME exposure is based on the upper-bound assumptions, and CT exposure is based on mean assumptions. Therefore, risk and hazard calculated using RME exposure assumptions are generally overestimates rather than underestimates. The following paragraphs discuss sources of uncertainty and variability pertinent to each exposure pathway evaluated.

cancer risk for each exposure pathway. If the individual exposure predictions were calculated based on the upper limit estimates of exposure to each chemical, the margin of safety of the cumulative incremental risk is the sum of all the individual safety margins applied throughout the process. Use of these safety margins during all exposure and risk/hazard computations provides an extremely conservative means of predicting potential human health effects. The margins of safety or "conservatism" inherent in each step of the human health risk assessment are addressed in the Risk Uncertainty discussion. It is not possible to eliminate all uncertainties or potential variability in the risk assessment process; however, recognizing the influences of these factors is fundamental to understanding and subsequently using risk assessment results.

The Risk Uncertainty section of each BRA presents the uncertainty and/or variability of site-specific and medium/pathway-specific factors introduced as part of the risk assessment process, in addition to other factors influencing the uncertainty of the calculated incremental excess cancer risks and hazard quotients/indices. Calculated risk/hazard levels reflect the underlying variability of the analytical results that they are based on; they also embody uncertainty about potentially unsampled maxima and minima in the analytes. The exposure pathways considered for selection in the Exposure Assessment Section of the BRA are extremely conservative.

Assumptions are made as part of the risk assessment process based on population studies and USEPA guidance. This guidance divides the assumptions into two basic categories: the upper bound (90 to 95th percentile) and the mean or 50th percentile central tendency (CT) exposure assumptions. As discussed in the Exposure Assessment section, the RME exposure is based on the upper-bound assumptions, and CT exposure is based on mean assumptions. Therefore, risk and hazard calculated using RME exposure assumptions are generally overestimates rather than underestimates. The following paragraphs discuss sources of uncertainty and variability pertinent to each exposure pathway evaluated.

7.3.9.2 Quality of Data

Data collected during the investigation of Zone C are presented in Section 10 of this RFI, which includes results from AOC and SWMU sites and the QA/QC of those data. The purpose of the data evaluation is to verify that the QC requirements of the dataset have been met and to characterize the weakness of questionable data.

Environmental samples were collected at Zone C sites from February 1995 to August 1997 (excluding the later quarterly groundwater sampling rounds). Samples analyzed for dioxins were submitted to Southwest Laboratory. Samples analyzed for organotins were submitted to Triangle Laboratories. All other samples were analyzed by CompuChem Laboratories Inc. Ninety percent of the samples were reported using USEPA DQO Level III, while 10% were analyzed for Appendix IX parameters using USEPA DQO Level IV. The analytical methods and DQO laboratory deliverables are summarized in Section 4, Data Validation.

As noted in Section 7.3.2, most Zone C data were deemed usable for risk assessment in their qualified form. Polychlorinated dibenzodioxin and dibenzofuran data for some samples were qualified as EMPC indicating that the reported values are potentially positively biased. As a result, all exposure predictions made using data so qualified should be considered absolute maxima.

Most analytical results for environmental samples have inherent uncertainty. This uncertainty is a function of the matrix characteristics and heterogeneity, the precision and accuracy of sampling, and preparation and analysis methods employed. Although data are typically considered to be exact values, they are in reality the laboratory's best estimate within a range defined by method control limits. As a result, reported concentrations for any chemical can be under or overestimates of actual concentrations.

7.3.9.3 Identification of COPCs

Rather than addressing risk/hazard for all chemicals detected, screening values were used to focus the BRA on pathways of concern and COPCs which individually exceed 10^6 risk or an HQ of 0.1.

Exposure Pathways and Contaminants

As discussed in Section 7.3.4.1, a comparison was made using the most conservative screening value (residential land use) provided by USEPA for each exposure medium. Many CPSSs were eliminated from the formal assessment on this basis. Although potential cumulative effects associated with multiple chemicals dismissed through this process are a valid concern, the fact that maximum detected concentrations were used in the screening comparison in concert with low range risk/hazard goals alleviates much uncertainty. A large number (i.e., greater than 10) of constituents would have to be present at near-RBC concentrations to substantiate a concern for cumulative effects. Although the screening method is highly conservative, inhalation and dermal exposure are not incorporated into the soil screening values calculated by USEPA. If these pathways were the primary concern (as opposed to ingestion), the screening method could eliminate contaminants that should be considered COPCs. An evaluation of Zone C surface soil data determined that VOCs were not widespread. Therefore, soil-to-air cross-media transport (via volatilization) was not identified as a potential concern. Therefore, omitting the indirect air pathway from the process of developing the risk-based screening concentrations did not adversely affect their use.

Comparison to Reference Concentrations (Background)

Because the intent of the BRA is to estimate the excess cancer risk or health hazard posed by COPCs, individual site data values of inorganic chemicals were compared to background reference concentrations in the RFI for Zone C subsequent to comparing the data to screening values. As a corollary background screening method, the Wilcoxon rank sum test was used to compare inorganic COPC data populations at individual sites with corresponding reference data

populations. The outcomes of the fixed point and Wilcoxon tests were used to determine whether the concentrations differed significantly between onsite and background locations, as detailed in Section 7.3.4.

Additional uncertainty is introduced by comparing site data to nonspecific screening reference data. Although the background concentrations are specific to Zone C, they are not individual SWMU-specific or AOC-specific. The dual approach to background screening reduces the probability that a COPC would be improperly dismissed from formal assessment.

Background or non-site-related contamination was not considered in identifying organic COPCs for SWMUs or AOCs in Zone C. The most frequently identified soil pathway-related COPCs were cPAHs which were addressed in terms of BEQs as described in Section 7.3.4.1. The compounds that make up this group are commonly found associated with asphalt, used oils, and combustion by-products. In Zone C, all three types of cPAH source have existed at some time. During RFI activities, cPAHs were frequently detected where surface soil samples were collected in proximity to roadways and parking lots. Spatial analysis of cPAH detections indicated that asphaltic materials were not the sole source.

This material, referred to as "coal clinker," has been used extensively across the zone for road base and general fill purposes. Due to its coal origins and combustion generation process, the detection of cPAHs in soil mixed with the material is not unexpected. The characteristics of the material, including a cinder consistency, would tend to minimize coingestion with native soil. The material was present at the surface in some areas and buried beneath more recent soil fill in others. As a result, construction of a comprehensive coal clinker distribution map was not possible.

Elimination of Essential Nutrients

In accordance with RAGS, the following nutrients were eliminated from Zone C BRAs: calcium, sodium, potassium, magnesium, and iron. Toxicity from overexposure to the nutrients listed above is possible only if human receptors are exposed to extremely high doses. USEPA recommends eliminating these compounds from formal risk assessment. Because no screening comparison was performed, the HIs calculated in the BRA could be positively influenced by the nutrient concentrations detected onsite. Therefore, the HIs are possibly underestimates.

7.3.9.4 Characterization of Exposure Setting and Identification of Exposure Pathways

The potential for high bias is introduced through the exposure setting and pathway selection due to the highly conservative assumptions (i.e., future residential use) recommended by USEPA Region IV when assessing potential future and current exposure. The exposure assumptions made in the site worker scenario are highly conservative and would tend to overestimate exposure. Current site workers are not exposed to site groundwater. They are infrequently exposed to surface soils when walking across the site, using commercial facilities, or mowing the grass. Site workers would not be expected to work onsite in contact with effected media for eight hours per day, 250 days per year, as assumed in the exposure assessment. Mowing grass 52 days per year would result in one-fifth the projected risk/hazard for site workers.

Residential use of the sites in Zone C is possible, based on current site uses, the nature of surrounding buildings, and potential reuse plans. If this area were developed as residential sites, most of the present buildings would be demolished and the surface soil conditions would likely change — the existing soil could be covered with roads, paved driveways, landscaping soil, and/or houses, or they could be made into playgrounds. Consequently, exposure to current surface soil conditions would not be likely under a true future residential scenario. These factors indicate that exposure pathways assessed in the BRA would generally overestimate the risk and hazard posed to current site workers and future site residents.

To more accurately assess potential exposure under current site conditions, existing features were 1
evaluated to determine whether they might preclude or minimize contact. Asphalt parking/road 2
surfaces, buildings, and concrete slabs are examples of features under which soil samples were 3
collected. Assuming the future site use involves maintaining these structures, onsite workers 4
would not be chronically exposed to soil beneath them. These factors were considered in 5
calculating alternative EPCs for SWMUs/AOCs with significant surface features (where 6
applicable) and generating descriptive text where formal analysis was deemed unnecessary. 7

Where chronic RME estimates of risk/hazard indicate that a significant threat would be posed to 8
human health, CT analyses were performed. CT exposure scenarios were constructed consistent 9
with standard CT exposure assumptions provided in *Superfund's Standard Default Exposure* 10
Factors for the Central Tendency and Reasonable Maximum Exposure — Draft 11
(USEPA, November 1993). 12

Groundwater is not currently used at any Zone C location as a source of potable or process water. 13
A basewide system provides drinking and process water to buildings throughout Zone C. This 14
system is to remain in operation under the current base reuse plan. As a result, shallow 15
groundwater would not be expected to be used under future site use scenarios. Therefore, the 16
scenario established to project risk/hazard associated with shallow groundwater exposure is highly 17
conservative, and associated pathways are not expected to be completed in the future. 18

In addition, the shallow aquifer, monitored during the RFI process, naturally contains significant 19
concentrations of chlorides and TDS. As a result, this water-bearing zone's potential as a source 20
of potable water is questionable. Absent potential potable uses, the applicability of tap 21
water-based screening or remedial standards is questionable. 22

Determination of Exposure Point Concentrations

Based on the guidance provided by USEPA, EPCs are concentrations used to estimate CDI. The uncertainty associated with EPCs stems primarily from their statistical determination or the imposition of maximum concentrations, described below.

Statistical Estimation of Exposure Point Concentrations

USEPA's *Supplemental Guidance to RAGS: Calculating the Concentration Term* guidance document, (May 1992), outlines a statistical estimation of EPC. These calculated concentrations are 95th percentile UCLs on the mean, which are based on certain assumptions. USEPA assumes that most (if not all) environmental data are lognormally distributed. This assumption can lead to over- or underestimation of the concentration term because many environmental data are neither normally nor lognormally distributed.

The UCL calculation method provided in the *Supplemental Guidance to RAGS: Calculating the Concentration Term*, (USEPA, May 1992), includes a statistical value, the *H*-statistic, which is based on the number of samples analyzed for each COPC and the standard deviation of the results. To obtain this number, a table must be referenced, and the value must be interpolated (an estimation) from the table. The equation for the *H*-statistic has not been provided in the supplemental guidance, nor does the document referred to in the guidance provide the equation. Although the statistic appears to be nonlinear, linearity was assumed to facilitate interpolation of the statistic for each COPC addressed in the BRAs.

Linear interpolation is a good estimate of *H*; however, the UCL formula and *H* are natural log values. The effect of multiplying natural log numbers is not equivalent to multiplying untransformed values. When data are log transformed, adding two numbers is the equivalent of multiplying the two numbers if they were not transformed. The effect of multiplying a number while in log form is exponential; and here, *H* is applied as a multiplier. In summary, using this

method to calculate the UCL has the effect of overestimating, and often provides concentrations greater than the maximum detected onsite. For all datasets having fewer than 10 total samples for a specific medium, the maximum concentrations detected were used as EPC. The datasets in these risk assessments are generally small; however, most consisted of 10 or more samples, and the UCL was calculated for those groups. The limited number of soil and groundwater samples used to assess site conditions often resulted in considerable variability between data points, and thus relatively high standard deviations about the mean. The high standard deviation elevates UCL projections.

Although RAGS advocates using neither worst-case scenarios nor maximum concentrations as EPCs, the use of the *H*-statistic often necessitates using the reported maximum concentration as the EPC. In accordance with RAGS, the lesser of either the maximum concentration or the UCL is used as the EPC. As reviewed above, summation of risk based on maximum concentrations leads to overestimation of exposure, especially in the case of low detection frequency or spatially segregated COPCs. This concept is further discussed below.

Frequency of Detection and Spatial Distribution

Because of the influence of standard deviation on EPC, low frequency of detection can cause COPCs to be addressed inappropriately in the risk assessment. More specifically, COPCs detected only once or twice in all samples analyzed (having concentrations exceeding the RBCs and reference concentrations) would be expected to have relatively higher standard deviation as concentration variability or range widens. Higher standard deviation results in a high *H*-statistic, and this typically leads to a UCL greater than the maximum concentration detected onsite. If that is the case, then using the UCL or maximum concentration detected as EPC (or possibly the inclusion of the COPC in question) may not be appropriate when EPC is assumed to be widely distributed. It is not feasible for a receptor to be simultaneously exposed to maximum concentrations of different contaminants at several locations. The use of the maximum

concentrations (or the UCL) is questionable for these contaminants, and the calculated risk and hazard could be skewed upward or downward due to the low frequency of detection.

In some instances, it is possible to define hot spots within the investigation area. A hot spot is an isolated area of concentrated contamination within a larger area which is not impacted or much less so. Exposure quantification in the presence of a hot spot may be achieved by calculating an FI/FC from a contaminated source factor based on the percentage of the total exposure area encompassed by the hot spot, then using this term to modify the maximum (or restricted area average) contaminant concentration to derive the EPC.

7.3.9.5 Toxicity Assessment Information

There is a generally recognized uncertainty in human toxicological risk values developed from experimental data primarily due to the uncertainty of data extrapolation in the areas of: (1) high-to low-dose exposure and (2) animal data to human experience. The site-specific uncertainty is mainly in the degree of accuracy of the exposure assumptions. Most of the assumptions used in this and any risk assessment have not been verified. For example, the degree of chemical absorption from the gut or through the skin or the amount of soil contact is not known with certainty.

The uncertainty of toxicological values from the IRIS and HEAST databases provided by USEPA is summarized (where available) in each BRA. The uncertainty factors assigned to these values account for acute to chronic dose extrapolation, study inadequacies, and sensitive subpopulations, among other factors. Although uncertainty factors for a specific compound may be 1,000 or higher, these safety factors are applied by USEPA to help guarantee that the overall assessment of risk/hazard is conservative toward human health concerns. In the presence of such uncertainty, the USEPA and the risk assessor are obligated to make conservative assumptions so that the chance is very small for the actual health risk to be greater than what is determined through the

risk assessment process. On the other hand, the process is not intended to yield overly conservative risk values that have no basis in actual conditions. This balance was kept in mind in developing exposure assumptions and pathways and in interpreting data and guidance for Zone C BRAs.

Evaluation of Dioxin Congeners as 2,3,7,8-TCDD Equivalents

Where chlorinated dibenzodioxins and dibenzofurans (dioxins) were detected in soil, TEQs were derived by multiplying the concentration of each dioxin congener by its corresponding USEPA TEF. The resulting TEQs were then summed for each sample, and the total was compared to the 1 $\mu\text{g}/\text{kg}$ AL. If the total TEQ value was found to be less than 1 $\mu\text{g}/\text{kg}$, it was concluded that soil dioxins do not pose an unacceptable risk. Groundwater exposure quantification was performed using TEQ values computed for each monitoring point.

Evaluation of Chemicals for Which No Toxicity Values Are Available

In addition to the typical uncertainties inherent in toxicity values, parameters that do not have corresponding RBCs due to the lack of approved toxicological values were not included in the CDI calculation data. This does not indicate that chemicals lacking approved toxicological values pose no risk/hazard. As stated previously, essential nutrients were eliminated based on their low potential for toxicity. Therefore, these chemicals were not assessed further in the BRA.

7.3.9.6 Quantification of Risk/Hazard

This section of each BRA is reserved for discussion of potential sources of uncertainty or variability identified in the quantification of risk and hazard that are not covered in preceding sections. Each exposure medium addressed in the formal risk assessment process is discussed briefly.

7.3.9.7 Mapping Risk/Hazard

Risk and hazard maps developed to present site-specific BRA results are in Section 10. Location-specific totals were summed and plotted to illustrate total risk and/or total hazard at sites where data supported such a representation. The methods used to construct the risk/hazard contour maps are discussed below. For most sites, point maps were constructed to show the cumulative risk/hazard computed at a specific point based on the location-specific data for the medium of interest. There were, however, instances where contouring the projected risk/hazard values was useful for scoping corrective measures. The following paragraphs discuss how contour maps were produced as well as sources of uncertainty inherent in any interpolation contouring process.

Contouring involves fitting isolines of elevation, concentration, risk, etc., to a scattered or gridded set of points with known values. The graphical result estimates a continuous surface. Because values are known at only a few of an infinite number of possible points on the surface, the mapping process involves extensive interpolation between known points to give estimated values.

Of many possible interpolation methods, kriging is, statistically, the best linear unbiased estimator. It provides more accurate estimates than other methods because it considers the variance of the underlying data values versus the distance between the data points. The relationship between variance and distance is modeled for each dataset using a variogram, and the model serves to differentially weight the data from nearby points with known values that are used to estimate values at unmeasured points (i.e., points whose values must be interpolated between known points). Spatial trends in the data can be recognized by specifying a "drift" (linear, quadratic, etc.), while any known error variance in the data allows use of a "nugget value" when determining the type of variogram model to be used. Risk/hazard maps for this RFI report were generated using Surfer for Windows default linear variogram model with no drift specified. The nugget value is automatically set to zero for the linear model.

Any method of contour mapping, manual or automatic, involves extensive estimation of values at unmeasured points. The mapping process itself is a generalization, in that it converts point data to area (surface) data. The resulting mapped surfaces are known to be accurate only near the control points (that is, within and immediately around the AOCs/SWMUs); accuracy decreases dramatically where there are large spatial gaps between clusters of points, as is the case in parts of Zone C. In these areas, the maps should be considered rough indicators of trends, rather than reliable sources of accurate data values at specific points.

Risk and hazard projection mapping is useful in risk assessment for determining whether hot spots (or isolated areas of gross contamination) exist within an otherwise unimpacted area. This is important, as the lack of homogeneous contaminant concentrations can affect the manner in which receptors are exposed to the affected media. As discussed earlier, it is sometimes appropriate to estimate the FI/FC from the contaminated source in computing CDI. Contour maps allow for visual analysis of contaminant distributions and facilitate estimation of the extent of hot spots relative to the overall site area. These maps also support preliminary scoping of remedial requirements as well as assessment of potential cleanup alternatives in the CMS.

As discussed above, lower confidence can be placed in the concentration estimates made by the kriging function (as represented by contours) in low sample density areas. Because the RFI focused on AOCs/SWMUs, concentrations of background samples that were collected between the sites were not incorporated into the contours, although these areas could influence risk/hazard plots developed for Zone C. In addition, any COC that was detected in only one sample location per AOC/SWMU was not included in the calculations or contours. The distribution of samples collected precluded meaningful graphical presentations at many AOCs/SWMUs. Because of the lack of calculated values for surrounding background locations, relatively planar risk/hazard results were computed for some AOC/SWMU and media combinations. Essentially "flat" plots would be of little use in interpreting risk/hazard projections. As a result, graphical outputs fitting

this description were not generated, and narrative discussions of contaminant distribution are provided instead. The contour maps presented in Section 10 of this RFI report represent the spatially distributed risk and/or hazard of COCs identified in the risk assessment.

7.3.10 Risk Summary

In each site-specific BRA, this section summarizes the risk and hazard projected for each receptor group, exposure medium, and exposure pathway.

7.3.11 Remedial Goal Options

RGOs are chemical concentrations computed to equate with specific risk and/or hazard goals that may be established for a particular site. As previously discussed, COCs are identified as any COPC that significantly contributes to a pathway of concern. A pathway having an ILCR greater than 10^{-6} or an HI greater than 1 is defined as a pathway of concern, and an individual chemical which contributes either 10^{-6} ILCR or 0.1 HI is considered to significantly contribute to the pathway ILCR or HI. Based on this method, COCs were identified which required calculating RGOs. These are listed in the Risk Characterization section of the BRA for each site. RGOs were calculated for all COPCs contributing to a pathway risk of 10^{-6} or greater. Inclusion in the RGO table does not necessarily indicate that remedial action will be required to address a specific chemical. Instead, RGOs are provided to facilitate risk management decisions.

In accordance with USEPA Supplemental RGO Guidance, RGOs were calculated at 10^{-4} , 10^{-5} , and 10^{-6} risk levels for carcinogenic COCs and HQ goals of 3, 1, and 0.1 for noncarcinogenic COCs. RGOs for carcinogens were based on the lifetime weighted average and the adult site worker. Groundwater RGOs for the site resident and site worker are presented in separate tables (where applicable) in each site-specific BRA. Hazard-based RGOs were calculated based on either the hypothetical child resident or the adult site worker, as noted in the each of the corresponding tables.

7.4 Site-Specific Human Health Risk Assessments

The following sections present the human health risk assessment organization prepared for individual SWMUs and AOCs grouped for the RFI. The BRAs were organized as described in the following paragraphs.

SWMU 44

This site is presented as a stand-alone section; no other SWMUs/AOCs were included in the assessment.

AOC 516 and SWMU 47

The soil and groundwater investigations at these two sites resulted in an overlapping sampling effort. Due to their proximity, the data for these sites were combined for use in a composite human health risk assessment.

AOCs 508 and 511

The soil investigations at these two sites resulted in an overlapping sampling effort. Due to their proximity, the data for these sites were combined for use in a composite human health risk assessment.

AOCs 515 and 519

The soil investigations at these two sites resulted in an overlapping sampling effort. Due to their proximity, the data for these sites were combined for use in a composite human health risk assessment.

AOC 523 (includes SWMU 49)

The soil and groundwater investigations at these two sites resulted in an overlapping sampling effort. Due to their proximity, the data for these sites were combined for use in a composite human health risk assessment.

AOCs 510, 512, 513, 517, 518, and 520

Although these sites were grouped in the approved work plan because of similar investigative approach, they will be addressed in the human health risk assessment as separate stand-alone sections.

AOC 522, Former Grease and Wash Building

This site was designated as a AOC following RFI Work Plan approval and completion of the Zone C field activities. As a result, a work plan revision was submitted for review. This site is presented as a stand-alone section; no other SWMUs/AOCs were included.

AOC 700, Golf Course Maintenance Building

This site was designated as a AOC following RFI Work Plan approval and completion of the Zone C field activities. As a result, a work plan revision was submitted for review.

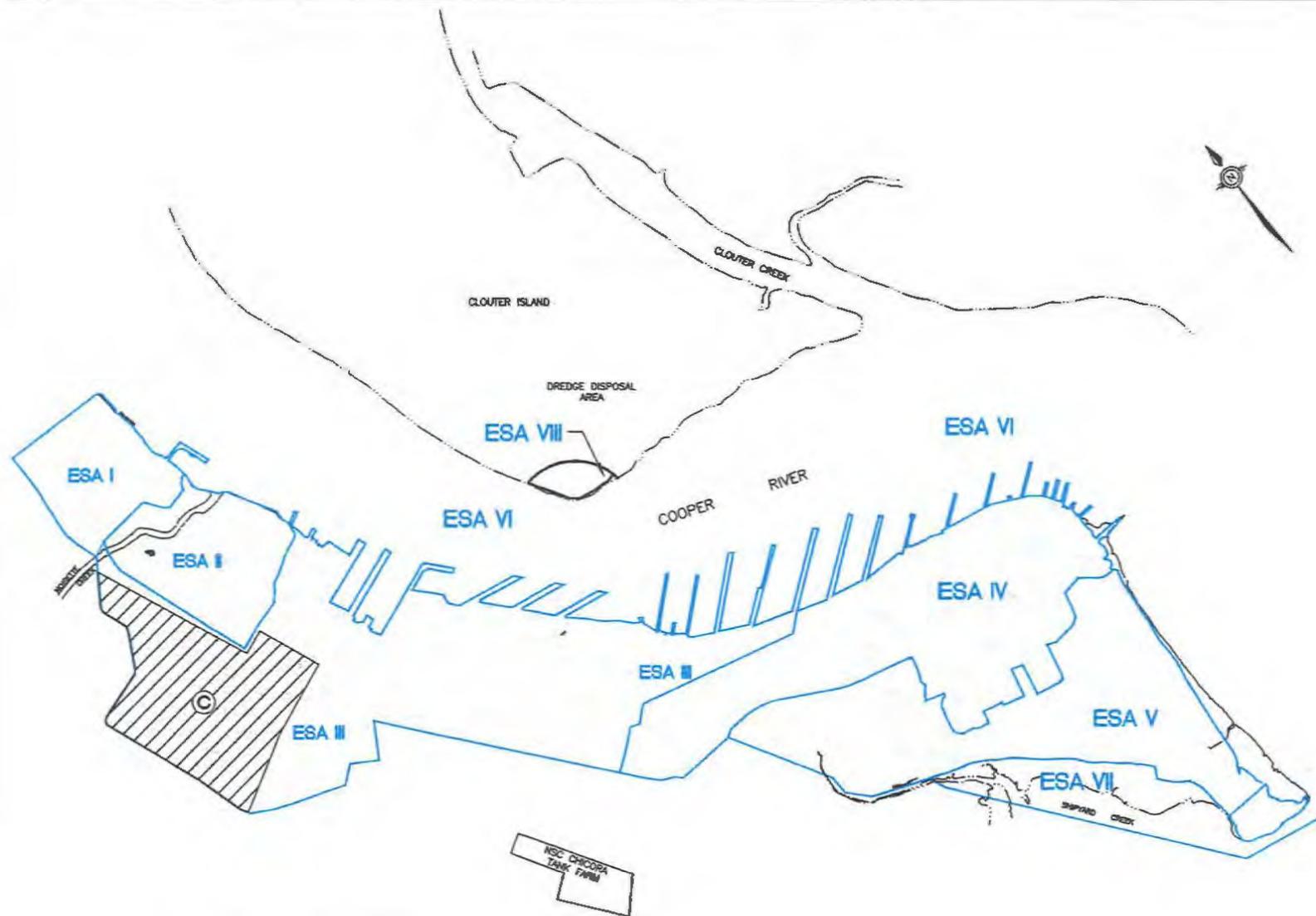
8.0 ECOLOGICAL RISK ASSESSMENT

The ecological risk assessment (ERA) is a key component of the BRA. Its purpose is to develop a qualitative and/or quantitative ecological appraisal of the actual or potential effects of Zone C contamination on the surrounding ecosystem. The assessment considers environmental media and exposure pathways that could result in unacceptable risk to flora and fauna now or in the foreseeable future. The approach to assessing risk components at Zone C was based on USEPA *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (Draft, USEPA, September 1994), *Risk Assessment Guidance for Superfund, Volume II - Environmental Evaluation Manual* (USEPA, 1989b), and *Framework for Ecological Risk Assessment* (USEPA, 1992a).

8.1 Zone Rationale

Base-wide, eight Ecological Study Areas (ESAs) were designated to assist in appropriately qualifying geographic boundaries with contiguous habitats or similar ecosystem distributions (Figure 8.1). To focus the investigation relative to potential SWMU/AOC contribution and receptor exposure within these ESAs, Areas of Ecological Concern (AECs) were further specified. Using an ecological survey form, all ESAs and AECs underwent habitat and resident biota evaluations to obtain preliminary ecological information essential to the Zone C ERA. The completed forms are presented in Appendices A and B of the Zone J RFI Work Plan and summarized below. This survey methodology, which is used in conjunction with the Zone C RFI report, is also described in the Zone J RFI Work Plan.

Base-wide, RFI zone configurations were based on the location of SWMUs or AOCs rather than habitat types and therefore do not necessarily parallel ESA boundaries. Zone C contains portions of ESA III and AECs III-1 and III-2. Some portions of Zone C within the industrialized and residential areas of the zone were not relevant to the Zone C ERA based on the lack of habitat and, thus, receptors. They are designated on Figure 8.2 as "Non-Ecological Areas" and will not



LEGEND

- - ESA BOUNDARY
- ZONE BOUNDARY



SOURCES: SOUTHW, n.d. ESE, 1981.



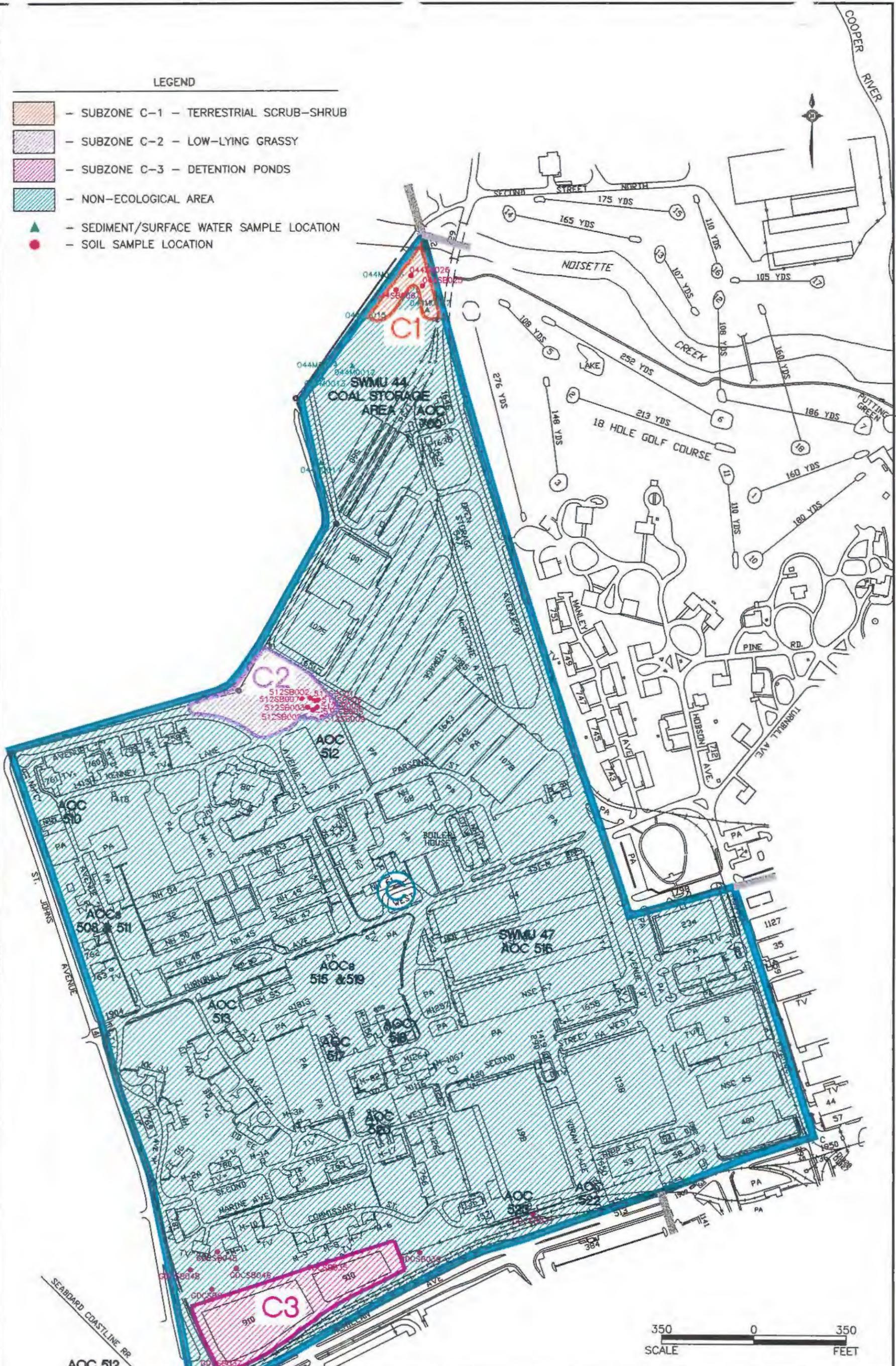
ZONE C
RCRA FACILITY
INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.

FIGURE 8.1
ECOLOGICAL STUDY AREA
LOCATION MAP

DWG DATE: 09/25/97 | DWG NAME: 29ECSALM3

LEGEND

-  - SUBZONE C-1 - TERRESTRIAL SCRUB-SHRUB
-  - SUBZONE C-2 - LOW-LYING GRASSY
-  - SUBZONE C-3 - DETENTION PONDS
-  - NON-ECOLOGICAL AREA
-  - SEDIMENT/SURFACE WATER SAMPLE LOCATION
-  - SOIL SAMPLE LOCATION



ZONE C
RCRA FACILITY
INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.

350 0 350
SCALE FEET

FIGURE 8.2
ECOLOGICAL SUBZONES WITHIN
ZONE C

DWG DATE: 10 NOV 97 | DWG NAME: 29ZCECHT

be discussed relative to ecological risk. Furthermore, if there is a potential for contaminant migration to aquatic areas outside of the Zone C perimeter, risk to applicable receptors in such water bodies will be evaluated during the Zone J investigation.

Subsequent to the AEC evaluations, three distinct ecological areas in Zone C, each with similar and contiguous habitats, will be addressed in this risk assessment. For the discussion purposes, these areas have been designated as Subzones C-1, C-2, and C-3 (Figure 8.2). Specific endpoints and assessment techniques are presented below. The AOCs/SWMUs within or near each subzone are identified in Table 8-1, along with nearby areas potentially impacted by those sites.

Table 8.1
AOCs/SWMUs associated with Zone C Subzones

AOC/SWMU	Description	Potentially Impacted Areas Outside Subzone
Subzone C-1		
SWMU 44	Former Coal Storage Yard	Noisette Creek/Cooper River
Subzone C-2		
AOC 512	Former Incinerator Building	Noisette Creek/Cooper River
AOC 509	Hazardous Flammable Storage (Bldg. 1079)	Noisette Creek/Cooper River
Subzone C-3		
AOC 504**	Railroad System (Zone L)	Cooper River

Note:

** AOC 504 railroads and their associated impacts are being investigated as part of the Zone L RFI. Due to the lack of identified contaminant pathways from Zone C AOC/SWMUs to Subzone C-3, no sampling has been conducted as part of the Zone C ERA.

8.2 Problem Formulation

Subzone C-1 Site Description

Subzone C-1 is an approximately 0.95-acre terrestrial scrub-shrub area at the extreme northern portion of Zone C and is associated with SWMU 44 — the Coal Storage Yard. The subzone is bordered to the north by Noisette Creek and on the west by a tidally influenced storm water runoff ditch that discharges into Noisette Creek and ultimately into the Cooper River. Vegetation consists of southern bayberry (*Myrica cerifera*), tallow trees (*Sapium sevirum*), and southern red cedar (*Juniperus silicicola*), as well as dense undergrowth consisting of *Viburnum* spp. and numerous herbaceous species. Sections of this subzone bordering on Noisette Creek contain suitable habitat to support a wide variety of semiaquatic vertebrate species such as frogs (Order *Anura*), salamanders (Order *Caudata*), snakes (Order *Squamata*), and aquatic insects such as dragonflies (Order *Odonata*), mayflies (Order *Ephemeroptera*), mosquitos, and midges (Order *Diptera*). Portions of subzone C-1 provide suitable nesting and/or foraging habitat for avian species such as mourning doves (*Zenaida macroura*), yellow-rumped warblers (*Dendroica coronata*), American robin (*Turdus migratorius*), and marsh wrens (*Cistothorus palustris*). Major terrestrial faunal species typically associated with this habitat include Eastern cottontail rabbit (*Sylvilagus floridanus*) and raccoon (*Procyon lotor*), along with other small rodents (mice, voles, shrews).

Subzone C-2 Site Description

Subzone C-2 is a 2.15-acre grassy low-lying area transected by three drainage ditches that contain small communities of cattail (*Typha* spp.) and sedges (Family *Cyperaceae*). This subzone also contains several mid-canopy trees including tallow trees, southern hackberry (*Celtis laevigata*) in addition to a woody undergrowth of *Viburnum* spp. The area is believed to be seasonally flooded by storm water runoff that drains north into an off-base marsh that is empties into Noisette Creek. Avian species that may use this type of habitat include American robin (*Turdus migratorius*), common grackles (*Quiscalus quiscula*), boat-tailed grackle (*Quiscalus major*), and European

starlings (*Sturnus vulgaris*), along with birds of prey (Families *Accipitridae* and *Falconidae*). 1
Mammals that frequent this type of habitat include the Eastern gray squirrel (*Sciurus carolinensis*), 2
Eastern cottontail rabbit, raccoon, and other small rodents. 3

Subzone C-3 Site Description

 4

Subzone C-3 includes a detention pond of approximately 3.75 acres which receives storm water 5
runoff from nearby areas of NAVBASE, in addition to off-base areas. A diverse community of 6
emergent vegetation occurs throughout the basin, making Subzone C-3 suitable habitat for a wide 7
variety of aquatic and semiaquatic species such as reptiles and amphibians, along with a number 8
of invertebrate species. Riparian areas of C-3 host black willow trees (*Salix nigra*) and numerous 9
herbaceous species. Avian species observed include mourning doves (*Zenaida macroura*), 10
northern mockingbird (*Mimus polyglottos*), red-winged blackbird (*Agelaius phoeniceus*), boat-tailed 11
grackles, and European starlings. Mammalian species common to this type of habitat include the 12
raccoon and Eastern cottontail rabbit, along with small rodents. 13

Due to the lack of any observed or suspected contaminant migration pathways leading from any 14
Zone C AOC or SWMU to the Subzone C-3 detention ponds, resulting exposure potentials are not 15
present. An assessment of ecological risk at this subzone has therefore been deemed unnecessary. 16
Unless future RFI activities suggest additional assessment of the ponds is warranted, no further 17
investigation of this subzone is anticipated. 18

Threatened and Endangered Species

 19

Several species of concern may be present within portions of Zone C. Table 8.2 lists those species 20
that have been historically or recently identified at or near NAVBASE. Risk to these species from 21
observed contamination will be addressed as appropriate. 22

Table 8.2
 Federal and State Listed Threatened, Endangered, and Candidate Species
 That Occur or Potentially Occur on NAVBASE

Species		Status		
Common Name	Scientific Name	Residence Status	USF&WS	SCWMRD
Reptiles and Amphibians				
American Alligator	<i>Alligator mississippiensis</i>	PR	T/SA	T/SA
Flatwoods Salamander	<i>Ambystoma cingulatum</i>	UR	C-2	SC
Eastern Tiger Salamander	<i>Ambystoma tigrinum tigrinum</i>	PR	—	SC
Broad-Striped Dwarf Siren	<i>Pseudobranchius striatus striatus</i>	PR	—	SC
Crawfish Frog	<i>Rana areolata</i>	PR	—	SC
Loggerhead Turtle	<i>Caretta caretta</i>	PM	T	T
Kemp's Ridley Sea Turtle	<i>Lepidochelys kempi</i>	PM	E	E
Island Glass Lizard	<i>Ophisaurus compressus</i>	UR	SR	SR
Birds				
Brown Pelican	<i>Pelecanus occidentalis</i>	LM	—	SC
Wood Stork	<i>Mycteria americana</i>	LM	E	E
Osprey	<i>Pandion haliaetus</i>	CR	—	SC
American Swallow-Tailed Kite	<i>Elanoides forficatus forficatus</i>	PM	SR	E
Bachman's Sparrow	<i>Aimophila aestivalis</i>	UR	SR	SR
Red-Cockaded Woodpecker	<i>Picoides borealis</i>	UR	E	E
Bachman's Warbler	<i>Vermivora bachmanii</i>	UR	E	E
Bald Eagle	<i>Haliaeetus leucocephalus</i>	LM	E	E
Arctic Peregrine Falcon	<i>Falco peregrinus tundrius</i>	PM	T	T
Piping Plover	<i>Charadrius melodus</i>	PM	T	T
Least Tern	<i>Sterna antillarum</i>	CR	—	T
Least Tern Breeding Colony		CR	—	SC
Wading Bird Breeding Colony		CR ^a	—	SC
Mammals				
Black Bear	<i>Ursus americanus</i>	UM	—	SC
West Indian Manatee	<i>Trichechus manatus</i>	PM	E	E
Fish				
Shortnose Sturgeon	<i>Acipenser brevirostrum</i>	LM	E	E
Plants				
Canby's Dropwort	<i>Oxypolis canbyi</i>	UR	E	E
Pondberry	<i>Lindera melissifolia</i>	UR	E	E
Incised Groovebur	<i>Agrimonia incisa</i>	UR	C-2	NC
Sea-beach Pigweed	<i>Amaranthus pumilus</i>	UR	SR	NC
Cypress Knee Sedge	<i>Carex decomposita</i>	UR	SR	—

Table 8.2
Federal and State Listed Threatened, Endangered, and Candidate Species
That Occur or Potentially Occur on NAVBASE

Species		Status		
Common Name	Scientific Name	Residence Status	USF&WS	SCWMRD
Plants (continued)				
Chaff-Seed	<i>Schwalbea americana</i>	UR	SR	NC
Whisk Fern	<i>Ptilotum nudum</i>	UR	—	SL
Climbing Fern	<i>Lygodium palmatum</i>	UR	—	SL
Piedmont Flatsedge	<i>Cyperus tetragonus</i>	PR	—	SL
Baldwin Nutrush	<i>Scleria baldwinii</i>	UR	—	SL
Nodding Pogonia	<i>Triphora trianthophora</i>	UR	—	SL
Savannah Milkweed	<i>Asclepias pedicellata</i>	UR	—	RC
Venus' Fly-Trap	<i>Dionaea muscipula</i>	UR	—	RC
Sweet Pinesap	<i>Monotropsis odorata</i>	UR	—	RC
Climbing Fetter-bush	<i>Pieris phillyrifolia</i>	UR	—	SL
Sea Purslane	<i>Trianthema portulacasfrum</i>	CR	—	SC

Notes:

- a = Wading bird colony has been a confirmed resident at the base, but was not present during field studies in April 1994.
- CR = Confirmed resident
- LR = Likely resident
- PR = Possible resident
- UR = Unlikely resident
- LM = Likely migrant or occasional visitor
- PM = Possibly migrant or occasional visitor
- UM = Unlikely migrant or occasional visitor
- SC = Of concern, state
- SR = Status review
- E = Endangered
- T = Threatened
- SL = State listed
- RC = Of concern, regional
- NC = Of concern, national
- C-2 = Candidate species for federal listing, Category 2
- T/SA = Threatened due to similarity of appearance
- USF&WS = U.S. Fish and Wildlife Service
- SCWMRD = South Carolina Wildlife and Marine Resources Department

Source: Final Environmental Impact Statement for Disposal and Reuse of the Charleston Naval Base (E & E, June 1995)

8.3 Conceptual Model

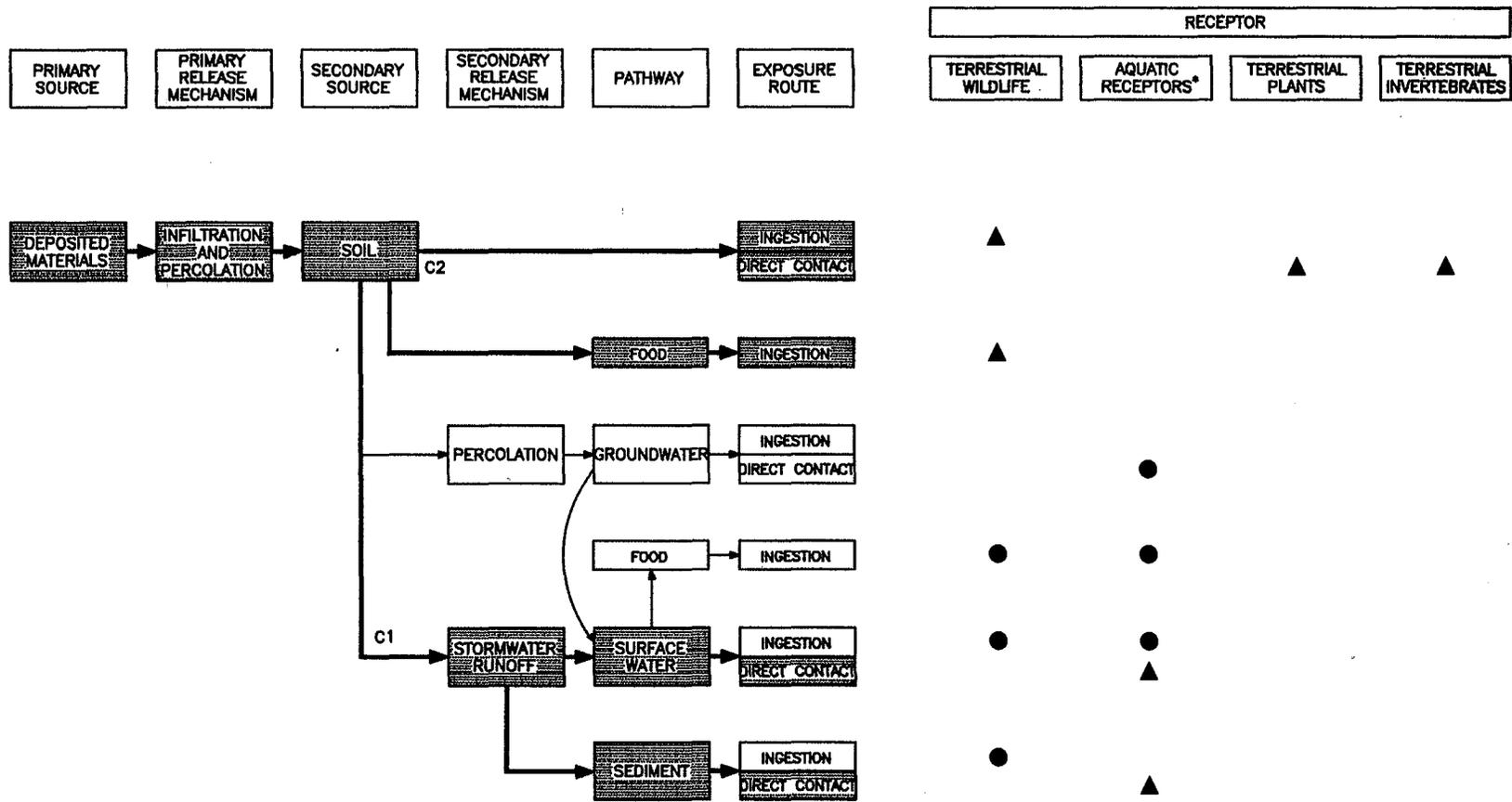
Figure 8.3 presents a conceptual model of the potential contaminant pathways from source to ecological receptors for Zone C subzones. For this assessment, exposure routes directly related to soil pathways are evaluated for Subzones C-1 and C-2. Subzone C-1, located upgradient of Noisette Creek, was also preliminarily characterized for sediment and water exposure routes to determine the need for additional assessment during the Zone J RFI study. Direct impacts to terrestrial plants are not included in this assessment but transfer mechanisms are considered in food chain transfer analyses. Information related to specific contaminant toxic mechanisms to vegetation are also discussed.

8.4 Selection of Ecological Chemicals of Potential Concern

Section 10 of this report discusses past activities at Zone C SWMUs and AOCs associated with the designated ecological subzones that may have impacted the surrounding ecosystem (see Table 8.1). COCs resulting from these activities have been identified and quantified according to USEPA methods and protocols for analyses of soil, surface water, and sediment. For the assessment of ecological risk, it was necessary to identify ecological contaminants of potential concern (ECPCs) using the following criteria. To evaluate impacts representative of both isolated hot spots as well as overall concentrations detected across each subzone, both the maximum and mean concentrations for each matrix are presented for comparison to the most appropriate screening value, UTL, or effect level (EL).

Surface Soil

In subzone surface soil, inorganic parameters with a mean concentration exceeding the UTL of background were identified as ECPCs. Since organic constituents do not occur naturally in surface soil, all detected organic parameters were identified as ECPCs. Only the results from surficial soil (0 to 1 foot bgs) are addressed. It is presumed, even considering root development in the lower strata, that most biological effects will be limited to the upper zone.



AQUATIC RECEPTORS - INVERTEBRATES, PLANTS, ALGAE, AMPHIBIANS, AND FISH
 NOTE: SHADED BOXES, BOLD ARROWS, AND TRIANGLES INDICATE SELECTED PATHWAY



ZONE C
 RCRA FACILITY
 INVESTIGATION REPORT
 NAVAL BASE CHARLESTON
 CHARLESTON, S.C.

FIGURE 8.3
 CONTAMINANT PATHWAY MODEL FOR
 ECOLOGICAL RECEPTORS

DWG DATE: 09/25/97 | DWG NAME: 29ZCCPMF

Sediment

In subzone sediment, analytes were selected as ECPCs if the mean detected concentration either: (1) exceeded the USEPA Region IV Sediment Screening Value, (2) exceeded the most conservative effects level found in literature, or (3) if neither of these benchmarks was available. To estimate both point-specific and subzone-wide risk potentials, the maximum and mean concentrations for sediment inorganic constituents were divided by the available benchmark to produce a respective Hazard Quotient (Max HQ or Mean HQ). HQs are a common screening method developed by Region III USEPA for predicting ecological risk. HQs greater than 1 are considered to demonstrate a potential risk. Values greater than 10 are considered to be of moderately high potential risk and above 100, extreme risk.

Surface Water

In subzone surface water, analytes were selected as ECPCs if the mean concentration detected either: (1) exceeded the South Carolina or USEPA water quality criteria, (2) exceeded the USEPA Region IV Surface Water Screening Value (November 1995), or (3) if neither of these benchmarks was available.

Calcium, magnesium, potassium, and sodium were not included in this assessment process because they are naturally occurring nutrients.

Although zone-specific groundwater has been monitored, water table depth (approximately 5 feet bgs) within Zone C precludes assessing ecological impacts from this medium immediately within the zone perimeter. Wetland areas in Zone C are either tidally influenced (such as those in C-1) or associated with storm water runoff (C-2) and not considered significantly affected by groundwater discharge. See Section 10 for further information on groundwater-to-surface water cross-media transport.

Subzone C-1

For the ERA of Subzone C-1, the analytical results from the three surface soil samples NBCC044SB006, -025, and -026 and eight Subzone C-1 sediment and surface water samples (NBCC/044-0011 through -0017, and -0019) were considered. Results for Zone C samples collected in Noisette Creek (Zone J) are preliminarily assessed in Section 10, but with the limited Zone C samples, it is considered more appropriate to assess ecological risk to the creek during the Zone J RFI in which additional sampling will be conducted both up and downgradient of Zone C's SWMU 44 outfall.

Subzone C-2

For the ERA of Subzone C-2, seven surface soil samples (NBCC/512-SB001 through SB007) were considered. One sample (SB003) was analyzed for Appendix IX parameters, including organophosphorous pesticides, herbicides, and dioxins. Although two additional soil samples were collected at AOC 512 (SB008 and SB009) and analyzed for semivolatile constituents, no SVOCs were present above the laboratory's detection limits. Furthermore, no sediment or surface water was present for analysis at Subzone C-2. Tables 8.3 (a, b, and c) and 8.4 (a and b) present the ECPCs identified for Subzones C-1 and C-2, respectively.

Table 8.3a
Subzone C-1
Inorganic Constituents in Surface Soil (mg/kg)

Inorganics	Detections (N=3)	Range of Concentrations	Mean Concentration	UTL of Background ^a	ECPC
Aluminum	3	2,800 - 36,600	18,966.67	9,990	Yes
Arsenic	3	2.8 - 103	44.13	14.2	Yes
Barium	3	6.7 - 55.4	36.17	77.2	No
Beryllium	3	0.16 - 2.0	1.35	NA	Yes
Cadmium	2	0.51 - 3.6	2.06	ND	Yes
Chromium	3	7.3 - 54.3	36.17	26.4	Yes
Cobalt	3	5.6 - 13.6	9.27	3.22	Yes
Copper	3	4.5 - 122	56.80	34.7	Yes
Iron	3	3,520 - 99,500	44,973.33	NA	Yes
Lead	3	26.1 - 64.2	42.70	330	No
Manganese	3	96.3 - 408	234.43	92.5	No
Mercury	2	0.15 - 0.53	0.34	0.24	Yes
Nickel	3	14.0 - 43.4	31.43	12.3	Yes
Selenium	2	0.72 - 8.8	4.76	1.44	Yes
Thallium	1	2.4	2.4	ND	Yes
Vanadium	3	7.1 - 68.2	39.10	23.4	Yes
Zinc	3	65.5 - 279	155.83	159	No

Notes:

- N = Total number of surface soil samples collected at the subzone.
- a = See Section 5 for Upper Tolerance Limit determination.
- ECPC = Ecological Chemical of Potential Concern. Mean Concentration > UTL of Background.
- NA = Data are not available.
- ND = Not Detected

Table 8.3b
Subzone C-1
Inorganic Constituents in Sediment (mg/kg)

Inorganic Elements	Detections (N=7)	Range of Concentrations	Mean Concentration	Effects Level ^a (EL)	Max HQ	Mean HQ	ECPC
Aluminum	7	3,500 - 10,900	6,372.86	NA	-	-	Yes
Antimony	3	0.53 - 1.20	0.90	12	0.1	0.08	No
Arsenic	7	4.0 - 69.20	40.26	7.24	9.3	5.56	Yes
Barium	7	12.0 - 70.7	35.50	NA	-	-	Yes
Beryllium	1	0.65	0.65	NA	-	-	Yes
Cadmium	5	0.04 - 0.84	0.42	1.0	0.8	0.42	No
Chromium	7	8.5 - 42.1	20.10	52.3	0.8	0.38	No
Cobalt	7	1.6 - 11.6	4.60	NA	-	-	Yes
Copper	7	7.2 - 75.3	33.77	18.7	4.0	1.81	Yes
Iron	7	5,160 - 93,700	35,227.14	NA	-	-	Yes
Lead	7	11.2 - 43.7	32.07	30.2	1.4	1.06	Yes
Manganese	6	36.9 - 96.1	66.67	NA	-	-	Yes
Mercury	6	0.17 - 1.6	0.59	0.13	12.3	4.54	Yes
Nickel	7	3.8 - 26.7	10.54	15.9	1.7	0.66	No
Selenium	5	0.83 - 9.3	3.45	NA	-	-	Yes
Thallium	4	1.9 - 4.6	2.83	NA	-	-	Yes
Vanadium	7	8.1 - 33.5	21.50	NA	-	-	Yes
Zinc	7	31.2 - 125.0	69.21	124	1.0	0.56	No

Notes:

- a = Effects Level (EL) represents USEPA Region IV (1995) Sediment Screening Values (SSV).
- Max HQ = Hazard Quotient calculated by dividing maximum concentration by the effect level.
- Mean HQ = Hazard Quotient calculated by dividing mean concentration by the effect level.
- ECPC = Ecological Chemical of Potential Concern. Parameter with mean concentration > EL or EL=NA.
- NA = Data are not available.

Table 8.3c
Subzone C-1
Inorganic Constituents in Surface Water (µg/L)

Inorganic Elements	Detections (N=8)	Range of Concentrations	Mean Concentrations	Effects Level* (EL)	Max HQ	Mean HQ	ECPC
Aluminum	6	188.0 - 16,400	5,169	87	189	59.4	Yes
Antimony	4	2.4 - 5.2	3.28	160	0.03	0.02	No
Arsenic	5	6.2 - 144.0	35.42	190	0.7	0.19	No
Barium	8	12.6 - 75.2	24.51	NA	-	-	Yes
Beryllium	2	3.7 - 5.2	4.45	0.33	9.8	8.4	Yes
Cadmium	1	0.70	0.70	0.66	1.1	1.1	Yes
Chromium (III)	8	1.6 - 52.4	10.24	117.32	0.4	0.09	No
Chromium (VI)	8	1.6 - 52.4	10.24	11	4.8	0.93	No
Cobalt	6	0.93 - 71.0	23.02	NA	-	-	Yes
Copper	7	4.9 - 92.5	24.41	6.54	14.1	3.7	Yes
Iron	8	578.0 - 85,900	16,954.50	1,000	85.9	17	Yes
Lead	5	3.8 - 9.2	5.8	1.32	6.9	4.4	Yes
Manganese	8	64.3 - 2,110.0	595.36	NA	-	-	Yes
Nickel	7	2.5 - 107.0	35.14	87.71	1.2	0.4	No
Selenium	4	4.6 - 10.4	7.40	5	2.1	1.5	Yes
Vanadium	8	0.71 - 6.9	3.28	NA	-	-	Yes
Zinc	8	15.1 - 202.0	69.16	58.91	3.4	1.2	Yes

Notes:

Reported concentrations of hardness-dependent compounds have not been adjusted for site-specific conditions.

- N = Total number of surface water samples collected in subzone.
- a = Effects Level (EL) represents USEPA Region IV (1995) Freshwater Chronic Screening Value (USEPA, 1995).
- Max HQ = Hazard Quotient calculated by dividing maximum concentration by the effect level.
- Mean HQ = Hazard Quotient calculated by dividing mean concentration by the effect level.
- = HQ not calculable
- ECPC = Ecological Chemical of Potential Concern. Parameter with mean concentration > EL or EL=NA.
- NA = Data are not available.

Table 8.4a
Subzone C-2
Organic ECPCs in Surface Soil ($\mu\text{g}/\text{kg}$)

Compound Name	Number of Detections	Range of Concentrations	Mean Concentration
Semivolatile Organic Compounds (N = 7)			
Benzo(a)anthracene	7	45 - 140	84
Benzo(a)pyrene	6	60 - 120	85.67
Benzo(b)fluoranthene	7	110 - 270	191.43
Benzo(g,h,i)perylene	1	66	66
Benzo(k)fluoranthene	7	95 - 300	176.43
Chrysene	7	58 - 170	94
Fluoranthene	7	76 - 240	152.29
Indeno(123-cd)pyrene	1	60	60
Phenanthrene	6	49 - 120	82.50
Pyrene	7	52 - 210	98.71
Pesticides/PCBs (N = 7)			
Aldrin	1	1-10	1.10
Aroclor 1254	1	60	60
beta-BHC	3	1.6 - 8.4	5.57
Chlordane	2	3.1 - 4.2	3.65
4,4'-DDD	2	4.1 - 37	20.55
4,4'-DDE	5	4.3 - 140	34.48
4,4'-DDT	3	7.6 - 55	27.87
Dieldrin	1	2	2
Endosulfan	1	2.4	2.4
Endrin aldehyde	4	1.6 - 13	5.13
Methoxychlor	1	4.3	4.3
Methyl parathion	1	4.7	4.7

Table 8.4a
Subzone C-2
Organic ECPCs in Surface Soil ($\mu\text{g}/\text{kg}$)

Compound Name	Number of Detections	Range of Concentrations	Mean Concentration
Organophosphorous Pesticide (N = 1)			
Disulfoton	1	5.2	5.2
Sulfotepp	1	4.5	4.5
Herbicide (N = 1)			
2,4,5-T	1	8.5	8.5
Dioxins (N=1, ng/kg)			
Total Hepta-Dioxins	1	77.57	77.57
Total Hexa-Dioxins	1	12.54	12.54
Total Hexa-Furans	1	13.04	13.04
Total Penta-Furans	1	8.0	8.0
1234678-HxCDF	1	31.62	31.62
123478-HxCDF	1	3.13	3.13
123678-HxCDF	1	1.13	1.13
234678-HxCDF	1	1.24	1.24
OCDD	1	186.12	186.12
OCDF	1	9.78	9.78

Notes:

ng/kg = nanograms per kilogram

N = Number of samples collected

ECPC = Ecological Chemical of Potential Concern; all organics are considered ECPCs.

Table 8.4b
Subzone C-2
Inorganic Constituents in Surface Soil (mg/kg)

Inorganic Elements	Detections (N=6)	Range of Concentrations	Mean Concentration	UTL of Background ^a	ECPC
Aluminum	6	3,960 - 10,600	6,842.86	9,990	No
Arsenic	6	2.2 - 8.2	4.74	14.2	No
Barium	6	14.10 - 40.7	22.74	77.2	No
Beryllium	4	0.27 - 0.44	0.34	NA	Yes
Cadmium	5	0.21 - 0.77	0.48	0.65	No
Chromium	6	9.3 - 21.7	13.82	26.4	No
Cobalt	6	1 - 4.4	2.58	3.22	No
Copper	6	10.7 - 39	23.38	34.7	No
Iron	6	5,570 - 11,800	8,640	NA	Yes
Lead	6	21.7 - 76.1	46.22	330	No
Manganese	6	46 - 280	173.52	92.5	Yes
Mercury	6	0.1 - 0.35	0.19	0.24	No
Nickel	6	2 - 9.5	6.22	12.3	No
Selenium	6	0.59 - 1.0	0.75	1.44	No
Tin	6	1.3 - 1.9	1.65	2.95	No
Vanadium	6	13.9 - 24.5	17.60	23.4	No
Zinc	6	35.3 - 124	76.73	159	No

Notes:

- a = See Section 5 for Upper Tolerance Limit determination.
- ECPC = Ecological Chemical of Potential Concern. Parameter with mean concentration > UTL or EL = Not Valid.
- NA = Not Available
- ND = Not Detected

8.5 Contaminant Fate and Transport

Surface soil across Zone C consists of fine-to medium-grained sand with silt and some clay. This soil type is typically low in organic material with medium permeability. These factors most likely limit development of a microbial community, thereby reducing the likelihood of microbial decomposition of sorbed organic contaminants. These contaminants will therefore be expected to either remain in the soil to undergo degradation or migrate downward.

In addition, contaminants sorbed to surface soil could be transported via air or surface water runoff. However, both of these pathways are unlikely as major routes. Contaminants are not expected to spread far via surface runoff due to the substrate's permeable nature. The physical adsorption of contaminants to soil particles and available organic material also limits horizontal migration. Migration via air pathways could be significant only as it relates to dispersal of upper soil layer particles during high winds typical of coastal areas. Because sand particles are relatively large and heavy, extended migration through this route is not expected. Fate and transport issues are discussed in detail in Section 6.

8.6 Exposure Pathways and Assessment

Once the ECPCs were identified for each subzone in Zone C, an assessment of the potential exposure pathways was performed. Because of the lack of an identified migration pathway from any known contaminant source, exposure routes associated with Subzone C-3 were not evaluated. If the potential exposure of a Zone C ECPC to an ecological receptor in either Subzone C-1 or C-2 was indicated, the potential risk to that receptor (or group of receptors) was then evaluated. Based on the habitat types observed in each Zone C subzone, the exposure pathways to the following potential receptors were identified: infaunal invertebrates (worms and insects living within the soil), terrestrial wildlife (birds/mammals), vegetation, and aquatic wildlife.

Infaunal Invertebrates

The primary exposure pathway evaluated for infaunal invertebrates will be via direct contact with surface soil. An assessment endpoint of a well-balanced soil infaunal community will be qualitatively measured by comparing literature data on toxic effects to actual soil concentrations.

Terrestrial Wildlife

For terrestrial wildlife species, exposure would include direct dermal contact, ingestion of soil particles, and food-chain transfer. Small mammals could contact contaminated soil if the area is a migratory corridor or if animals burrow into it. Contact time (exposure) will be limited when animals are crossing the area, but could be lengthy if burrows are established. Dermal contact by small reptiles and amphibians would be similar to that for mammals. For insect populations, direct exposure to ground-dwelling species could provide a link for contaminant transfer to higher-level predators.

The assessment endpoint selected for terrestrial wildlife is the maintenance of well-balanced terrestrial wildlife populations and communities. As a measure of the assessment endpoint selected, EnSafe used results of laboratory toxicity studies in literature that relate the oral dose of a contaminant to adverse response to growth, reproduction, or survival. Selected measurement endpoint species include: Eastern cottontail rabbit (*Sylvilagus floridanus*), short-tailed shrew (*Blarina brevicauda*), and American robin (*Turdus migratorius*). All of these species (or an equivalent) are likely to occur within the designated subzones in Zone C.

To assess biotransfer of contaminants along food chains, the total potential dietary exposure (PDE) has been modeled for representative terrestrial wildlife species within Subzones C-1 and C-2. PDEs are calculated based on predicted concentrations of the ECPCs in food items that the species would consume, the amount of soil it would ingest, the relative amount of different food items in its diet, body weight, and food ingestion rate (Table 8.5). The concentrations of ECPCs in food

items are estimated based upon literature reported bioaccumulation factors (BAFs), which are a ratio of the ECPC concentration in dietary items to the concentration in surface soil. The BAFs reported for avian and mammalian species are reported ratios of ECPCs in the tissue of the animals to the concentrations of ECPCs in their diets.

Table 8.5
Wildlife Contaminant Exposure Model for Surface Soil

$$\text{Food Contaminant Concentration (mg/kg)} = \text{BAF}^1 \times \text{Soil Contaminant Concentration (mg/kg)}$$

$$\text{Soil Exposure [SE](mg/kg)} = (\% \text{ diet soil}) \times \text{Soil Contaminant Concentration (mg/kg)}$$

$$\text{PDE (mg contaminant/kg BW/day)} = \frac{[P_1 \times T_1 + P_2 \times T_2 + \dots P_n \times T_n + \text{SE}] \times \text{IR}_{\text{diet}} \times \text{SFF}}{\text{BW}}$$

where:

- P_n = percent of diet composed of food item N
- T_n = tissue concentration in food item N (FCC in mg/kg)
- IR_{diet} = food ingestion rate of receptor (kg of food per day)
- SFF = site foraging factor (cannot exceed 1)
- BW = receptor body weight (kg)
- 1 = BAF from Table 8-7
- PDE = Potential Dietary Exposure

The site foraging factor (SFF) allows the frequency of feeding in the area to be considered by estimating it relative to the receptor's feeding range and by considering the fraction of the year the receptor would be exposed to site contaminants.

Vegetation

Woody and herbaceous vegetation in Subzones C-1 and C-2 could likely incorporate certain detected constituents (primarily metals) through processes such as uptake/accumulation, translocation, adhesion, or biotransformation. These plant-borne constituents could also be ingested by terrestrial herbivores.

Aquatic Wildlife

The primary exposure pathway evaluated for aquatic wildlife species in Subzone C-1 (Noisette Creek tributary), is contact or interface with water and sediment. An assessment endpoint, evaluating the aquatic community health, has been selected with a measurement endpoint that predicts chronic effects to aquatic community species. The complete assessment of Noisette Creek is to be conducted during the more comprehensive Zone J RFI, which will incorporate all pertinent information obtained during the Zone C ERA.

8.7 Ecological Effects Assessment

In addition to determining the exposure potentials associated with each site, the effects of certain ECPCs upon selected receptors was examined. Based on the known characteristics of these potential contaminants or "stressors," their associated effects can be better predicted.

Stressor Characteristics

Inorganics

In general, heavy metals adversely affect survival, growth, reproduction, development, and metabolism of both terrestrial and aquatic invertebrate species, but effects are substantially modified by physical, chemical, and biological variables. Pascoe et al. (1994) observed that, in general, bioavailability of metals in soil to small mammals was limited. Their study also suggests that metal intake for higher tropic species may be similarly limited. Most heavy metals do not

biomagnify. In contact tests with terrestrial earthworms the order of toxicity for heavy metals 1
from most toxic to least toxic was copper > zinc > nickel = cadmium > lead. 2

Arsenic, an ECPC in sediments at Subzone C-1, naturally occurs and, with respect to cycling in 3
the environment, is constantly changing. Many inorganic arsenicals are known teratogens and are 4
more toxic than organic arsenicals (Eisler, 1988). Soil biota appear to be capable of tolerating and 5
metabolizing relatively high concentrations (microbiota to 1,600 ppm) of arsenic (Wang et al., 6
1984). But adverse effects to aquatic organisms have been reported at concentrations of 19 to 7
48 ppb in water. Arsenic in soil does not appear to magnify along the aquatic food chain. 8

Cadmium, an ECPC in Subzone C-1 soils and surface water, is a relatively rare heavy metal. It 9
is a known teratogen and carcinogen and probably a mutagen, and has been implicated as the cause 10
of severe deleterious effects on fish and wildlife (Eisler, 1985). Birds and mammals are 11
comparatively resistant to the biocidal properties of cadmium. Freshwater organisms appear to 12
be the most susceptible group to cadmium toxicity, which is modified significantly by water 13
hardness. Adsorption and desorption processes are likely to be major factors in controlling 14
cadmium concentrations in natural waters. Adsorption and desorption rates of cadmium are rapid 15
on mud solids and particles of clay, silica, humic material, and other naturally occurring solids. 16

Chromium is an ECPC in the surface waters at Subzone C-1. Hexavalent chromium (Cr VI) 17
produces more adverse effects to biota than the trivalent phase does. In clayey sediments, trivalent 18
chromium dominates and benthic invertebrate bioaccumulation is limited (Neff et al., 1978). 19

Copper, an ECPC in Subzone C-1 soil, sediment, and surface water, is an essential micronutrient, 20
and therefore, it is readily accumulated by aquatic organisms. It is a broad-spectrum biocide and 21
may be associated with both acute and chronic toxicity. 22

Lead, an ECPC in Subzone C-1 sediments and surface water, is primarily found in association with iron and manganese hydroxides and may also form associations with clays and organic matter. Under oxidizing conditions, lead tends to remain tightly bound to sediments, but is released into the water column under reducing conditions. Lead may accumulate to relatively high concentrations in aquatic biota.

Mercury, an ECPC in Subzone C-1 sediments, is a known mutagen, teratogen, and carcinogen. It adversely affects reproduction, growth, development, motor coordination, and metabolism. Mercury has a high potential for bioaccumulation and biomagnification and is slow to depurate. Organomercury compounds produce more adverse effects than inorganic mercury compounds. Inorganic mercury can be biologically transformed to organic mercury compounds.

Zinc is an ECPC in Subzone C-1 surface water. In water, zinc speciates into the toxic aquo ion, other dissolved chemical species, and various inorganic and organic complexes. It is readily transported. Most zinc introduced into aquatic environments is eventually partitioned into the sediments. Reduced conditions enhance zinc's bioavailability.

No information was available on the toxicological effects associated with other inorganic ECPCs for soil, sediment, or surface water.

Organics

Little information exists on the toxic effects from VOCs. Primarily, the only information available are effects studies related to human health from inhalation of specific compounds by laboratory animals.

PAHs, detected in Subzone C-2 surface soils, vary by molecular weight. With increasing molecular weight, aqueous solubility decreases and the octanol-water partition coefficient ($\log K_{ow}$)

increases, suggesting increased solubility in fats, a decrease in resistance to oxidation and reduction, and a decrease in vapor pressure (Eisler, 1987a). Accordingly, PAHs of different molecular weight vary substantially in their behavior and distribution in the environment and in their biological effects. In water, PAHs either evaporate, disperse into the water column, become incorporated into sediments, or undergo degradative processes such as photooxidation, chemical oxidation, and biological transformation by bacteria and animals (Neff, 1979). PAHs show little tendency to biomagnify in food chains because most are rapidly metabolized (Eisler, 1987a). Very little information is available on adverse effects to a food chain as a result of soil PAH contamination.

Organochlorine pesticides, an ECPC in Subzone C-2 soils, have been used extensively in the United States since the 1940s. They appear to be ubiquitous in the environment, being found in surface water, sediment, and biological tissues across the nation. They are readily absorbed by warm-blooded species and degradatory products are frequently more toxic than the parent form. Food chain biomagnification is usually low, except in some marine mammals. In soil invertebrates, organochlorine pesticides can accumulate to concentrations higher than those in the surrounding soil, and residues may in turn be ingested by birds and other animals feeding on earthworms (Beyer and Gish, 1980). Most environmental effects studies have been directed at mammals and birds.

PCBs, classified as ECPCs in Subzone C-2 soils, are distributed worldwide with measurable concentrations recorded in fishery and wildlife resources from numerous locations (Eisler, 1986). They are known to bioaccumulate and to biomagnify within the food chain and to elicit biological effects such as death, birth defects, tumors, and a wasting syndrome. In terrestrial environments, PCBs are rapidly metabolized from the soil into the terrestrial food chain (McKee, 1992). Subsoil-dwelling organisms may directly absorb PCBs and may transfer through the food chain to species.

Dioxins (an ECPC in Subzone C-2 surface soil) are trace compounds in some commercial herbicides and chlorophenols (Eisler, 1986). The most toxic and most extensively studied dioxin is 2,3,7,8-TCDD. Laboratory studies with birds, mammals, aquatic organisms, and other species have demonstrated that exposure to 2,3,7,8-TCDD can result in acute and delayed mortality as well as mutagenic and reproductive effects. In soil, microbial decomposition of TCDD is slow (Ramel, 1978) and uptake by vegetation is considered negligible (Blair, 1973).

Assessment of Potential Receptors

Infaunal Invertebrates

Predicted potential adverse ecological effects to soil invertebrates from identified ECPCs in Zone C are based on effects information in available literature. Because soil MCLs are unavailable for effects levels, studies are used for comparative qualitative assessments only.

Terrestrial Wildlife

Potential adverse effects associated with the identified ECPCs to bird and mammal species are based on food uptake potential. Available toxicity reference values (TRVs) were determined for each measurement endpoint species selected. The TRV relates the dose of a respective ECPC in an oral exposure with an adverse effect. The lethal TRV has been determined to be one-fifth of the lowest reported LD₅₀ value (concentration of a contaminant at which half of the exposed test population die) for the most closely related test species (Table 8.6). One fifth of an oral LD₅₀ value is considered to be protective of lethal effects for 99.9 % of individuals in a test population (USEPA, 1986). It is assumed that this level of risk to individuals within terrestrial wildlife populations across Zone C is acceptable.

A sublethal TRV is also identified, representing a threshold for sublethal effects. Sublethal effects are defined as those that impair or prevent reproduction, growth, or survival. Sublethal TRVs are therefore based on the lowest observed adverse effect level (LOAEL) for the most closely related

Table 8.6
Chemical Effects Studies on Terrestrial Infaunal Invertebrates

Study	Organisms	Measured Parameter	Effects Level	Measured Response
Parmelee et al. (1993)	nematode/microarthropods	Copper	200 mg/kg	Significant decline in numbers
Neuhauser et al. (1986)	earthworm <i>Eisenia foetida</i>	Copper salts	643 mg/kg	LC ₅₀
		Zinc salts	662 mg/kg	LC ₅₀
		Nickel salts	757 mg/kg	LC ₅₀
		Cadmium salts	1,843 mg/kg	LC ₅₀
		Lead salts	6,000 mg/kg	LC ₅₀
		4-Nitrophenol	38 mg/kg	LC ₅₀
		Fluorene	173 mg/kg	LC ₅₀
Roberts & Dorough (1984)	<i>Eisenia foetida</i>	Cadmium chloride	10 - 100 µg/cm ²	LC ₅₀
		Copper sulfate	10 - 100 µg/cm ²	LC ₅₀
		Lead nitrate	10 - 100 µg/cm ²	LC ₅₀
Malecki et al. (1982) ^a	<i>Eisenia foetida</i>	Cadmium	250 mg/kg	
		Nickel	440 mg/kg	
		Copper	1,320 mg/kg	
		Zinc	2,800 mg/kg	Growth difference to control
		Lead	21,600 mg/kg	
Strait (1984)	Mite <i>Platynothrus peltifer</i>	Copper	200 mg/kg	Population decrease
van Straalen et al. (1989)	Mites	Cadmium	> 128 mg/kg	Mortality

Table 8.6
Chemical Effects Studies on Terrestrial Infaunal Invertebrates

Study	Organisms	Measured Parameter	Effects Level	Measured Response
McKee (1992)	Terrestrial epigeic ^b Invertebrates	PCBs	120,000 mg/kg	No community structure effects
Callahan, et al. (1991)	earthworms <i>L. terrestris</i>	DDT	400 µg/kg	No detectable concentration in tissue from soil concentrations
		DDD	700 µg/kg	
		DDE	200 µg/kg	
Menzie et al. (1992)	<i>Eisenia foetida</i>	DDT	1,000 [4,000] ^c µg/kg	Survival; no effect for LC ₅₀ test
		DDD	1,000 [12,000] ^c µg/kg	
		DDE	1,000 [2,000] ^c µg/kg	
Miller et al. (1985)	Earthworm	Copper	644 mg/kg	EC ₅₀
		Zinc	628 mg/kg	EC ₅₀
	Microtox (15 min.)	Copper	0.28 - 0.42 mg/kg	Photo reduction
		Zinc	1.6 mg/kg	Photo reduction
Paine et al. (1993)	Crickets <i>Acheta domesticus</i>	PCBs	1,200 mg/kg	LC ₅₀
Reinecke & Nash (1984)	Earthworm <i>Allolobophora caliginosa</i> <i>Lumbricus rubellus</i>	Dioxin	< 5 mg/kg	No mortality
			> 10 mg/kg	Lethality
Ma (1984)	<i>Lumbricus rubellus</i>	Copper	100 - 150 mg/kg	Cocoon production decrease
		Copper	300 mg/kg	Mortality
Beyer et al. (1985)	<i>Eisenia foetida</i>	Methyl Mercury	25 mg/kg	100% mortality
			5 mg/kg	21% mortality

Table 8.6
Chemical Effects Studies on Terrestrial Infaunal Invertebrates

Study	Organisms	Measured Parameter	Effects Level	Measured Response
Abbasi and Soni (1983)	Earthworm <i>Octochaetus pattoni</i>	Inorganic Mercury	0.79 mg/kg 5 mg/kg	50% mortality 100% mortality
Rhett et al. (1988)	<i>Eisenia foetida</i>	PCBs	240 mg/kg	LC ₅₀
Nielson (1951)	earthworms	Copper	150 mg/kg 260 mg/kg	Population reduced by 0.5 Population eliminated
Van Rhee (1967)	earthworms	Copper	85 mg/kg	Gradual decline of population
Ma (1982)	<i>Lumbricus rubellus</i>	Copper chloride	1,000 mg/kg	6-wk LC ₅₀

Notes:

- a = Growth effects levels are an average of at least five of six compounds: metal acetate; metal carbonate; metal chloride; metal nitrate; metal oxide, metal sulfate
- b = Aboveground species include Carabidae, Entobeyidae, Formicidae, Gryllidae and Staphylinidae.
- c = Average soil concentration levels [maximum values].

test species. The sublethal TRV reflects the assessment endpoint chosen as the basis for establishing risk.

Vegetation

Toxicity to terrestrial plants from soil contaminants detected within the subzones is qualitatively evaluated. Risk potentials are discussed relative to literature studies and general information on phytotoxic mechanisms by selected ECPCs.

Aquatic Wildlife

Potential adverse ecological effects to aquatic species from identified ECPCs are predicted based on the most conservative benchmark available (i.e., chronic water quality criteria, sediment screening values, or effects information from literature). Effects are predicted using a preliminary screening approach. Maximum water and sediment concentrations for ECPCs are divided by the available benchmark to produce an HQ. Calculated HQs for ECPCs from each media will be summed to determine an HI. HQs with a result higher than one are considered to demonstrate a potential risk. Values higher than 10 are considered to be of moderately high potential risk and above 100, extreme risk.

8.8 Risk Characterization

8.8.1 Infaunal Invertebrates

Most toxicological information reviewed for the infaunal invertebrates assessment (Section 8.7) dealt with earthworms and other infaunal species. It is important to note that soil in Zone C is predominantly sand and may not support these specific organisms. Although infaunal species in the sandy environment may not be the same as those dealt with in the literature, the ecological niche they occupy should be similar and, therefore, comparison to toxicological concentrations should apply.

Although some of the semivolatiles in soil are considered carcinogenic to mammals, very few field studies exist on their toxicity to terrestrial infauna. Generally, PAHs break down in natural systems via photodegradation and microbial transformation. Neuhauser et al. (1986) found that specific phenol compounds (4-nitrophenol, 2,4,6-trichlorophenol, phenol) were somewhat toxic to earthworms, with PAHs being relatively less toxic than other semivolatile compounds studied. Artificial soil tests produced lethal concentration (LC_{50}) values for fluorene and phenol near 200 mg/kg and 400 mg/kg, respectively (refer to Table 8.6). Callahan et al. (1994) found similar results in their study on toxicity of 62 chemicals to several earthworm species. Fluorene is considered to be acutely toxic at certain concentrations but it is not considered a carcinogen. It is important to note that field variability and soil chemical matrices can greatly influence toxicological effects of PAH compounds.

Most toxicological studies on terrestrial infaunal organisms have been directed at measuring pesticide effects. Earthworm toxicology and response information is the most prevalent. In a study by Beyer and Gish (1980), persistence of DDT, dieldrin, and heptachlor was observed in earthworms from field study plots. Investigators agree that earthworms can accumulate pesticides to concentrations found in residence soil. Callahan et al. (1991) showed very good soil-to-tissue correlation ($R = 0.725$), with accumulation of DDT in single earthworms up to 22 mg/kg. Beyer and Gish (1980) found that earthworms accumulated DDT to 32 mg/kg. Barker (1958) associated poisoning (lethality) of robins with 60 mg/kg DDT in earthworms, and Collett and Harrison (1968) found that blackbirds and thrushes were impacted at residues near 20 mg/kg. At concentrations observed in their study, Callahan et al. (1991) suggested that a feeding rate by robins of 10 to 12 earthworms in as many minutes (as observed by McDonald, 1983) could provide a sufficient concentration of contamination for impacts to robins. Callahan et al. (1991) also found that Chlordane, as other pesticides, was taken up rapidly by earthworms. In Callahan et al. (1991) total DDT concentrations greater than 1,000 mg/kg in soil, along with documented long half-life information (5.7 years DDT), indicated a long-term significant risk to receptors.

Risk factors associated with PCBs are similar to those for pesticides. After acute mortality, food chain biomagnification and transfer are the most important issues considered when assessing long-term risk. Paine et al. (1993) suggested a benchmark value between 100 to 300 mg/kg PCB for mortality in terrestrial insects. Also, Rhett et al. (1988) observed LC₅₀ values for earthworms treated with PCBs at 240 mg/kg. McKee (1992) reported that soil invertebrate community structure was not reduced by exposure to PCB-contaminated soil (maximum concentrations to 120,000 mg/kg wet weight) based on family level classification of invertebrates.

Reinecke and Nash (1984) studied the toxic effects of dioxin (2,3,7,8-TCDD) in soil to earthworms. For two species, *Allolobophora caliginosa* and *Lumbricus rubellus*, concentrations of 5 mg/kg or less had no acute effect, but concentrations of 10 mg/kg and above were lethal.

Most studies on metals toxicity to terrestrial receptors have been directed at infaunal ecosystems or avian biology. Information on relative metal toxicities to earthworms was provided by Roberts and Dorough (1984) where, along with 90 other chemicals, three metal salts (cadmium chloride, copper sulfate, and lead nitrate) were tested. The results showed that these heavy metal salts fell into the "very toxic" category, with LC₅₀ values in the 10 to 100 micrograms per square centimeter ($\mu\text{g}/\text{cm}^2$) range. Although these concentrations (more specifically, application doses) may be relative to earthworms, it is improper to apply them to upper-level trophic species. Studies indicate that some degradation products become increasingly more toxic to earthworms and less toxic to upper-level vertebrates. Other studies on toxicities of metal salts to earthworms have been conducted by Neuhauser et al. (1986) and Malecki et al. (1982). In the former study, metal nitrate compounds were relatively toxic to earthworms in this order: copper > zinc > nickel = cadmium > lead. Mean LC₅₀ values for these metals were 643, 662, 757, 1,843 and 6,000 mg/kg, respectively. In the latter study, six chemical forms of each metal were chosen to cover a broad range of solubility and to represent the forms likely to be found in the soil. Overall, cadmium was most toxic, followed by nickel, copper, zinc, and lead. It appears obvious from the

results of these two studies that the form of the metal in soil is a major consideration in judging effects of their concentrations on soil biota.

Ma (1984) investigated sublethal effects of copper in soil to growth, cocoon production, and litter breakdown activity for *Lumbricus rubellus*. Cocoon and litter breakdown activity were significantly reduced at 131 mg/kg copper and mortality was first observed at concentrations near 300 mg/kg.

Parmelee et al. (1993) found that total nematode/microarthropod (mostly mites) numbers declined in soil having copper concentrations above 200 mg/kg; omnivore-predator nematodes and specific microarthropod groups were significantly reduced at 100 mg/kg copper.

Subzone-Specific Risk Characterization

The risk characterization for terrestrial infaunal invertebrates was determined through the comparison of the detected concentrations (maximum and mean) to the effects levels presented in Table 8.6.

Subzone C-1

Within Subzone C-1 a moderate potential for risk to infaunal communities from the maximum copper concentration observed (122 mg/kg) is predicted. This concentration is similar to the 100 to 150 mg/kg effect-level determined by Ma (1984), which decreased earthworm cocoon production, and just below the concentration of 150 mg/kg, which reduced earthworm populations (Nielson, 1951). The mean copper concentration across the subzone, however, was only 56.8 mg/kg, well below the reported effect levels. Other maximum inorganic concentrations were also below effects levels reported in the literature. No organic data were available for soil within C-1.

Subzone C-2

Based on a comparison of surface soil concentrations presented in Tables 8.4a and 8.4b to the effect levels presented in Table 8.7, no risks to infaunal organisms from inorganic or organic concentrations at Subzone C-2 are predicted.

8.8.2 Terrestrial Wildlife

Risks for the representative wildlife species associated with ingestion of surface soil and food are quantitatively evaluated using HQs, which are calculated for each ECPC by dividing the PDE concentration by the TRV. HIs are determined for each representative wildlife species by summing the HQs for all ECPCs. When the estimated PDE is less than the TRV ($HQ < 1$), the contaminant exposure is assumed to fall below the range considered to be associated with adverse effects for growth, reproduction, and survival and no risks to the wildlife populations are assumed. When the HQ or HI is greater than one, the ecological significance is discussed and risk is assumed. When HIs are greater than one, the HQs constituting the HI were evaluated.

For representative terrestrial wildlife species, PDEs were calculated using available bioaccumulation data (Table 8.7) for ECPCs presented in Tables 8.3 and 8.4. Exposure parameters and assumptions for representative species at Subzones C-1 and C-2 (Tables 8.8 and 8.9, respectively) were used to calculate food contaminant concentrations. Using the model for prediction of contaminant exposure presented in Table 8.5, PDE values were obtained. HQs for both lethal and sublethal effects for ECPCs at Subzones C-1 and C-2 were determined and are presented in Tables 8.10 and 8.11, respectively, with HI values for each representative species determined. If the HI from maximum concentrations was greater than one, then the mean concentration of the parameters which comprise the HI are presented to characterize subzone-wide risk from that parameter.

Table 8.7
Bioaccumulation Data¹
Baseline Risk Assessment

Bioaccumulation or Biotransfer Factor (unitless)

Analyte	Log K_{ow}	Plant	Terrestrial Invertebrate	Mammal	Bird
Semivolatiles					
Anthracene	4.4 [c]	NA	0.005 [d]	6.30E-04 [a]	1 [ab]
Benzo(a)anthracene	5.74 [c]	0.019 [e]	0.0125 [d]	1.38E-02 [a]	1 [ab]
Benzo(a)pyrene	6.07 [c]	0.012 [e]	0.0342 [d]	2.95E-02 [a]	1 [ab]
Benzo(b)fluoranthene	6.32 [c]	0.008 [e]	0.032 [d]	5.25E-02 [a]	1 [ab]
Benzo(g,h,i)perylene	7 [c]	0.003 [e]	0.024 [d]	2.50E-01 [a]	1 [ab]
Benzo(k)fluoranthene	6.45 [c]	0.007 [e]	0.025 [d]	7.08E-02 [a]	1 [ab]
Bis(2-ethylhexyl)phthalate (BEHP)	5.3 [f]	0.033 [e]	0.022 [aj]	5.00E-03 [a]	1 [ab]
Butylbenzylphthalate	4.78 [g]	0.049 [e]	0.022 [aj]	1.50E-03 [a]	1 [ab]
Chrysene	5.71 [c]	0.019 [e]	0.031 [d]	1.29E-02 [a]	1 [ab]
Dibenzo(a,h)anthracene	6.42 [c]	0.008 [e]	0.022 [aj]	6.61E-02 [a]	1 [ab]
Di-n-butylphthalate	4.8 [h]	NA	0.022 [aj]	1.60E-03 [a]	1 [ab]
Fluoranthene	5.25 [c]	0.036 [e]	0.007 [d]	4.50E-03 [a]	1 [ab]
Indeno(1,2,3-cd)pyrene	7.7 [c]	0.0014 [e]	0.042 [d]	1.26E+00 [a]	1 [ab]
Phenanthrene	4.43 [c]	NA	0.012 [d]	6.70E-04 [a]	1 [ab]
Pyrene	5.09 [c]	0.044 [e]	0.018 [d]	3.10E-03 [a]	1 [ab]

Table 8.7
Bioaccumulation Data¹
Baseline Risk Assessment

Analyte	Log K _{ow}	Plant	Bioaccumulation or Biotransfer Factor (unitless)		
			Terrestrial Invertebrate	Mammal	Bird
Pesticides/PCBs/Dioxins					
Aroclor-1248	6 [c]	0.013 [e]	1.2 [i]	1.00E+00 [ak]	1 [ab]
Aroclor-1254	6.02 [c]	0.013 [e]	1.2 [i]	1.00E+00 [ak]	1 [ab]
Aroclor-1260	6 [c]	0.013 [e]	1.2 [i]	1.00E+00 [ak]	1 [ab]
alpha-Chlordane	2.78 [f]	0.027 [ac]	0.8 [j]	7.10E-01 [ak]	0.71 [ai]
gamma-Chlordane	3.32 [f]	0.027 [ac]	0.8 [j]	7.10E-01 [ak]	0.71 [ai]
4,4'-DDE	5.69 [f]	0.02 [e]	0.98 [v]	2.91E+00 [ak]	2.91 [i]
4,4'-DDT	4.48 [f]	0.027 [ac]	0.98 [v]	2.91E+00 [ak]	2.91 [i]
Dieldrin	4.95 [f]	0.049 [e]	1.2 [m]	7.10E-01 [ak]	0.71 [n]
2,3,7,8 TCDD	6.80 [am]	0.005 [e]	5.0 [b]	8.40E-01 [an]	1 [ab]
Inorganics					
Arsenic	NA	0.3 [p]	0.77 [ae]	3.60E-01 [ag]	0.45 [ah]
Barium	NA	0.56 [ag]	0.77 [ae]	3.40E-01 [af]	0.45 [ah]
Cadmium	NA	33 [q]	1.4 [k]	2.06E+00 [r]	0.38 [s]
Copper	NA	0.78 [t]	0.16 [j]	6.00E-01 [q]	0.45 [ah]
Lead	NA	0 [q]	0.22 [u]	5.40E-01 [w]	0.45 [ah]
Manganese	NA	0.56 [ag]	0.77 [ae]	3.40E-01 [ag]	0.45 [ah]
Mercury	NA	0.56 [ag]	0.34 [x]	1.00E-02 [aa]	2.33 [aa]

Table 8.7
Bioaccumulation Data¹
Baseline Risk Assessment

Analyte	Log K _{ow}	Bioaccumulation or Biotransfer Factor (unitless)			
		Plant	Terrestrial Invertebrate	Mammal	Bird
Inorganics (continued)					
Selenium	NA	0.009 [y]	0.77 [ac]	3.40E-01 [af]	0.51 [z]
Zinc	NA	0.61 [t]	1.77 [i]	2.06E+00 [w]	0.45 [ah]

Notes:

- [a] = Calculated using the following equation (Travis and Arms, 1988), unless otherwise noted: $\log \text{BAF} - \log K_{ow} - 7.6$; result multiplied by average of ingestion rates for non-lactating and lactating test animals. There is an uncertainty involved in using this equation for PAHs, because this study did not use any PAHs in the regression analysis.
- [b] = Reinecke and Nash (1984).
- [c] = Geometric mean of values from USEPA (1986).
- [d] = Marquerie et al. (1987) as cited in Beyer (1990). Mean of values. Converted to wet weight assuming 90% body weight as water.
- [e] = Calculated using the following equation in Travis and Arms (1988) for analytes with $\log K_{ow} > 5$: $\log (\text{Plant Uptake Factor}) = 1.588 - 0.578 \log K_{ow}$.
- [f] = From USEPA (1986).
- [g] = Value from Verschuere (1983).
- [h] = Value from Howard (1990).
- [i] = BCF for earthworms from Diercxsens, et al. (1985).
- [j] = Value from Gish (1970).
- [k] = Mean of values reported for soil invertebrates in Macfadyen (1980) converted from dry weight to wet weight.
- [l] = Whole body pheasant BAF for 4,4'-DDT presented in USEPA (1985), derived from Kenaga (1973).
- [m] = Average of values reported for soil invertebrates in Edwards and Thompson (1973).
- [n] = Jeffries and Davis (1968).
- [o] = Value reported for endrin from Gish (1970).
- [p] = Average of BAF values reported from Wang et al. (1984), Sheppard et al. (1985) and Merry et al. (1986).
- [q] = Levine et al. (1989).
- [r] = Mean of values reported for *Sorex araneus* in Macfadyen (1980).
- [s] = Based on accumulation of cadmium in kidneys of European quail in Pimentel et al. (1984).

Notes: (continued):

- [t] = Median of values reported from Levine et al. (1989).
- [u] = Geometric mean of BAF values (fresh st. worm/dry st. soil) for worms and woodlice (USEPA, 1985). Fresh weight tissue concentrations calculated assuming 90% body water content.
- [v] = Beyer and Gish (1980) reported dry weight to wet weight ratio.
- [w] = Mean of values for *Microtus agrestis* and *Apodemus sylvaticus* in Macfadyen (1980).
- [x] = Value from USEPA (1985) sludge document.
- [y] = Based on reported ratio of selenium in plant tissue and iron fly ash amended soil (Stoewsand et al., 1978).
- [z] = Based on average of reported ratio of selenium in diet to liver, kidney, and breast tissue of chickens (Ort and Latshaw, 1977).
- [aa] = USEPA, 1985.
- [ab] = Assumption.
- [ac] = Assumed value based on average of BAFs calculated for other pesticides and PCBs.
- [ad] = Assumed value base on average of BAFs for Aroclor 1260, alpha-chlordane, 4,4'-DDE, Dieldrin and endrin ketone.
- [ae] = Assumed value based on average of BAFs reported for other metals.
- [af] = Assumed value based on average of reported BAFs for Cd, Cu, Pb and Hg.
- [ag] = Assumed value based on average of reported BAFs for As, Cu, Hg and Zn.
- [ah] = Assumed value based on average of reported BAF values for Cd and Se.
- [ai] = Assumed value based on reported BAF for dieldrin.
- [aj] = Assumed value based on average of BAFs for semivolatiles.
- [ak] = Value for mammal unavailable. Bioaccumulation assumed to be the same as values reported for birds.
- [am] = Polder et al. (1995).
- [an] = Rose et al. (1976).
- [ao] = Travis and Arms (1988).
- [ap] = van Gestel and Ma (1988).
- NA = Not available.
- ' = Table adapted from BRA, NAS Cecil Field, Jacksonville, Florida.

Table 8.8
Exposure Parameters and Assumptions for Representative Wildlife Species at Subzone C-1

Representative Wildlife Species	Trophic Status	Prey in Diet (%)					Incidental Soil Ingestion (%)	Home Range (acres)	ED	Site Foraging Factor (SFF)	Ingestion Rate (kg/day)	Body Weight (kg)
		Inverts	Plants	Small Mammals	Herpeto-fauna	Small Birds						
American Robin ^a	Small Carnivorous Bird	83	7	0	0	0	10	1.04	1	9.13e-01	0.10	0.077
Eastern Cottontail ^b	Small Herbivorous Mammal	0	97	0	0	0	3	9.3	1	1.02e-01	0.08	1.2
Short-tailed Shrew ^c	Small Carnivorous Mammal	78	12	0	0	0	10	0.96	1	1.00e+00	0.0025	0.018

SITE AREA: 0.95 acres

Notes:

- a =
 - Diet assumptions based on data from Hamilton, 1943 and Wheelwright, 1986.
 - Food ingestion rate (FI) from formula: $FI(kg/day) = 0.0582 W^{0.651} (kg)$ (Nagy, 1987).
 - Body weight from Clench & Leberman, 1978.
 - Home range reflects interpolated values from Howell, 1992; and Weatherhood & McRae, 1990.

- b =
 - Diet assumptions based on data from Dusi, 1952; and Spencer & Chapman, 1986.
 - Food ingestion rate (FI) from formula: $FI(kg/day) = 0.0687 \times W^{0.822} (kg)$ (Nagy, 1987).
 - Body weight reflects interpolated values from Chapman & Morgan 1973; Pelton & Jenkins, 1970.
 - Home range reflects interpolated values from Althoff & Storm, 1989; and Dixon et al., 1981.

- c =
 - Diet assumption based on data from Whitaker & Ferraro, 1963.
 - Food ingestion rate (FI) from formula: $FI (kg/day) = 0.0687 \times w^{0.822} (kg)$ (Nagy, 1987).
 - Body weight from Lomolino, 1984.
 - Home range value from Buckner, 1966.

- ED = Exposure Duration (percentage of year receptor is expected to be found at study area expressed as a factor, i.e., 100% = 1.0)
- SFF = Site area (acres) times exposure duration (ED) divided by Home Range (HR); cannot exceed 1.0.

Table 8.9
Exposure Parameters and Assumptions for Representative Wildlife Species at Subzone C-2

Representative Wildlife Species	Trophic Status	Prey in Diet (%)					Incidental Soil Ingestion (%)	Home Range (acres)	ED	Site Foraging Factor (SFF)	Ingestion Rate (kg/day)	Body Weight (kg)
		Inverts	Plants	Small Mammals	Herpeto-fauna	Small Birds						
American Robin ^a	Small Carnivorous Bird	83	7	0	0	0	10	1.04	1	1.00e+00	0.10	0.077
Eastern Cottontail ^b	Small Herbivorous Mammal	0	97	0	0	0	3	9.3	1	2.31e-01	0.08	1.2
Short-tailed Shrew ^c	Small Carnivorous Mammal	78	12	0	0	0	10	0.96	1	1.00e+00	0.0025	0.018

SITE AREA: 2.15 acres

Notes:

- a = Diet assumptions based on data from Hamilton, 1943 and Wheelwright, 1986.
 Food ingestion rate (FI) from formula: $FI(kg/day) = 0.0582 W^{0.651}$ (kg) (Nagy, 1987).
 Body weight from Clench & Leberman, 1978.
 Home range reflects interpolated values from Howell, 1992; and Weatherhood & McRae, 1990.

- b = Diet assumptions based on data from Dusi, 1952; and Spencer & Chapman, 1986.
 Food ingestion rate (FI) from formula: $FI(kg/day) = 0.0687 \times W^{0.822}$ (kg) (Nagy, 1987).
 Body weight reflects interpolated values from Chapman & Morgan 1973; Pelton & Jenkins, 1970.
 Home range reflects interpolated values from Althoff & Storm, 1989; and Dixon et al., 1981.

- c = Diet assumption based on data from Whitaker & Ferraro, 1963.
 Food ingestion rate (FI) from formula: $FI(kg/day) = 0.0687 \times w^{0.822}$ (kg) (Nagy, 1987).
 Body weight from Lomolino, 1984.
 Home range value from Buckner, 1966.

- ED = Exposure Duration (percentage of year receptor is expected to be found at study area expressed as a factor, i.e., 100% = 1.0)
- SFF = Site area (acres) times exposure duration (ED) divided by Home Range (HR); cannot exceed 1.0.

Table 8.10a
 Hazard Quotients for Potential Lethal Effects for Wildlife Species Associated with
 Maximum Exposure Concentrations of ECPCs in Surface Soil at Subzone C-1

Analyte	Maximum Concentration (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Aluminum	36,600	NC	NA	NC	NC	NA	NC	NC	NA	NC
Arsenic	103	9.28e+00	NA	NC	2.25e-01	1.53e+02	1.47e-03	1.57e+01	2.90e+01	5.41e-01
Beryllium	2.0	NC	NA	NC	NC	NA	NC	4.54e-02	NA	NC
Cadmium	3.6	1.52e+00	NA	NC	7.84e-01	3.00e+01	2.61e-02	1.46e+01	1.78e+02	8.20e-02
Chromium	54.3	NC	NA	NC	NC	NA	NC	NC	NA	NC
Cobalt	13.6	NC	NA	NC	NC	NA	NC	NC	NA	NC
Copper	122	4.16e+00	NA	NC	6.53e-01	2.40e+02	2.72e-03	1.78e+01	NA	NC
Iron	99,500	NC	NA	NC	NC	NA	NC	NC	NA	NC
Mercury	0.53	2.65e-02	2.50e+00	1.06e-02	2.07e-03	3.60e+00	5.75e-04	5.21e-02	4.40e+00	1.18e-02
Nickel	43.4	NC	NA	NC	NC	NA	NC	NC	NA	NC
Selenium	8.8	7.72e-01	NA	NC	2.32e-03	1.30e+03	1.78e-06	1.10e+00	1.30e+02	8.46e-03
Thallium	2.4	NC	NA	NC	NC	NA	NC	NC	NA	NC
Vanadium	68.2	NC	1.90e+01	NC	NC	NA	NC	NC	NA	NA
Lethal HI =				1.06e-02			3.09e-02			6.44e-01

Notes:

- NA = Data are not available.
- NC = Not able to calculate value.
- PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.5.
- TRV = Toxicity Reference Value (mg/kg/BW/day) - 1/5 of the lowest reported LD₅₀ value from Appendix G for closest related species.
- HQ = Hazard Quotient - PDE divided by the TRV.
- HI = Hazard Index (HQ₁ + HQ₂ + ...HQ_n).

Table 8.10b
Hazard Quotients for Potential Lethal Effects for Wildlife Species Associated with
Mean Exposure Concentrations of ECPCs in Surface Soil at Subzone C-1

Analyte	Mean Concentration (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Aluminum	18,967.67	NC	NA	NC	NC	NA	NC	NC	NA	NC
Arsenic	44.13	3.98e+00	NA	NC	9.63e-02	1.53e+02	6.29e-04	6.72e+00	2.90e+01	2.32e-01
Beryllium	1.35	NC	NA	NC	NC	NA	NC	NC	2.00e+00	NC
Cadmium	2.06	8.72e-01	NA	NC	4.49e-01	3.00e+01	1.50e-02	6.36e+00	4.48e+02	1.42e-02
Chromium	36.17	NC	NA	NC	NC	NA	NC	NC	NA	NC
Cobalt	9.27	NC	NA	NC	NC	NA	NC	NC	NA	NC
Copper	56.8	1.94e+00	NA	NC	3.04e-01	2.40e+01	1.27e-03	8.31e+00	NA	NC
Iron	44,973.33	NC	NA	NC	NC	NA	NC	NC	NA	NC
Mercury	0.34	1.70e-02	2.50e+00	6.80e-03	1.33e-03	3.60e+00	3.69e-04	3.34e-02	4.40e+00	7.59e-03
Nickel	31.43	NC	NA	NC	NC	NA	NC	NC	NA	NC
Selenium	4.76	4.18e-01	NA	NC	1.25e-03	1.30e+02	9.62e-06	6.02e-01	1.30e+02	4.63e-03
Thallium	2.4	NC	NA	NC	NC	NA	NC	NC	NA	NC
Vanadium	39.10	NC	1.90e+01	NC	NC	NA	NC	NC	NA	NC
Lethal HI =		6.80e-03			1.72e-02			2.58e-01		

Notes:

- NA = Data are not available.
- NC = Not able to calculate value.
- PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.5.
- TRV = Toxicity Reference Value (mg/kg/BW/day) - 1/5 of the lowest reported LD₅₀ value from Appendix G for closest related species.
- HQ = Hazard Quotient - PDE divided by the TRV.
- HI = Hazard Index (HQ₁ + HQ₂ + ...HQ_n).

Table 8.10c
Hazard Quotients for Potential Sublethal Effects for Wildlife Species Associated with
Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-1

Analyte	Maximum Concentration (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Aluminum	36,600	NC	NA	NC	NC	NA	NC	NC	NA	NC
Arsenic	103	9.28e+00	NA	NC	2.25e-01	5.80e-01	3.88e-01	1.57e+01	5.80e-01	2.71e+01
Beryllium	2.0	NC	NA	NC	NC	NA	NC	NC	NA	NC
Cadmium	3.6	1.52e+00	1.00e+01	1.52e-01	7.84e-01	2.20e+01	3.56e-02	1.11e+01	4.48e+02	2.48e-02
Chromium	54.3	NC	NA	NC	NC	NA	NC	NC	NA	NC
Cobalt	13.6	NC	NA	NC	NC	NA	NC	NC	NA	NC
Copper	122	4.16e+00	1.10e+01	3.78e-01	6.53e-01	1.50e+02	4.35e-03	1.78e+01	1.50e+02	1.19e-01
Iron	99,500	NC	NA	NC	NC	NA	NC	NC	NA	NC
Mercury	0.33	2.65e-02	6.40e-02	4.14e-01	2.07e-03	5.00e-01	4.13e-01	5.21e-02	5.00e-01	1.04e-01
Nickel	43.4	NC	NA	NC	NC	NA	NC	NC	NA	NC
Selenium	8.8	7.72e-01	1.80e+00	4.29e-01	2.32e-03	1.30e+02	1.78e-05	1.10e+00	1.30e+02	8.46e-03
Thallium	2.4	NC	NA	NC	NC	NA	NC	NC	NA	NC
Vanadium	68.2	NC	1.90e+01	NC	NC	NA	NC	NC	NA	NC
Sublethal HI =		1.37e+00			8.41e-01			2.73e+01		

Notes:

- NA = Data are not available.
- NC = Not able to calculate value.
- PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.5.
- TRV = Toxicity Reference Value (mg/kg/BW/day) - the lowest LOAEL from Appendix G.
- HQ = Hazard Quotient - PDE divided by the TRV.
- HI = Hazard Index (HQ₁ + HQ₂ + ...HQ_n).

Table 8.11a
Hazard Quotients for Potential Lethal Effects for Wildlife Species Associated with
Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-2

Analyte	Max Conc (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Benzo(a)anthracene	0.140	2.03e-03	NA	NC	1.04e-04	NA	NC	2.52e-03	NA	NC
Benzo(b)fluoranthene	0.270	4.46e-03	NA	NC	1.57e-04	NA	NC	6.05e-03	NA	NC
Benzo(k)fluoranthene	0.300	4.27e-03	NA	NC	1.70e-04	NA	NC	6.92e-03	NA	NC
Benzo(a)pyrene	0.120	2.01e-03	NA	NC	7.70e-05	1.00e+01	7.70e-06	2.53e-03	1.00e+01	2.53e-04
Chrysene	0.170	2.81e-03	NA	NC	1.27e-04	NA	NC	3.38e-03	NA	NC
Fluoranthene	0.240	3.38e-03	NA	NC	2.40e-04	NA	NC	4.33e-03	NA	NC
Phenanthrene	0.120	NC	NA	NC	NA	NA	NC	NA	NA	NC
Pyrene	0.210	3.22e-03	NA	NC	2.35e-04	5.40e+02	4.85e-07	4.15e-03	1.60e+02	2.59e-05
Aldrin	0.0011	NC	NA	NC	NC	NA	NC	NC	NA	NC
beta-BHC	0.0084	NC	NA	NC	NC	NA	NC	NC	NA	NC
Chlordane	0.0042	4.18e-05	4.80e+00	8.70e-05	3.63e-06	2.00e+01	1.82e-07	6.80e-04	5.70e+01	1.20e-05
4,4'-DDD	0.037	NC	NA	NC	NC	NA	NC	NC	NA	NC
4,4'-DDE	0.190	2.26e-02	NA	NC	1.64e-04	1.60e+02	3.90e-04	6.93e-02	1.04e+02	4.95e-04
4,4'-DDT	0.067	7.96e-03	8.00e+02	9.95e-06	5.80e-05	5.00e+01	1.10e-05	2.44e-02	2.70e+01	9.05e-04
Aroclor 1254	0.060	8.55e-03	3.00e+02	2.85e-05	3.94e-05	2.00e+00	1.97e-05	1.47e-02	2.00e+01	6.85e-04
Dieldrin	0.002	2.86e-04	9.60e+00	2.98e-05	2.39e-06	9.00e+00	1.10e-06	4.14e-04	7.60e+00	5.45e-05
Disulfoton	0.0052	NC	NA	NC	NC	NA	NC	NC	NA	NC
Endosulfan	0.0024	2.00e-04	6.20e+00	3.20e-05	4.87e-06	4.80e+00	1.00e-06	1.57e-04	4.80e+00	3.30e-05
Endrin aldehyde	0.0013	NC	NA	NC	NC	NA	NC	NC	NA	NC
Methoxychlor	0.0043	NC	NA	NC	NC	NA	NC	NC	NA	NC

Table 8.11a
Hazard Quotients for Potential Lethal Effects for Wildlife Species Associated with
Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-2

Analyte	Max Conc (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Methyl parathion	0.0047	NC	NA	NC	NC	NA	NC	NC	NA	NC
Sulfotepp	0.0045	NC	NA	NC	NC	NA	NC	NC	NA	NC
Vinyl acetate		NC	NA	NC	NC	NA	NC	NC	NA	NC
2,4,5-T	0.0085	NC	NA	NC	NC	NA	NC	NC	NA	NC
Beryllium	0.44	NC	NA	NC	NC	NA	NC	NC	NA	NC
Iron	11,800	NC	NA	NC	NC	NA	NC	NC	NA	NC
Manganese	280	2.83e+01	NA	NC	2.47e+00	8.00e+01	3.09e-02	4.82e+01	4.50e+01	1.07e+00
Lethal HI =				1.87e-04			3.13e-02			1.07e+00

- Notes:**
- Max Conc = Maximum Concentration of Analyte.
 - NA = Data are not available.
 - NC = Not able to calculate value.
 - PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.5.
 - TRV = Reference Toxicity Value (mg/kg/BW/day) - 1/5 of the lowest reported LD₅₀ value from Appendix G for closest related species.
 - HQ = Hazard Quotient - PDE divided by the TRV.
 - HI = Hazard Index (HQ₁ + HQ₂ + ...HQ_n).

Zone C RCRA Facility Investigation Report
 NAVBASE Charleston
 Section 8 – Ecological Risk Assessment
 Revision: 0

Table 8.11b
Hazard Quotients for Potential Sub-Lethal Effects for Wildlife Species Associated with
Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-2

Analyte	Max Conc (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Benzo(a)anthracene	0.140	2.03e-03	NA	NC	1.04e-04	NA	NC	2.32e-03	NA	NC
Benzo(b)fluoranthene	0.270	4.46e-03	NA	NC	1.57e-04	NA	NC	6.05e-03	NA	NC
Benzo(k)fluoranthene	0.300	4.27e-03	NA	NC	1.70e-04	NA	NC	6.92e-03	NA	NC
Benzo(a)pyrene	0.120	2.01e-03	NA	NC	7.70e-05	4.00e+01	1.93e-06	2.53e-03	4.00e+01	6.33e-05
Chrysene	0.170	2.81e-03	NA	NC	1.27e-04	NA	NC	3.38e-03	NA	NC
Fluoranthene	0.240	3.38e-03	NA	NC	2.40e-04	NA	NC	4.33e-03	NA	NC
Phenanthrene	0.120	NC	NA	NC	NA	NA	NC	NA	NA	NC
Pyrene	0.210	3.22e-03	NA	NC	2.35e-04	NA	NC	4.15e-03	NA	NC
Aldrin	0.0011	NC	NA	NC	NC	NA	NC	NC	NA	NC
beta-BHC	0.0084	NC	NA	NC	NC	NA	NC	NC	NA	NC
Chlordane	0.0042	4.18e-05	NA	NC	3.63e-06	NA	NC	6.80e-04	NA	NC
4,4'-DDD	0.037	NC	NA	NC	NC	NA	NC	NC	NA	NC
4,4'-DDE	0.190	2.26e-02	5.80e-01	3.90e-02	1.64e-04	NA	NC	6.93e-02	NA	NC
4,4'-DDT	0.067	7.96e-03	1.40e-01	5.69e-02	5.80e-05	1.50e+02	3.87e-07	2.44e-02	8.10e+01	3.01e-04
Aroclor 1254	0.060	8.55e-03	9.00e-01	9.50e-03	3.94e-05	9.60e-02	4.10e-04	1.47e-02	1.53e+00	9.61e-03
Dieldrin	0.002	2.86e-04	NA	NC	2.39e-06	NA	NC	4.14e-04	3.30e-01	1.25e-03
Disulfoton	0.0052	NC	NA	NC	NC	NA	NC	NC	NA	NC
Endosulfan	0.0024	2.00e-04	NA	NC	4.87e-06	NA	NC	1.57e-04	NA	NC
Endrin aldehyde	0.0013	NC	NA	NC	NC	NA	NC	NC	NA	NC
Methoxychlor	0.0043	NC	NA	NC	NC	NA	NC	NC	NA	NC

Table 8.11b
 Hazard Quotients for Potential Sub-Lethal Effects for Wildlife Species Associated with
 Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-2

Analyte	Max Conc (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Methyl parathion	0.0047	NC	NA	NC	NC	NA	NC	NC	NA	NC
Sulfotepp	0.0045	NC	NA	NC	NC	NA	NC	NC	NA	NC
Vinyl acetate		NC	NA	NC	NC	NA	NC	NC	NA	NC
2,4,5-T	0.0085	NC	NA	NC	NC	NA	NC	NC	NA	NC
Beryllium	0.44	NC	NA	NC	NC	NA	NC	NC	NA	NC
Iron	11,800	NC	NA	NC	NC	NA	NC	NC	NA	NC
Manganese	280	2.83e+01	NA	NC	2.47e+00	NA	NC	4.82e+01	1.40e+02	3.45e-01
Sublethal HI=		1.05e-01			4.13e-04			3.56e-01		

- Notes:**
- Max Conc = Maximum Concentration of Analyte.
 - NA = Data are not available
 - NC = Not able to calculate value.
 - PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.5.
 - TRV = Toxicity Reference Value (mg/kg/BW/day) - lowest reported LOAEL from Appendix G.
 - HQ = Hazard Quotient - PDE divided by the TRV.
 - HI = Hazard Index (HQ₁ + HQ₂ + ...HQ_n).

Subzone-Specific Risk Characterization

Subzone C-1

All lethal HQ and HI values calculated for each of the representative wildlife species selected for maximum (point specific risk) soil concentrations in Subzone C-1 were less than one (Table 8.10a). No potential lethal effects exist as a result of exposure to ECPCs in surface soil.

Using the maximum concentrations for HQ calculations, potential sublethal effects to small vertebrates and avian species from soil contamination at Subzone C-1 are present based on the modeled HI value (shrew HI=27.3 and robin HI=1.37). For the shrew, the maximum arsenic concentration of 103 mg/kg (HQ = 27.1) for the short-tailed shrew was almost entirely responsible for the produced HI value. Using the mean arsenic concentration (44.13 mg/kg) at Subzone C-1, the shrew's sub-lethal HQ is reduced to 11.6, still indicating a moderate sub-lethal risk.

For the robin, no individual HQs exceeded one, however the HI slightly exceeds one due to the elevated HQs of selenium, mercury, copper, and cadmium. Using the mean concentration, however, the HI drops well below one.

The risk potential for the shrew produced by the model contradicts some of the literature on arsenic transfer to small mammals. Pascoe et al. (1994) found that the bioavailable fraction of arsenic in soils to small mammals was limited. But results of the model agree with other studies that show transfer of metal to small mammals via plant uptake from soils to be feasible (Leita et al., 1991). Measurement of tissue concentrations or in-situ bioaccumulation studies would be necessary to assess the actual potential for impacts to small mammals at Subzone C-1.

Subzone C-2

The lethal HQ and HI values calculated using the maximum soil concentration in Subzone C-2 indicate a slight potential for lethal effects to the short-tailed shrew (HI=1.07). Manganese (HQ=1.07 [rounded]) is almost entirely responsible for the HI. The HIs for each of the remaining representative wildlife species were less than one (Table 8.11a). Using the mean concentration for manganese, the shrew's HQ drops to 0.354, indicating that lethal effects from subzone-wide manganese concentrations in surface soil are unlikely .

No potential sub-lethal effects from exposure to ECPCs in soil at Subzone C-2 exists based on the model prediction. All sub-lethal HQ and HI values calculated for terrestrial species for potential effects from soil contamination in Subzone C-2 were less than one (Table 8.11b).

8.8.3 Vegetation

Limited information exists on toxic effects of soil contamination to plants in natural environments. Most literature containing effects information deals with herbicide or fungicide application programs. Beyer et al. (1985) demonstrated that only a small portion of all metals measured in soil became incorporated in plant foliage. In their study, the origin for plant metal residues was suggested to have come primarily from aerial deposition. Table 8.12 presents phytotoxic effects levels for arsenic, lead and zinc for several species. Effects levels vary depending on specific soil physico-chemical conditions such as pH, organic content, and cation-exchange-capacity.

Arsenic availability to plants is typically highest in coarse-textured soils having little cation exchange capacity and lowest in clay having organic material, and containing iron, calcium and phosphate (NRCC, 1978). Cadmium appears to be taken up by plants in soils that have abnormally high cadmium residues. For chromium, Towill et al.'s (1978) study showed no phytotoxic effects to plants for elevated chromium levels.

Table 8.12
Summary of Chemical Effects Studies on Vegetation

Study	Organisms	Measured Parameter	Effects Level (mg/kg)	Measured Response
USEPA (1987)	<i>Acer rubrum</i> , Red Maple	Zinc	100	Lethal to seedlings
USEPA (1987)	<i>Quercus rubra</i> , Oak	Zinc	100	Lethal to seedlings
NRCC (1978)	Canadian crops	Arsenic	25-85	Depressed crop yield
	<i>Oryza sativum</i> , Rice	Arsenic (disodium methylarsenate)	50	75% decrease yield
Sadiq (1985)	Corn plant	Lead	800	No elevated concentration in plants
Krishnayya and Bedi (1986)	<i>Cassia</i> spp., Weeds	Lead	500	90% reduced pollen germination
Miller et al. (1985)	Radish (seed germination)	Copper	47	EC 50
		Zinc	53	EC 50
	Cucumber (see germination)	Copper	55	EC 50
		Zinc	61	EC 50

Like other metals, the bioavailability of lead in soil to plants is enhanced by reduced soil pH, 1
reduced organic matter, and reduced iron oxides and phosphorous content (NRCC, 1973). Studies 2
have shown that there is no convincing evidence that terrestrial vegetation is important in food 3
chain biomagnification of lead (USEPA, 1980). Chang et al. (1983) observed that zinc uptake was 4
lower in coarse loamy soils than in fine loamy soils. The phytotoxic nature of copper to crop 5
production has been studied relative to application rates (Hirst, et al. 1961). Little information 6
exists on mercury effects to higher plants (Eisler, 1987b). 7

Studies by USEPA (1980), Lee and Grant (1981), Wang and Meresz (1982) and Edwards (1983) 8
generally conclude six points for PAH's effects to plants. First, plants can absorb PAHs from 9
soil through roots to other parts. Second, lower molecular weight compounds are absorbed more 10
readily than higher molecular weight compounds. Third, aboveground parts have higher residue 11
levels, which are most likely attributable to airborne deposition. Fourth, PAH-induced phytotoxic 12
effects are rare. Fifth, higher plants can catabolize benzo(a)pyrene and possibly other 13
PAH compounds, and finally, plant up-take of PAHs is most likely not a significant pathway to 14
terrestrial vertebrate species. 15

For PCBs, Klekowski (1982) suggested that there was no evidence of genetic damage to terrestrial 16
plants at a PCB-contaminated site in Massachusetts. 17

For dioxins, Isensee and Jones (1971) indicated that isomer were less readily taken up by 18
terrestrial plants was less readily compared to aquatic plants, and studies by Blair (1973) and 19
Ramel (1978) considered uptake of 2,3,7,8-TCDD from soils by vegetation to be negligible. 20

Eisler (1990) noted that there was little information available on phytotoxicity of chlordane and 21
that there was little evidence to indicate accumulation by crop plants. In soils, chlordane is mostly 22

immobile and there is only a limited capacity for translocation into edible portions of food crops 1
(NRCC, 1975). 2

Subzone-Specific Risk Characterization 3

Subzone C-1 4

Based on the maximum concentration of copper (122 mg/kg) and considering the physical nature 5
of soil within Subzone C-1, a potential risk to woody seedlings and young herbaceous species 6
exists. Also, the arsenic concentration (103 mg/kg) was above the effect level reported for 7
impacts to rice crops in Canada (NRCC, 1978). The potential impact of arsenic in a natural field 8
setting cannot be determined. Effects from organic concentrations could not be assessed. 9

Subzone C-2 10

A potential risk to woody seedlings and young herbaceous species exists from metal contamination 11
observed in Subzone C-2 soil. Copper (117 mg/kg), lead (339 mg/kg), and zinc (410 mg/kg) 12
concentrations were above effects levels reported in literature. Effects from organic 13
concentrations could not be assessed. 14

8.8.4 Aquatic Wildlife 15

Risk to aquatic receptors present in Noisette Creek will be fully addressed during the Zone J RFI. 16

Subzone C-1 17

Contamination in surface water and sediments were measured to assess the potential for risk to 18
aquatic receptor species. The maximum concentration of 10 of the 14 inorganic ECPCs detected 19
in surface water exceed their respective surface water criteria effects level (see Table 8.3c). 20
Aluminum, iron, and copper are the most critical ECPCs (HQs = 189, 85.9 and 14.1, 21
respectively) with beryllium, lead, zinc, selenium, and cadmium each having HQs between 22

1 and 10. Overall, based on the concentrations observed, a moderate to high risk to aquatic receptors exists from inorganic constituents present in surface water.

A potential risk to aquatic receptors from maximum sediment concentrations at Subzone C-1 exists based on exceedances of USEPA Region V Sediment Screening Values (see Table 8.3b). Using the maximum concentrations, HQ values greater than one were determined for the following ECPCs: arsenic (9.3), copper (4.0), lead (1.4), and mercury (12.3). Only the maximum HQ for mercury was greater than 10. Using the mean sediment concentrations, the HQ for mercury drops to 4.54, with arsenic having the highest HQ (5.56) followed by copper and lead (HQs=1.81 and 1.06, respectively). Because SSVs are derived from statistical interpretation of effects databases obtained from literature, actual risks to receptors within the surface water at C-1 may be lower than that implied by use of the SSV in the screening assessment.

Although effects levels were exceeded in both media (water and sediment), it is predicted that specific impacts to receptors would be difficult to determine without actual biological testing. However, since concentrations only minimally exceed screening values a risk management decision needs to be made whether or not biological sampling is really necessary.

8.9 Uncertainty

General uncertainties are associated with ERA for Zone C.

- Degradation of chemicals has not been considered in the ECPC selection process.
- Specific effects to biota within the area are unknown.
- Acute and chronic effects data on some ECPCs were unavailable.

- Synergistic or antagonistic effects cannot be quantified. 1

- For some ECPCs, only assumptions relative to similar compounds or classes of elements can be made. 2 3

- Use of related species for risk determination may over or underestimate risk to selected representative wildlife species. 4 5

- Dermal or inhalation exposure pathways were not evaluated. 6

- Maximum exposure scenarios and concentrations may tend to overestimate risk potentials. 7

- On occasion, BAFs were assumed due to lack of information. 8

- Actual occurrence of selected wildlife species within the contaminated area is uncertain. 9

- Food ingestion rates in food chain analyses may be a source of uncertainty to exposure. 10

- Sediment screening values are obtained from laboratory studies and may not reflect field-based exposure scenarios. 11 12

8.10 Risk Summary 13

Risk for ecological receptors was evaluated for ECPCs in surface soil, surface water, and sediment at Subzone C-1 and for soil only at Subzone C-2. This is primarily because of the change in scope to the Final Zone J RFI work plan. By the time these changes were implemented, field work for Zone C had already been completed as originally proposed and report preparation was underway, thus creating data gaps for sediments and surface water in Subzone C-2. Risk associated with 14 15 16 17 18

exposure to ECPCs in surface soil was evaluated for terrestrial wildlife based on a model that predicts the amount of contaminant exposure via the diet and incidental ingestion of soil. The risk evaluation is based on a comparison of predicted doses for representative wildlife species with doses representing thresholds for both lethal and sublethal effects (TRVs). Risk for soil invertebrates and plants was evaluated based on qualitative comparison to literature effects levels for taxonomic groups similar to those potentially occurring at Zone C. Risk for aquatic organisms were evaluated by calculating HQs from benchmark values that are either promulgated or proposed by federal and state regulatory agencies.

Infaunal Invertebrates — Based on the effect levels, the maximum concentration of copper poses a moderate risk potential to infaunal invertebrate species within Subzone C-1. The mean HQ for copper, however, was well below the effect level. All other maximum concentrations in both subzones were below their respective effect level (Table 8.6).

Terrestrial Wildlife — No risk potential for lethal effects to terrestrial wildlife exist based on soil ECPCs within Subzones C-1. All HQ and HI values calculated for each of the representative wildlife species within each subzones were less than one (Tables 8.10a)

Using the maximum concentrations in Subzone C-2, the model predicts a slight risk potential (HI=1.07) for lethal effects to the short-tailed shrew from exposure to manganese in surface soil (Table 8.11a).

Potential sub-lethal effects to both small vertebrates (shrew) and avian species (robin) exist at Subzone C-1. A moderate risk to the shrew from exposure to arsenic in surface soil (HI=27.3).

Based on the sub-lethal HI generated by the model for the American robin, cumulative exposure to selenium, mercury, copper and cadmium in surface soil presents a low potential for excess risk (HI=1.37), although the HQ for each analyte is below 1.

Vegetation — A potential risk to woody seedlings and young herbaceous species exist at Subzones C-1 and C-2. At C-1, maximum concentrations of copper and arsenic constitute the risk. At C-2 copper, lead, manganese, and zinc concentrations are above effect levels reported in literature. Organic concentrations could not be assessed.

Aquatic Receptors — Aquatic receptors present in Subzone C-1 do not appear to be at risk or significantly impacted.

A potential risk to aquatic receptors exists in sediments at Subzone C-1 because HQ values derived from the maximum ECPC concentrations detected are greater than 10 for mercury and above one for arsenic, copper, and lead. Using the mean concentrations to calculate HQs also indicates low risk with arsenic. Actual risk to receptors within the water body may be lower than that implied by using the SSV in the screening assessment. At Subzone C-1, specific impacts to receptors from water and sediment concentrations would be difficult to determine.

9.0 CORRECTIVE MEASURES

According to Permit Condition IV.E. Corrective Action Plan, SCDHEC will review the final RFI report and notify NAVBASE of the need for further investigations, corrective actions, a corrective action study, or plans to meet the requirements of R.61-79.264.101, Corrective Action for SWMUs. This section has been prepared based on SCDHEC's comment that "the RFI report should discuss whether the extent of contamination has been defined, and proposed recommended actions for the SWMUs and AOCs, such as collection of additional samples, proceed into a Corrective Measures Study, or No Further Investigation, whichever is appropriate." EPA and SCDHEC recognizes risk in the 10^{-4} to 10^{-6} as an acceptable risk range. Risk greater than 10^{-4} will require a CMS or if there is an excess risk to ecological resources. The following discussions address the overall approach for looking at corrective measures (CMs), list potential remedies, and outline the steps to be conducted during a CMS. The site-specific conclusions regarding which sites will require CMs are discussed in Section 10, Site-Specific Evaluations.

9.1 Introduction

Any CMS at NAVBASE will be conducted according to standard methods presented in the USEPA guidance document, *RCRA Corrective Action Plan* (USEPA, 1994). The standard methodology will be presented in the CMS Work Plan, and will facilitate collecting necessary data, evaluating potential alternatives, and developing a final remedial alternative by establishing a set procedure for evaluation and assessment.

To establish this procedure, the CMS Work Plan will outline the CMS report, discussing basic elements. The overall structure of the plan will be explained to illustrate the decision-making process. Briefly, the report outline is:

Report Outline	1
A. Introduction/Purpose	2
B. Description of Current Conditions	3
C. Corrective Action Objectives	4
D. Identification, Screening, and Development of Corrective Measure Alternatives	5
E. Evaluation of a Final Corrective Measure Alternative	6
F. Recommendation by a Permittee/Respondent for a Final Corrective Measure Alternative	7
G. Public Involvement Plan	8

Each required element will be discussed in detail in the CMS Work Plan. The discussion will achieve the following:

- Identify minimum requirements for CMS reports in each area. 11
- Define the base pool of technologies to be evaluated for each medium. 12
- Define the evaluation process. 13
- Identify selection criteria for the final corrective measure alternative. 14

Issues to be discussed under each element are identified below: 15

- An activity-specific description of the overall purpose of the CMS for NAVBASE. 16

SWMUs and AOCs at NAVBASE will be discussed in the CMS Work Plan on a zone-wide basis. Activities, contaminants, and issues specific to each zone will be discussed. The CMS Work Plan will identify: specific sites to be addressed in the CMS, any focused approach (such as naming a primary technology in lieu of the full screening), and the subsequent cleanup goals.

- A description of the corrective action objectives for NAVBASE, including how target media cleanup standards, points of compliance, or human health and ecological risk assessments will be established and performed for each site, zone, and activity. 1
2
3

Cleanup standards will be developed for each site, zone, or activity using the designated exposure scenario (residential, commercial, or industrial) for that area. BRAs (including human health and ecological), conducted in conjunction with the RFI for each zone, will be used to identify areas with unacceptable risk/hazard as per the designated exposure scenario. During the CMS, areas with unacceptable risk will be evaluated according to media, primary contaminants contributing to risk, and the potential for groundwater contamination. 4
5
6
7
8
9
10

- Identification, screening, and development of corrective measures alternatives. 11

Tables similar to those presented in the NAVBASE RFI work plans will be used in the CMS Work Plan to present the pool of technologies initially evaluated in the CMS. These tables represent a range of technologies with different applications; each technology must be screened and evaluated before it is discarded from further consideration. The tables, therefore, preclude any bias toward a particular technology through full-scale screening techniques. 12
13
14
15
16
17

Technologies will be screened using site- and waste-specific characteristics. The CMS Work Plan will identify factors to be considered, including type of media, depth of contamination, areal extent of contamination, number and type of contaminants, remedial goals, excess risk to ecological receptors, future land use scenarios, and adjacent remedial activities. In addition, the CMS Work Plan will present the requirements for implementing Corrective Action Management Units (CAMUs). 18
19
20
21
22
23

Once technologies have been screened, they will be assembled into corrective action alternatives. These alternatives will be evaluated according to criteria discussed below.

- A description of the general approach to investigating and evaluating potential corrective action measures.

Corrective measures alternatives will be evaluated using four primary and five secondary criteria, listed below:

Primary

1. *Protect human health and the environment*
2. *Attain media cleanup standards set by the implementing agency*
3. *Control the source of releases so as to reduce or eliminate, to the extent practicable, further releases that may pose a threat to human health and the environment*
4. *Comply with any applicable standards for management of wastes*

Secondary

1. *Long-term reliability and effectiveness*
2. *Reduction in the toxicity, mobility, or volume of waste.*
3. *Short-term effectiveness*
4. *Implementability*
5. *Cost*

Alternatives will be discussed and compared according to these criteria, which are used to gauge their relative effectiveness and implementability.

- A detailed description of how pilot, laboratory, and/or bench-scale studies will be selected, performed, evaluated, reported, and transferred to full scale. 1
2

Treatability studies will be implemented when more involved treatment units are being considered. For example, air stripping technologies usually do not require treatability studies to determine optimal process for treating groundwater. However, ultraviolet (UV)/oxidation, an innovative technology, may require extensive treatability testing to determine oxidant dosages and retention times. 3
4
5
6
7

The base structure and objectives of a treatability study will be discussed. Objectives may include: dosages, percent reduction in contaminant(s), treatment cost per unit volume, and implementation constraints. Study results will be used to assess the alternatives presented in the CMS and determine the optimal remedial approach for each site, zone, or activity. 8
9
10
11

- A description of how statement of basis/response to comments or permit modifications are to be processed. 12
13

Statement of basis/response to comments will be handled through NAVBASE and Southern Division, Naval Facilities Engineering Command (SOUTHDIIV). The Comprehensive Long-Term Environmental Action Navy (CLEAN) contractor, EnSafe, will assist the Navy in preparing a statement of basis/response to comments. Permit modifications will be managed through NAVBASE as the permit holder until the base is closed. Upon closure, SOUTHDIIV and NAVBASE's caretaker will manage permit modifications. According to the RCRA permit issued May 4, 1990, Appendix C, Facility Submission Summary, a permit modification is required to prepare and conduct a Corrective Action Study/Plan. 14
15
16
17
18
19
20
21

- A description of the overall project management approach, including levels of authority (i.e., organizational charts), lines of communication, project schedules, budgets, and personnel.

The overall project management is the responsibility of SOUTHDIV for NAVBASE. The lines of authority, communication, and project schedules have been developed and agreed upon and are provided in the Comprehensive Project Management Plan dated August 30, 1994, and amendments. In general, NAVBASE is responsible for ensuring that conditions of the permit are satisfied with the ultimate responsibility held by the Commander of Charleston Naval Shipyard (CNSY). The budget for conducting a CMS is defined by SOUTHDIV and funds are provided by the U.S. Congress. Personnel to conduct the CMS will be assigned by EnSafe on an as-needed basis for project-specific items. EnSafe will manage the CMS effort through EnSafe's Charleston, South Carolina, office.

- Qualifications of personnel to direct or perform the work will be described.

EnSafe will use trained qualified and/or registered geologists and engineers of South Carolina where required.

9.2 Remedy Selection Approach

As agreed in the *Final Comprehensive Project Management Plan* (E/A&H, 1994), remedies will be selected in accordance with statutory and RCRA CMS criteria. Particular attention will be given to the following items when evaluating alternatives:

- Background concentrations, particularly of inorganic compounds
- Land use/risk assessment

- Base-wide treatment facilities 1
- Presumptive remedies 2
- Remedies for petroleum, oils, lubricants, and other contaminants of this type 3

CAMUs and temporary units (TUs) will be used where necessary to facilitate storage and treatment during remediation activities. 4
5

9.3 Proposed Remedy 6

Before selecting and implementing CMs for releases, environmental and cost-effectiveness goals must be established. Typically, the environmental goal is to reduce exposure via direct contact with air, groundwater, and surface water pathways to some level of acceptability. The cost-effectiveness goal is usually to achieve the environmental goals using the least costly alternative that is both technically feasible and reliable. 7
8
9
10
11

9.4 Development of Target Media Cleanup Goals 12

Cleanup goals will be developed for each site at NAVBASE where human health and/or ecological risk exceeds acceptable levels as specified in the Part B permit. Sites requiring further remediation will undergo CMS. During the CMS, alternatives will be developed for future residential and/or future worker scenarios. Two sets of alternatives may be presented for each site; they may differ due to the media cleanup standards required under residential versus site worker scenarios. 13
14
15
16
17

The USEPA guidance document, *RCRA Corrective Action Plan* (USEPA, 1994) outlines issues to be considered in developing cleanup goals for groundwater, soil, surface water, sediment, and air. These recommendations are outlined below. 18
19
20

9.4.1 Groundwater Cleanup Goals 21

The CMS will provide information to support the development of groundwater cleanup goals for all Appendix IX constituents found in groundwater during the facility investigation. The following information may be required: 22
23
24

- For any constituents for which an MCL has been promulgated under the Safe Drinking Water Act, the MCL value; 1
2
- Background concentration of the constituent in groundwater; and 3
- An alternate standard (e.g., an alternative concentration limit for a regulated unit) to be approved by the implementing agency. 4
5

Additional factors to be considered while developing cleanup goals include the classification and primary use of the contaminated groundwater unit, proposed future uses for groundwater, proximity to surface water, etc. 6
7
8

9.4.2 Soil Cleanup Goals 10

The CMS will provide information to support the development of soil cleanup goals. The following information may be required: 11
12

- The volume, physical, and chemical characteristics of the wastes in the unit; 13
- The effectiveness and reliability of containing, confining, and collecting systems and structures in preventing contaminant migration; 14
15
- The hydrologic characteristics of the unit and the surrounding area, including the topography of the surrounding land; 16
17
- Regional precipitation patterns; 18

- The existing quality of surface soil, including other sources of contamination and their cumulative impacts on surface soil; 1
2
- The potential for contaminant migration and impact to the underlying groundwater; 3
- The land use patterns in the region; 4
- The potential for health risks caused by human exposure to waste constituents; and 5
- The potential for damage to wildlife, food chains, and vegetation caused by exposure to waste constituents. 6
7
- The potential for damage to domestic animals, crops, and physical structures caused by exposure to waste constituents. 8
9

Additional information that may be considered includes background soil concentrations, regulatory guidance (e.g., UST guidance documents). 10
11

9.4.3 Surface Water and Sediment Cleanup Goals 12

The CMS will provide information to support the development of surface water and sediment cleanup goals. The following information may be required: 13
14

- The volume and physical and chemical characteristics of waste in the unit; 15
- The effectiveness and reliability of containing, confining, and collecting systems and structures in preventing contaminant migration; 16
17

- The hydrologic characteristics of the unit and the surrounding area, including the topography of surrounding land; 1
2
- Regional precipitation patterns; 3
- The quantity, quality, and direction of groundwater flow; 4
- The proximity of the unit to surface water; 5
- The current and potential uses of nearby surface water and any established water quality standards; 6
7
- The existing quality of surface water, including other sources of contamination and their cumulative impacts on surface water; 8
9
- The potential for damage to wildlife, food chains, and vegetation caused by exposure to waste constituents; 10
11
- The potential for damage to domestic animals, crops, and physical structures caused by exposure to waste constituents; 12
13
- The land use patterns in the region; and 14
- The potential for health risks caused by human exposure to waste constituents. 15

Additional data which may be considered include the presence of endangered, threatened, or ecologically sensitive species, National Oceanic and Atmospheric Association sediment values, etc. 16
17
18

9.4.4 Air Cleanup Goals

The CMS will provide information to support the development of air cleanup goals. The following information may be required:

- The volume and physical and chemical characteristics of the waste in the unit, including its potential for the emission and dispersal of gases, aerosols, and particulates;
- The effectiveness and reliability of systems and structures to reduce or prevent emissions of hazardous constituents to the air;
- The operating characteristics of the unit;
- The atmospheric, meteorological, and topographic characteristics of the unit and the surrounding areas;
- The existing quality of the air, including other sources of contamination and their cumulative impact on that medium;
- The potential for health risks caused by human exposure to waste constituents; and
- The potential for damage to wildlife, food chains, and vegetation caused by exposure to waste constituents.
- The potential for damage to domestic animals, crops, and physical structures caused by exposure to waste constituents.

Other factors which may be considered include National Ambient Air Quality Standards, state and local air quality regulations, etc.

9.5 Identification, Screening, and Development of Corrective Measures Technologies

The initial step in assembling corrective measures alternatives is to identify, screen, and develop corrective measure technologies that apply to the site. Technologies are typically screened using waste-, media-, and site-specific characteristics. This section addresses the range of technologies that may be assessed for each site, the screening process, and screening criteria.

9.5.1 Identification of Corrective Measure Technologies

Each site will be assessed using the cleanup standard methodology described in Section 9.2. An initial list of impacted media and contaminants of concern have been identified in the RFI. The site-specific BRAs in Section 10 will identify soil and groundwater as the contaminated media. For each site, the major contaminants present have been grouped into one or more of the following categories:

- Chlorinated volatiles
- Nonchlorinated volatiles
- Chlorinated semivolatiles
- Nonchlorinated semivolatiles
- Pesticides/herbicides
- PCBs
- Dioxins
- Inorganic compounds (includes metals)
- Petroleum hydrocarbons

Remedial technologies are described in Section 9.5.2 of this document. Table 9.1 lists non-treatment options for soil, groundwater/leachate, sediment, surface water, and air. These options include removal containment, and disposal. Table 9.2 lists types of compounds and the recommended types of treatment for each medium. These tables supply general waste management options for various situations.

It should be noted that some sites may contain a combination of contaminants (i.e., inorganics, pesticides, and petroleum hydrocarbons). As a result, multiple technology types may be required to remove these contaminants. However, some sites will only contain one type of contaminant.

The following example presents a common situation where more than one type of contaminant exists at a site. The site contains volatile and semivolatile compounds that have been identified as slightly exceeding risk-based remedial goals. A containment alternative in this situation may include fencing to restrict unauthorized access, aerating the contaminated area, adding fertilizer and enriched soil, seeding to maintain a vegetative cover to control runoff, and monitoring. This containment approach seeks to minimize health risks through land management and natural attenuation.

As discussed in previous sections, because each site may be evaluated under both residential and site worker scenarios, COCs may vary between scenarios. Two lists of applicable technologies may be developed for each site, one for each scenario.

**Table 9.1
 Removal/Containment/Disposal Options**

Action	Soil	Groundwater/ Leachate	Sediment	Surface Water	Air
Removal	Excavation	Groundwater extraction Leachate collection	Dredging	Diversion Pumping	N/A
Containment	Institutional controls Capping Storm water controls Long-term monitoring Intrinsic (natural) bioremediation/attenuation	Slurry wall Gradient controls Long-term monitoring Intrinsic (natural) bioremediation/attenuation	Berms/diversion Storm water controls	Diversion	N/A
Disposal	Landfill	POTW NPDES Discharge Land application	Landfill	POTW NPDES Discharge	Discharge via air permit

Notes:
 POTW = Publicly Owned Treatment Works
 NPDES = National Pollutant Discharge Elimination System
 N/A = Not Applicable

**Table 9.2
 Treatment Technology Options**

Contaminant Type	Soil	Groundwater/ Leachate	Sediment	Air
Chlorinated volatiles	Soil washing Incineration Thermal desorption Bioremediation	Chemical Oxidation Bioremediation Adsorption Air stripping UV/Ozone Oxidation	Same as soil	Oxidation
Nonchlorinated volatiles	Soil washing Incineration Thermal desorption Soil Vapor Extraction Bioremediation Steam extraction	Oxidation Bioremediation Adsorption Air stripping	Same as soil	Adsorption Oxidation
Chlorinated semivolatiles	Soil washing Bioremediation Incineration Thermal desorption Solidification/stabilization	Oxidation Bioremediation Air stripping	Same as soil	Adsorption Oxidation
Nonchlorinated semivolatiles	Soil washing Incineration Thermal desorption Bioremediation Solidification/stabilization	Oxidation Bioremediation Sorption	Same as soil	Oxidation Adsorption

**Table 9.2
 Treatment Technology Options**

Contaminant Type	Soil	Groundwater/ Leachate	Sediment	Air
Pesticides/ Herbicides	Solidification/stabilization Soil washing Bioremediation Incineration Thermal desorption	Oxidation Bioremediation Sorption	Same as soil	Oxidation
PCBs	Solidification/stabilization Soil washing Dehalogenation Incineration Thermal desorption	Oxidation Dehalogenation Incineration Solidification	Solvent extraction Dehalogenation Solidification/stabilization	Oxidation
Dioxins	Incineration Solidification/stabilization	Oxidation		Oxidation
Inorganics	Solidification/stabilization Soil washing	Chemical Precipitation Adsorption Sedimentation Filtration	Same as soil	Filtration Scrubbers Adsorption

9.5.2 Description of Pre-screened Technologies

The following paragraphs describe technologies that appear to be the most feasible for the initial CMS. These technologies are divided into four categories: in-situ soil, ex-situ soil, in-situ groundwater, and ex-situ groundwater.

In-Situ Soil

Bioremediation

This technology uses microorganisms to biologically oxidize contaminants into harmless chemicals such as carbon dioxide and water. The organisms can be naturally occurring or they can be added to the soil. In many circumstances, nutrients can be supplemented to enhance this process. Nitrate and phosphate are often the limiting nutrients at a site. However, having insufficient electron acceptors is the greatest variable limiting bioremediation. The most common electron acceptor is oxygen for aerobic biodegradation. For these sites, it is likely that bioremediation via natural attenuation is a good candidate for some of the compounds. Typically nonchlorinated VOCs and SVOCs are good candidates for this technology.

Solidification/Stabilization

This technology consists of mixing reagents with soil to prevent contaminants from leaching to the groundwater below. This technology immobilizes contaminants, preventing migration. However, this technology does not remove the contaminant.

Ex-Situ Treatment of Soils

All ex-situ soil treatments require excavation to another location or at least bringing the material to the surface. Typically heavy equipment is used to move the soil. If contaminated soil is limited

in volume and considered nonhazardous, it may be feasible to dispose of it in a landfill. If sites 1
have a limited area of contaminated soil, it may be feasible to remove the soil with heavy 2
equipment and treat it ex-situ, or if nonhazardous, it could be disposed of in the SWMU 9 landfill. 3

Soil Washing

 4

Soil washing physically separates soil particles by size, then treats the smaller grains with solutions 5
that desorb the contaminants. The resulting solution containing contaminants is then treated by 6
another technology. In general, small soil particles such as clay and silt have a higher TOC 7
content, which tends to absorb hydrophobic compounds such as chlorinated contaminants. 8
Essentially the technology compacts contaminated soil, then washes it with a solvent to remove 9
the contaminants. 10

Thermal Desorption

 11

Thermal desorption technologies are performed at high or low temperatures, depending on the 12
contaminant. Both of these technologies are used in combination with incineration or some other 13
type of offgas treatment. Soil is excavated and put in the treatment systems for both high- and 14
low-temperature desorption to separate the contaminants from the soil, not to destroy the 15
chemicals. The volatilized contaminants enter an air stream and travel to some type of gas 16
treatment for the contaminant destruction. Low-temperature (200°F to 600°F) thermal desorption 17
(LTTD) is only applicable for VOCs while high-temperature (600°F to 1000 °F) thermal 18
desorption (HTTD) is applicable for SVOCs, PAHs, PCBs, and pesticides. 19

Thermal Destruction/Incineration

 20

This technology is used in conjunction with ex-situ soil technologies. Typically the contaminant 21
is removed from the soil matrix and transferred to an air stream. The air stream is treated with 22
the thermal destruction on a catalyst or burned in an incinerator or a combination of the two. High 23

temperatures (1,800°F to 2,000°F) are required to destroy organics such as PCBs, dioxins, furans, pesticides, and others. 1
2

Solidification/Stabilization 3

This technology is similar to the in-situ methods; however, the soil is first excavated before being mixed with the chemical reagents or concrete. 4
5

In-Situ Groundwater Treatment 6

Bioremediation 7

Bioremediating contaminants in groundwater involves adding nutrients (phosphate, nitrate, etc.) and an electron acceptor (i.e., oxygen, nitrate, etc.) to the groundwater via injection wells. The most typical electron acceptor addition comes from either oxygen via air sparging, and/or nitrate with the addition of other nutrients. 8
9
10
11

Intrinsic Remediation 12

This technology, also called natural attenuation, simply allows naturally occurring bioremediation, oxidation, hydrolysis, dispersion, and advection to occur unassisted. No nutrients or electron acceptors are added to the site. The site may be monitored to observe the contaminant reduction. Many case studies have demonstrated this technology on TPH analysis. 13
14
15
16

Ex-Situ Treatment of Groundwater 17

Any ex-situ treatment of groundwater requires a system of extraction wells and pumps to deliver the groundwater to the treatment location. 18
19

Chemical Precipitation

The solubility of many metals is a function of pH. As a result, chemical agents can be added to change the pH of the water, that results in the metals becoming insoluble. In other cases, a chemical can be added to chelate the metal and precipitate it out of the solution. Either way, the contaminants can then be removed by filtering.

Air Stripping

Groundwater can be extracted from the subsurface and pumped to a nearby publicly owned treatment works (POTW). While the contaminated groundwater is in the aeration basin of the water treatment plant, the volatile compounds (compounds with a high Henry's Law Constant) will mass transfer from the water to the air. Steam can also be used to heat the groundwater, causing organics to volatilize. These air vapors can be treated with an appropriate technology or can be permitted as an air emission source.

Chemical Oxidation/UV-Ozone

Ozone is one of the strongest chemical oxidizers. Almost any organic compound can be oxidized. Ozone can be generated with UV light sources. Water can pass through a flowstream surrounded by UV lights. Oxygen in the water is converted to ozone and the organics are oxidized into harmless by-products. Compounds that typically are recalcitrant to biological oxidation, such as chlorinated organics, can easily be oxidized with ozone. Good light transmission is essential; therefore, very turbid water is not a good candidate for UV ozonation.

Activated Sludge

Activated sludge treatment of wastes occurs in a wastewater treatment plant. The activated sludge process uses microorganisms to convert organic wastes to inorganic wastes and/or bacterial cell mass, carbon dioxide, and water.

9.5.3 Screening Criteria

When more than one technology applies to a specific site, it is necessary to evaluate their limitations to show why certain CMS technologies may prove infeasible to implement waste- and site-specific conditions. Therefore, for each technology, the following criteria will be discussed:

- Site Characteristics
- Waste Characteristics
- Technology Limitations

Site Characteristics

Site characteristics define the site and any constraints that may impact selecting and implementing remedial technologies. Characteristics to be considered include primarily the current and future use of the site or SWMU. Other characteristics include the contaminated media, areal distribution of contamination, and depth to/of contamination. Current migration pathways and the potential for intrinsic remediation will also be considered. Each site may have one or two technology lists that will be evaluated for residential and BRAC-specified future uses.

Waste Characteristics

Waste characteristics define the nature of contamination. The primary waste characteristic to be considered is the general type of contamination — volatiles, semivolatiles, pesticides/herbicides, PCBs, dioxins, inorganic compounds, and TPH analysis. Also critical is the presence of halogenated compounds, such as chlorinated benzenes or trichloroethylene.

Where multiple types of contamination are present (such as PCBs and dioxins, or pesticides and volatiles), certain technologies may be eliminated from consideration due to the inability to

effectively treat the wastes. For example, soil vapor extraction (SVE) typically is not used on pesticide sites, although it is very effective for most volatile compounds. If both contaminants must be treated concurrently, SVE would be eliminated from further evaluation. Where appropriate, contaminant concentrations will be considered to screen remedial technologies.

Technology Limitations

Technology limitations are used to assess the implementation feasibility of a particular technology. These limitations may include technical restrictions on application, including the presence of a shallow water table, depth to bedrock, etc. Additional limitations include minimum or maximum process volumes, such as technologies that are cost-effective only when contaminated soil volume exceeds 1,000 cubic yards. Other limitation to be assessed include effectiveness in meeting treatment goals and remedial time frame. Technologies meeting this screening criterion may differ from residential to BRAC-specified use scenarios due to the differences in cleanup goals for each scenario.

9.6 Identification of Corrective Measure Alternatives

Once specific remedial technologies are identified for the site; they will be assembled into specific alternatives that may meet the corrective action objectives for all media. Each alternative may consist of an individual technology or a combination of technologies used in sequence (i.e., treatment train). Depending upon site-specific situations, different alternatives may be considered for separate areas of the facility.

Less complex sites may be relatively straightforward and may only require evaluating one or two alternatives. Because the NAVBASE CMS will evaluate both residential and BRAC-specified future uses, two sets of alternatives may be developed for each site.

9.7 Evaluation of Corrective Measure Alternatives

Each alternative proposed (including single proposed alternatives) will be evaluated according to five standards reflecting the major technical components of remedies, including cleanup of releases, source control, and management of wastes that are generated by remedial activities. The specific standards are provided below.

- Protect human health and the environment.
- Attain media cleanup standards set by the implementing agency.
- Control the source of releases so as to reduce or eliminate, to the extent practical, further releases that may threaten human health and/or the environment.
- Comply with any applicable standards for managing wastes.
- Consider other factors.

These standards are detailed in the following sections.

9.7.1 Protect Human Health and the Environment

Corrective action remedies must be protective of human health and the environment. The degree of protection afforded by each alternative will be discussed in this section.

Remedies may also include those measures that are needed to be protective, but are not directly related to media cleanup, source control, or waste management. For example, access controls and deed restrictions may be implemented to prevent contact with contaminated media while intrinsic remediation or attenuation processes are monitored or augmented. This section will discuss any short-term remedies that may be implemented to meet this standard.

9.7.2 Attain Media Cleanup Standards Set by the Implementing Agency

Each alternative will be evaluated as to whether the potential remedy will achieve the remedial objective(s). This evaluation will estimate the time frame needed for each alternative to attain these standards. The selected remedy will be required to attain media cleanup standards set by the implementing agency, that may be derived from current state, federal, or other regulations or standards. The media cleanup standard will often play a large part in determining the extent of and technical approaches to the remedy. In some cases, the practical capabilities of remedial technologies (or other technical aspects of the remedy) may influence, to some degree, the cleanup standards that are established.

9.7.3 Control the Sources of Releases

As part of the CMS report, source control measures will be evaluated to determine if they are necessary to control or eliminate further releases that may threaten human health or the environment. If a source control measure is proposed, it will include a discussion on how well the method is expected to work, given site conditions, and the known reliability of the selected technology.

Source control measures will be considered when it is necessary to stop further environmental degradation by controlling or eliminating further releases that may threaten human health or the environment. In some cases efforts to clean up releases without source control measures, may be

ineffective or (at best) will essentially involve a perpetual remedial effort. In these cases, an effective source control program may be essential to ensure the long-term effectiveness and protectiveness of the corrective action program. Source control measures may include all protective remedies to control the source. Such remedies may include partial waste removal, capping, slurry walls, in-situ treatment and/or stabilization, and consolidation.

9.7.4 Comply with Any Applicable Standards for Management of Wastes

Each alternative will discuss how the specific waste management activities will comply with all applicable state or federal regulations, such as closure requirements, land disposal restrictions, etc.

9.7.5 Other Factors

Five general factors will be considered in selecting/approving a remedy that meets the standards listed above. These factors combine technical measures and management controls to address the environmental problems at the site. The five general decision factors include:

- Long-term reliability and effectiveness
- Reduction in the toxicity, mobility, or volume of wastes
- Short-term effectiveness
- Implementability
- Cost

Long-Term Reliability and Effectiveness

The CMS will evaluate whether the technology or a combination of technologies has been used effectively under similar site conditions, whether failure of any one technology in the alternative would have an immediate impact on receptors, and whether the alternative would have the flexibility to deal with uncontrollable changes onsite.

This criterion will assess the proposed useful life of the overall alternative and its component technologies. Useful life is defined as the length of time the level of effectiveness can be maintained. Typically, most corrective measure technologies deteriorate with time. Deterioration can often be slowed through proper system operation and maintenance, but the technology may eventually require replacement to maintain effectiveness. The CMS will consider these issues.

Reduction in the Toxicity, Mobility, or Volume of Wastes

This criterion will be used to assess the degree that each alternative reduces the toxicity, mobility, or volume of wastes. In general, preferred remedies employ treatment and are capable of eliminating (or substantially reducing) the potential for contaminated media to cause future environmental releases or other risks to human health and the environment. Estimates of how much the corrective measure alternatives will reduce the waste toxicity, mobility, or volume may help in assessing this criterion.

In some situations, reducing toxicity, mobility, or volume may not be practical or even desirable. For example, large municipal-type landfills or unexploded munitions may be extremely dangerous to handle. In these situations, the short-term risks of treatment outweigh the potential long-term benefits.

Short-Term Effectiveness

The short-term effectiveness of each alternative will be assessed, including: the potential for fire, explosion, and exposure to hazardous substances; as well as threats associated with treatment, excavation, transportation, and redisposal or containment of waste material. This criterion is important in densely populated areas and where waste characteristics are such that risks to workers or to the environment are high and special protective measures are needed.

Implementability

Each alternative will be evaluated to assess any potential impacts on the time required to implement a given remedy. Information to consider for implementability includes:

- The administrative activities needed to implement the corrective measure alternative (e.g., permits, rights-of-way, offsite approvals) and the length of time these activities will take.
- The constructability, time for implementation, and time for beneficial results.
- The availability of adequate offsite treatment, storage capacity, disposal services, needed technical services, and materials.
- The availability of prospective technologies for each corrective measure alternative.

Cost

The CMS will consider the relative cost for each remedy. This criterion is especially useful when several technologies offer the same degree of protection to human health and the environment but vary dramatically in cost. Cost estimates will include: engineering, site preparation, construction,

materials, labor, sampling/analysis, waste management/disposal, permitting, health and safety
measures, training, operations and maintenance, etc.

9.8 Ranking the Corrective Measures Alternatives

Once corrective measures have been discussed for each site using applicable scenarios (residential and/or BRAC-specified future use), alternatives under each will be ranked in order of desirability. The ranking system has been developed with input from the Restoration Advisory Board, to determine the importance of each corrective measure criterion. The system is included in the *Comprehensive CMS Work Plan (E/A&H, 1997)*. Table 9.3 shows the format of the ranking system.

The example presented in Table 9.3 considers a hypothetical site in which soil is contaminated with relatively high (10 to 1,000 ppm) PAH concentrations. Three alternatives were developed: excavation and disposal in a permitted landfill, excavation and thermal treatment, and capping in-situ. The purpose of this example is to show the format and the nature of comparisons that will be made in the CMS.

Once the weighing factors are selected, the rankings are set by multiplying the criteria values by the weighing factor. The weighted criteria values are then summed. Alternatives are ranked in order, with the highest total being most preferable, and the lowest total being the least preferable.

Table 9.3
Comparison and Ranking of Alternatives

Objective & Criteria	Weighing Factor	Alternative 1		Alternative 2		Alternative 3	
		Description	Meets Criteria	Description	Meets Criteria	Description	Meets Criteria
Protect human health and the environment		Protective of human health and community	3	Protective of human health and community	3	Protective of human health and community	3
Attain media cleanup standards		Excavates soil above cleanup goals	3	Excavates soil above cleanup goals	3	No	1
Control the sources of releases		Eliminates source material above cleanup goals	3	Eliminates source material above cleanup goals	3	Controls sources of releases through containment, reduction in leachate	3
Comply with any applicable standards for management of wastes		Must comply with LDRs, USDOT regulations	3	Must comply with LDRs, air emissions regulations	3	Must comply with RCRA cap requirements, monitoring	3
Other Factors							
Long-term reliability and effectiveness		Effective over the long term	3	Effective over the long term	3	Effective with regular maintenance activities	3
Reduction in toxicity, mobility, and volume		Does not reduce toxicity, mobility, or volume	1	Reduces toxicity, mobility, and volume through treatment	4	Does not reduce toxicity, mobility, or volume	1

**Table 9.3
 Comparison and Ranking of Alternatives**

Objective & Criteria	Weighing Factor	Alternative 1			Alternative 2			Alternative 3		
		Description	Meets Criteria	Weighted Criteria Value	Description	Meets Criteria	Weighted Criteria Value	Description	Meets Criteria	Weighted Criteria Value
Short-term effectiveness		Minimal exposure to site workers during excavation	3		Minimal exposure to site workers during excavation and treatment	3		Minimal exposure to site workers during excavation	4	
Implementability		Easily implemented, common approach to contaminated soil	4		Requires mobile treatment unit mobilization; may be time inefficient	2		Easily implemented, common approach to contaminated soil	3	
Cost		Present worth cost = \$193,000	3		Present worth cost = \$354,000	1		Present worth cost = \$8,000	4	
Totals										

Notes:

Meets criteria ranking values are based on the following scale:
 4 = Meets and far exceeds criteria/objectives
 3 = Slightly exceeds criteria/objectives
 2 = Meets only minimally the criteria/objectives
 1 = Does not meet criteria/objectives

Weighting Factors will be determined by NAVBASE
 LDRs = Land Disposal Restrictions
 USDOT = U.S. Department of Transportation