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RESOURCE CONSERVATION AND RECOVERY ACT FACILITY INVESTIGATION REPORT
ZONE A VOLUME I OF V SECTIONS 1 TO 9 CNC CHARLESTON SC

8/7/1998
ENSAFE

**ZONE A
RCRA FACILITY INVESTIGATION REPORT
NAVBASE CHARLESTON
NORTH CHARLESTON, SOUTH CAROLINA**

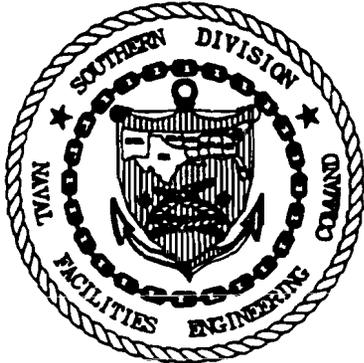


**Volume I of V
Sections 1 to 9**

**CTO-029
Contract Number: N62467-89-D-0318**

Prepared for:

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



Prepared by:

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

**August 7, 1998
Revision: 0**

Release of this document requires prior notification of the Commanding Officer of the Southern Division, Naval Facilities Engineering Command, North Charleston, South Carolina.



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CERTIFIED MAIL

July 9, 1998

Henry Shepard II, P.E.
Caretaker Site Office
NAVFACENCOM, Southern Division
1690 Turnbull Avenue
Building NH-51
Charleston, SC 29405

Re: Review of the Zone A Draft RCRA Facility Investigation Report
Dated April 14, 1998 - Volumes I and II
Charleston Naval Complex
SC0 170 022 560

Dear Mr. Shepard:

The South Carolina Department of Health and Environmental Control (Department) has reviewed the above referenced Zone A Draft RFI Report. The attached comments were provided by Mr. Paul Bergstrand of the Hydrogeology division and should be considered in addition to the verbally presented comments at the June 1998 Tier I meeting in Charleston. The review of this information was done according to applicable State and Federal Regulations, and the Charleston Naval Base Hazardous Waste Permit, effective June 5, 1990. The US EPA did not provide written comments. Based on this review, the Department believes that the Charleston Naval Base needs to revise the Draft Zone A RFI Report accordingly.

Upon receipt of this letter and within forty five (45) days, please make the specified changes/corrections and resubmit responses to the Department's comments and the Final Zone A RFI Report to the Department and U.S. EPA for a final review. The responses should be complete and the changes/corrections should be clearly identified for a more efficient review.

Should you have any questions regarding this issue, please contact me at (803) 896-4179 or Paul Bergstrand at (803) 896-4016.

Sincerely,


Johnny Tapia P., Environmental Engineer Associate
Corrective Action Engineering Section
Bureau of Land & Waste Management

Attachments

cc: Paul Bergstrand, Hydrogeology
Rick Richter, Trident EQC
Tony Hunt, SOUTHNAVFACENCOM
Dan Spariosu, EPA Region IV



Bull Street
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RECEIVED

JUL 09 1998
S. CAROLINA DEPT. OF HEALTH &
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Waste Management

MEMORANDUM

TO: Johnny Tapia, Environmental Engineer Associate
Corrective Action Engineering Section
Hazardous and Infectious Waste Management
Bureau of Land and Waste Management

FROM: Paul M. Bergstrand, P.G., Hydrogeologist
Hazardous Waste Section
Division of Hydrogeology
Bureau of Land and Waste Management

DATE: 8 July 1998

RE: Charleston Naval Base (CNAV)
Charleston, South Carolina
SCO 170 022 560

RCRA Facility Investigation Report
Zone A
Dated April 14, 1998, Revision 0

The materials referenced above have been reviewed with respect to the requirements of R.61-79 of the South Carolina Hazardous Waste Management Regulations, The Environmental Protection Agencies (EPA) RCRA Facility Investigation Guidance Document dated May 1989, the EPA Region IV Environmental Compliance Branch Standard Operating Procedures and Quality Assurance Manual (SOP/QAM) dated May 1996 and the CNAV Final Comprehensive Sampling and Analysis Plan dated 30 August 1994.

Based on this review, comments are attached.

DD980494.PMB

Zone A
Draft RFI Report Comments

Paul Bergstrand, SCDHEC

8 July 1998

1. Pages 10.1.8, 10.1.11, 10.4.6 and 10.4.22

The tables on these pages compare contaminants detected to RBCs but do not compare contaminants with SSLs or MCLs. Previous comments have been made regarding the applicability of MCLs at CNAV. Also, there are several constituents, such as with mercury, where the RBC is greater than the MCL. SSLs and MCLs should be included on all appropriate tables.

2. Page 10.2.34

This section of the report compares the maximum soil contaminants to SSLs then compares those values to maximum groundwater detections. It is not clear if the groundwater detections are downgradient from the highest SSL values. This type of comparison should be made using a figure or map. Please revise.

3. SWMU 39.

The possibility of groundwater influence from the storm sewers or the sanitary sewer should be included in the CMS investigation for this SWMU. The area of wells 39-013 should be included because some of the higher levels of contamination are detected here and they are in the vicinity of storm drain manholes. This contamination should also be considered along with any results from the Zone L investigation.

4. Page 10.4.74, Data Contouring

The computer generated contaminants maps for SWMU 39 lack closure in the intermediate and deep wells. Groundwater flow maps indicate intermediate and deep groundwater flows to the east. The CMS workplan must provide resolution to this lack of data.

5. Pages 10.4.92 and 10.4.94

This section of the report discusses geoprobe data and the laboratory confirmation samples. It is not clear how the geoprobe data results compared to the laboratory samples. Please address.

6. Page 10.4.92

This section of the report discusses the extent of the shallow groundwater contamination based on shallow groundwater geoprobe data. This information should be presented on a map or figure 10.4.26. Please note, samples 4 and 6 were included in the samples which approximated the contaminate boundary. Sample 4 reported the highest PCE levels in the shallow aquifer and sample 6 reported moderate levels of Vinyl Chloride, both being above MCLs. Please revise.

7. Page 10.5.31, Section 10.5.5.1

This comment is similar to comment # 2. This section of the workplan discusses the leaching potential of soils to groundwater. In this case PCE was detected in soils at levels that are less than the SSL but PCE was reported in the groundwater above the MCL. The implications are that the SSL is not protective of groundwater or that the soil sample locations have not identified the hot spots at the spill site. This issue should be addressed in the report. Any other similar situations should be addressed in the CMS work plan.

8. Page 10.5.36, Section 10.5.5.1

This section states that Arochlor 1260 was above the SSL at soil boring 505SB008. There are apparently no downgradient wells from this soil boring location to verify if groundwater has or has not been impacted. Please address.

9. Page 10.6.15

This section describes two VOCs were detected in the duplicate sample which was sent to the off site laboratory for analysis. It is not clear which sample the duplicate was

collected from or how the results reflect on the quality of the geoprobe data. While both sample results were below the respective RBCs, it is not understood how the groundwater was contaminated by the constituents or if the sample was upgradient or downgradient of the SWMU. Please address.

10. Pages 10.7.11 and 10.7.12

There is a discrepancy between the text which states 1,1-trichloroethane was detected in shallow groundwater and table 10.7.5 which lists 1,1-dichloroethane in four groundwater samples. Please revise.

It should be noted that 1,1-dichloroethane is a breakdown product of TCA and was consistently detected in four of four samples in the permanent monitoring well at this SWMU. 1,1-dichloroethane does not have a MCL and all detections were below the RBC of 810 ppb.

11. GRID SAMPLES

This section of the Report states TCE was detected in 8 of 13 soil boring locations. However the levels detected and the locations was not discussed. This may indicate the selected sample locations are not suitable for grid based samples. Please address.

This section of the Report stated that 1,1,1-trichloroethane was detected below the MCL in one of three monitoring wells during one quarters sampling. Neither the text or the tables indicated which well the VOCs were detected in or how the detections may affect the grid sample results. Because there is no explanation of how the groundwater was contaminated with TCA, this detection may require further investigation in the CMS. Please address.

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



RESPONSE TO COMMENTS FOR

FINAL ZONE A RFI REPORT
*(Section 10 - Site-Specific Discussions
Dated April 14, 1998)*

DRAFT ZONE A RFI REPORT
*(Site-Specific Discussions for SWMUs 1, 2 and 39
Dated August 19, 1997)*

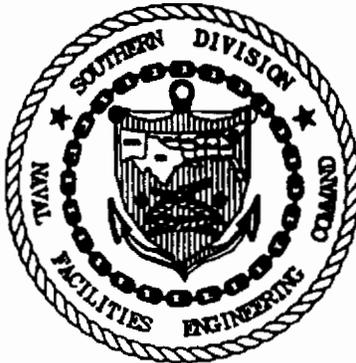
DRAFT ZONE A RFI REPORT
(Dated September 12, 1998)

NAVAL BASE 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**

**August 7, 1998
Revision: 0**

South Carolina Department of Health and Environment Control
Comments on the Final Zone A RFI Report
Section 10 — Site-Specific Discussions
Dated April 14, 1998

Paul Bergstrand, SCDHEC
(Comments received via e-mail July 8, 1998)

Comment 1:

Pages 10.1.8, 10.1.11, 10.4.6 and 10.4.22

The tables on these pages compare contaminants detected to RBCs but do not compare contaminants with SSLs or MCLs. Previous comments have been made regarding the applicability of MCLs at CNAV. Also, there are several constituents, such as with mercury, where the RBC is greater than the MCL. SSLs and MCLs should be included on all appropriate tables.

Response 1:

All requested data comparisons (RBCs, SSLs, and RCs for surface soil; SSLs and RCs for subsurface soil; RBCs and MCLs for groundwater) are provided within for each site-specific discussion. This comment specifically addresses the lack of all comparisons in the "nature and extent" subsections. The goal of this subsection is to provide a full data summary and prepare the reader, by calling attention to critical data, for the subsequent fate and transport and risk assessment subsections (where the data comparisons to applicable screening values are required and appropriate). While an advanced reader might want comparisons of the data to all potentially applicable screening values in the nature and extent subsection, the redundancy and complexity of providing all comparisons in this subsection would be detrimental to the overall presentation.

Comment 2:

Page 10.2.34

This section of the report compares the maximum soil contaminants to SSLs then compares those values to maximum groundwater detections. It is not clear if the groundwater detections are downgradient from the highest SSL values. This type of comparison should be made using a figure or map. Please revise.

Response 2:

Figures 10.2.9 through 10.2.16 (pages 10.2.47 through 10.2.61), which present all SSL exceedances and groundwater detections, have been added to the final version of the report.

Comment 3:
SWMU 39

The possibility of groundwater influence from the storm sewers or the sanitary sewer should be included in the CMS investigation for this SWMU. The area of wells 39-013 should be included because some of the higher levels of contamination are detected here and they are in the vicinity of storm drain manholes. This contamination should also be considered along with any results from the Zone L investigation.

Response 3:

The Navy concurs with this comment, and the influence of storm/sanitary sewers at this site will be addressed in the CMS.

Comment 4:

Page 10.4.74, Data Contouring

The computer generated contaminants maps for SWMU 39 lack closure in the intermediate and deep wells. Groundwater flow maps indicate intermediate and deep groundwater flows to the east. The CMS workplan must provide resolution to this lack of data.

Response 4:

The Navy concurs with this comment, and additional intermediate and deep monitoring wells have been proposed to fill this data gap as described in the July 30, 1998 technical memorandum, "Proposed Permanent and Temporary Well Locations at SWMU 39".

Comment 5:

Pages 10.4.92 and 10.4.94

This section of the report discusses geoprobe data and the laboratory confirmation samples. It is not clear how the geoprobe data results compared to the laboratory samples. Please address.

Response 5:

The text on page 10.4.118 has been revised to make it clearer to the reader how split samples were labeled and to compare the offsite data in Table 10.4.24 to the onsite data in Table 10.4.23 (pages 10.4.121 to 10.4.123). A detailed statistical analysis was not performed because the two datasets were comparable (i.e., compounds detected, concentration ranges, etc.), verifying that the onsite dataset was suitable for its primary intended use (i.e., selecting monitoring well locations).

Comment 6:

Page 10.4.92

This section of the report discusses the extent of the shallow groundwater contamination based on shallow groundwater geoprobe data. This information should be presented on a map or figure 10.4.26. Please note, samples 4 and 6 were included in the samples which approximated the contaminate boundary. Sample 4 reported the highest PCE levels in the shallow aquifer and sample 6 reported moderate levels of Vinyl Chloride, both being above MCLs. Please revise.

Response 6:

As requested, Figure 10.4.26 (page 10.4.119) has been revised to illustrate the extent of shallow groundwater contamination. The comment is correct in stating that groundwater samples collected at geoprobe locations GP004 and GP006 contained the aforementioned detections. However, the text refers to monitoring wells NBCA-002-004 and NBCA-002-006 when describing the approximate contaminant boundary.

Comment 7:

Page 10.5.31, Section 10.5.5.1

This comment is similar to comment # 2. This section of the workplan discusses the leaching potential of soils to groundwater. In this case PCE was detected in soils at levels that are less than the SSL but PCE was reported in the groundwater above the MCL. The implications are that the SSL is not protective of groundwater or that the soil sample locations have not identified the hot spots at the spill site. This issue should be addressed in the report. Any other similar situations should be addressed in the CMS work plan.

Response 7:

Section 10.5.5.1 (page 10.5.34) has been modified to address this issue. In this case, the neighboring VOC plume in SWMU 39 groundwater should be considered prior to concluding that the data indicates the SSL is not protective of groundwater or that the soil sample locations have not identified the "hot spots" onsite. The PCE detections in soil that this comment refers to are unrelated to the groundwater sample detections because the soil borings are approximately 300 feet downgradient of NBCA-042-001 and the monitoring well near the soil borings (NBCA-505-001) did not detect PCE.

Section 10.5.7 (page 10.5.106), Corrective Measures Considerations, has also been modified to discuss the SWMU 39 plume as the possible source of the groundwater PCE contamination at SWMU 42/AOC 505.

Comment 8:

Page 10.5.36, Section 10.5.5.1

This section states that Arochlor 1260 was above the SSL at soil boring 505SB008. There are apparently no downgradient wells from this soil boring location to verify if groundwater has or has not been impacted. Please address.

Response 8:

The text has been revised (page 10.5.16) to point out that the lower-interval Arochlor-1260 detection (59 µg/kg) did not exceed the SSL. Also, this hydrophobic compound is not typically a groundwater concern because it is practically insoluble in water. As Table 6.1 indicates, the critical range for solubility is 0 to 100 mg/L, with lower values indicating a greater tendency to sorb to soil and be immobile in water. The solubility of Arochlor-1260 is 0.08 mg/L. It is the Navy's belief that a downgradient monitoring well is not necessary.

Comment 9:

Page 10.6.15

This section describes two VOCs were detected in the duplicate sample which was sent to the off site laboratory for analysis. It is not clear which sample the duplicate was collected from or how the results reflect on the quality of the geoprobe data. While both sample results were below the respective RBCs, it is not understood how the groundwater was contaminated by the constituents or if the sample was upgradient or downgradient of the SWMU. Please address.

Response 9:

The text (pages 10.6.10 and 10.6.17) has been modified to indicate that the offsite duplicate sample was collected from upgradient geoprobe location GP002. The "J-flagged" (estimated) detections of acetone and toluene in the offsite sample that were not reported in the onsite sample have no bearing on the onsite data quality for two reasons. First, the toluene detection in the offsite sample approached the onsite laboratory's practical quantitation limit (PQL), resulting in very little difference between the split sample results. There are numerous possible explanations (i.e. sample collection, analytical variability, laboratory artifact, etc.) for this narrow difference in analytical results. Second, acetone was not on the onsite laboratory's target compound list, therefore, the split sample results cannot be compared for this compound. The comment is accurate in that no definitive conclusions can be made regarding the source of these groundwater detections. It is noteworthy, however, that such low detections could be "false-positives", are far below RBCs, and were not detected in four quarters of groundwater samples collected from the downgradient well. The Navy believes that these detections in the

upgradient geoprobe location are not indicative of a site-related problem and do not warrant further investigation.

Comment 10:

Pages 10.7.11 and 10.7.12

There is a discrepancy between the text which states 1,1-trichloroethane was detected in shallow groundwater and table 10.7.5 which lists 1,1-dichloroethane in four groundwater samples. Please revise.

It should be noted that 1,1-dichloroethane is a breakdown product of TCA and was consistently detected in four of four samples in the permanent monitoring well at this SWMU. 1,1-dichloroethane does not have a MCL and all detections were below the RBC of 810 ppb.

Response 10:

Page 10.7.13 has been corrected to indicate that 1,1-dichloroethane was detected in shallow groundwater.

Comment 11:

GRID SAMPLES

This section of the Report states TCE was detected in 8 of 13 soil boring locations. However the levels detected and the locations was not discussed. This may indicate the selected sample locations are not suitable for grid based samples. Please address.

This section of the Report stated that 1,1,1-trichloroethane was detected below the MCL in one of three monitoring wells during one quarters sampling. Neither the text or the tables indicated which well the VOCs were detected in or how the detections may affect the grid sample results. Because there is no explanation of how the groundwater was contaminated with TCA, this detection may require further investigation in the CMS. Please address.

Response 11:

The grid-based data presentation has been reformatted. The new nature and extent subsection parallels other site-specific presentations. Because no fate and transport or risk assessment subsections were completed for the grid-based samples, Tables 10.8.7 and 10.8.8 (pages 10.8.30 through 10.8.39) have been added to provide locations and screening comparisons for all grid-based detections.

Johnny Tapia

(Verbal comments presented at the June 9, 1998 Project Team Meeting)

General Comment

Dioxins should be screened against RBC not EPA RGO.

By project team consensus, Zone A will continue to use 1 µg/kg for dioxin comparison, rather than the residential RBC. The justification for this risk management decision will be provided in Section 11 of the final version of the report. It was also agreed that future zones will use the residential RBC as the default screening concentration for dioxin, with exceptions to the default evaluated on a zone-by-zone basis.

SWMU 1 Comment

If we are to separate SWMU 1 from SWMU 2 then we will need to provide a risk assessment specific to SWMU 1.

A detailed risk assessment for SWMU 1 has been included in the final version of the report. Justification for risk management decisions pertinent to this site will be provided in Section 11.

SWMU 2 Comment

Need to explain why well CNSY-02-05 was abandoned. It presents a problem because numerous hits occurred but were not included in the BRA.

As described on pages 10.2.28 and 10.2.66, CNSY-02-05 was damaged by heavy equipment rendering it unavailable for fourth-quarter sampling. The numerous hits not included in the BRA were from the initial 1993 sample collected after the well was installed. This data is presented in the "nature and extent" portion of the site-specific discussion. As noted on page 10.2.36, turbidity measurements were not taken during the 1993 pre-RFI sampling event although field notes indicate the sample was "gray and cloudy". In order to use the 1993 wells during the RFI, the Final Zones A and B RFI Work Plan specifically called for their redevelopment prior to sampling primarily due to the turbidity issue associated with CNSY-02-05. This well was again noted to be highly turbid and slow to recharge during redevelopment and sampling in December 1995 for the first-quarter RFI sampling event. Redeveloping efforts prior to collecting the first-quarter sample were successful in reducing the turbidity in this well.

As described on page 10.2.66, this data was not included in the risk assessment due to the time-dependence of groundwater samples. Because there is no indication that the 1993 data is representative of current ambient groundwater conditions, it is not appropriate for risk analysis and subsequent corrective measures considerations. The 1995 dataset is considered both adequate and representative.

SWMU 38 Comments

Johnny asked what will be done about the 2400 ppm hit of TPH. Was the hit co-located with a pesticide hit and excavated already?

This TPH detection was in sample 038SB00101, co-located with significant pesticide detections that warranted interim measures at the site. Although the RFI report theoretically precedes interim measures and does not summarize or document IM activities, a reference to the removal of the TPH detection has been added to page 10.3.84 of the final version.

Well NBCA-002-004 was only sampled for metals yet it was not analyzed for all constituents.

NBCA-002-004 was sampled for all parameters outlined in the work plan during the first-quarter sampling event. The omission of pesticide/PCB sampling in subsequent quarterly samples collected from this well is detailed on page 10.3.16 both in the text and as a "deviation" in Table 10.3.5. It is appropriate to include data from this well in the groundwater summary of SWMU 38 because it was adequately sampled during the first-quarter event, which is the most crucial for determining groundwater COPCs at the site.

This oversight is not likely to impact the conclusions or corrective measures considerations for SMWU 38, although one additional pesticide/PCB sample will be collected from this well during the CMS. Also, there is no indication that the pesticides detected in monitoring well NBCA-038-001 are indicative of a large-scale groundwater contamination problem. As detailed in the text, the elevated concentrations in soil boring 038SB001 are a likely source of the pesticide detections and subsequent identification as COCs for groundwater at SWMU 38.

FI/FC - sometimes calculated based on frequency of detection, sometimes based on area. Johnny was used to area. When is it more appropriate to use the different methods?

This comment will be addressed in a brief technical memorandum as it does not require changes to the Zone A RFI Report.

Missing page 59 and 60 from BRA.

These pages are included in the final version of the report (page numbers 10.3.63 and 10.3.64).

SWMU 39 Comments

Do you have any screens that overlap due to shallow depth of the marsh clay? If so what is the potential impact on data?

None of the well screens at SWMU 39 "overlap". There are three well pairs (NBCA-039-008/-08D, -014/-14D, and -015/-15D) and five well clusters (NBCA-039-004/-04I/-04D, -009/-09I/-09D, -010/-10I/-10D, -012/-12I/-12D, and -013/-13I/-13D). The screened intervals for each of these wells are shown on Figure 10.4.30 (page 10.4.137) and the monitoring well construction diagrams are included in Appendix A.

For the groundwater BRA several compounds were excluded. Johnny was okay with everything but 1,2-dibromo-3-chloropropane which was detected 1 of 5 times, Table 10.4.34.

As indicated in Table 10.4.34, 1,2-dibromo-3-chloropropane is identified as a COPC for groundwater at SWMU 39. As described on page 10.4.221, this compound was eliminated as a COC due to its low frequency of detection. The report states that associated risk maps and tables include all COPCs, and the contribution of risk due to this detection is on the second page of Table 10.4.49. Considering the numerous volatile organic groundwater COCs for SWMU 39, additional sampling will be required as part of the CMS. If this compound is detected in future sampling, the frequency of detection will inherently increase, and the compound will be included as a COC.

Table 10.4.31 appears a page is missing. The list of VOCs seems short based on what was in the text.

A complete version of Table 10.4.31 (pages 10.4.167 through 10.4.169) is included in the final version of the report.

Table 10.4.37 some EPCs considered (average data in plume) seem higher than the maximum detected.

Table 10.4.37 (page 10.4.187) has been checked for accuracy and only 1,1,2,2-tetrachloroethane fits this description. The low frequency of detection (1 detection of 108 samples) resulted in the EPC exceeding the maximum detection because one-half the SQL was substituted for the non-detects.

Table 10.4.51 some MCLs missing.

Table 10.4.51 (page 10.4.251) has been revised.

SWMU 39 addition not due to regulatory comment.

During recent review of the database for QA/QC prior to the submittal of the final report, an additional subsurface soil sample was discovered that has not been previously reported. During the installation of NBCA-039-10I, soil was encountered with strong petroleum odor at 3' to 5' bgs. A biased sample of this material was collected and analyzed for VOCs and SVOCs. This sample has been added to the lower-interval dataset. Due to the omission, the final version of the report contains significant detail of both sample collection and results (pages 10.4.2, 10.4.5, 10.4.6 and 10.4.16).

**South Carolina Department of Health and Environmental Control
Comments on Draft Zone A RFI Report
Site-Specific RFI Discussions for SWMUs 1, 2 AND 39.
Dated August 19, 1997**

SCDHEC Comments Dated November 5, 1997

Comment 1:

For SWMU 2, detections at the former wetland should be compared to soils Risk Based Screening levels (RBCs) and zone A reference concentrations. This should be corrected on table 10.2.10.

Response 1:

Data for these samples collected from the former wetland has been removed from the sediment section (including Table 10.2.10) and incorporated into the surface soil data set. See Tables 10.2.5 (new addition) and 10.2.6 (former 10.2.5) in the revised report for the requested comparisons. Also, a paragraph specifically detailing this change has been added on page 10.2.8.

Comment 2:

It seems that the information contained on tables 10.2.24 and 10.2.25 are switched. Table 10.2.24 appears to have commercial industrial assumptions, while table 10.2.25 appears to be for residential assumptions.

Response 2:

The information in these tables has been switched to match the correct title. Because a new table was created for organic soil data at SWMU 2 (Table 10.2.5), these tables have been renumbered (see Tables 10.2.25 and 10.2.26 in the revised report).

Comment 3:

The calculations made using the Adult Exposure Model for lead should be included in the final report. The information included should be able to provide enough detail so the Department would be able to verify assumptions and results obtained.

Response 3:

The calculation used to determine lead cleanup levels based on the Adult Lead Model have been provided in the revised report on page 10.2.74. Currently, the Project Team are in the process of agreeing on parameters to be used in the Adult Lead Model. The original number used in the Draft Zone A RFI has not been changed in the Final Zone A RFI. Once the Project Team has reached agreement on parameters to be used in the Adult Lead Model, errata pages can be issued for the Final Zone A RFI.

Comment 4:

Page 10.53 states that site-specific soil screening levels were calculated using a Dilution Attenuation Factor (DAF) of 14. The final report should include the calculations and assumptions used to obtain site-specific SSLs and DAF. Identical request is made for travel-time analysis which is mentioned on page 10-54. All the requested information should be detailed, clear and has to be included in the final report.

Response 4:

Following the Technical Subcommittee meeting on February 9, 1998, Johnny Tapia and Paul Bergstrand of SCDHEC and Ron Severson of EnSafe agreed that a DAF of 10 was appropriate for determining soil to groundwater SSLs for Zone A. Section 6.2 of the revised report provides details of the fate and transport screening process. Section 6.3 provides a comparison of site conditions with the Soil Screening Guidance default conditions. It is important to note that the background sections for the Zone A RFI report were submitted with the draft version of the report, and not included with the SWMU 1, 2, and 39 document.

Comment 5:

Thallium needs to be identified as a COC at SWMU 2. Its hazard contribution to the future child residential scenario is 0.14. Although the final decision about thallium presence at NAVBASE will be based on the results of a base-wide study, it still needs to be identified as a COPC/COC if the detections/ risk results meet the criteria.

Response 5:

Thallium has been identified as both a COPC and COC for soil at SWMU 2 in the revised report.

Comment 6:

The Department received a set of contour maps dated September 30, 1997 for specific contaminants present at sites in Zone A. This maps should be placed in their corresponding location in the final RFI report. Visual representations of contaminants and their levels are helpful on making decisions about the fate of these sites.

Response 6:

Thirteen contour maps have been included in the nature and extent portion of SWMU 39 (Figures 10.4.13 through 10.4.25). In addition to the set received by DHEC, benzene groundwater contour maps have been added. Also, two contour maps (surface soil lead and surface soil arsenic) have been included in the nature and extent portion of SWMU 2 (Figures 10.2.4 and 10.2.6).

Comment 7:

Page 10-261 states that a DNAPL sample collected on the first round at well NBCA-039-005 was analyzed for VOCs instead of the "requested characterization analyses". This event should be explained further. What are the "requested characterization analyses"? How not getting the expected results affected evaluation and conclusions about the site?

Response 7:

The revised report has been modified for clarity on page Page 10.4.88. Analytical characterization of the unknown material to determine the type of product (e.g. solvent, pesticide, or petroleum) was not performed due to a misunderstanding at the laboratory. The VOC analysis does provide useful information for determining that the product did not contain large quantities of either chlorinated solvent or BTEX constituents. The text in the report was not expanded because the DNAPL was not present during subsequent sampling events and any conclusions would be speculative.

Comment 8:

Table 10.4.22 shows detections of the Geoprobe sampling event. Although this technique is only used as a screening tool it should be discussed how high detection limits could influence the results and the validity of using this screening tool. It was observed that 7 out of 12 Geoprobe sampling locations had a detection limit for Vinyl Chloride higher than the MCL (2 µg/L). How this high detection limits affect the screening process? Was this fact taken into consideration when reaching conclusions about the presence/absence of contaminants? Please provide a discussion of this issues in the final report.

Response 8:

Although the reported detection limit (Practical Quantitation Limit) for vinyl chloride during the geoprobe sampling event exceeds the MCL, detections between the Method Detection Limit and the PQL would have been reported as a detection with a "J" flag. For example, two 1,2,4-trimethylbenzene detections were reported as such in the data set.

Inserting the requested discussion would imply that the data from the geoprobe investigation was used to define the extent of individual contaminants. Instead, the geoprobe data were used to select locations for the second-round installation of monitoring wells. Data from these monitoring wells have been incorporated into the groundwater "nature and extent" section, and the geoprobe data is reported simply for documentation. Ultimately, the coverage provided by the SWMU 39 monitoring wells either delineates a vinyl chloride plume or identifies vinyl chloride data gaps. The Navy believes no data gaps exist for vinyl chloride in shallow groundwater at SWMU 39. Therefore, no additional discussion was added to this section of the revised report.

Comment 9:

Section 10.4.8 makes only mention of analysis/detections on surface water and sediments. This section should provide a more adequate discussion of the findings in these media. This section should compare detections to appropriate levels and reach a conclusion. As written it does not contribute with useful information to the report.

Response 9:

The text on page 10.4.100 has been revised to include a discussion of this data. Because the only VOC detected in these samples, methylene chloride, was detected both infrequently and at much greater concentrations than SWMU 39 groundwater samples, NAVBASE is not a suspected source for the detections in the marsh. Therefore, there is no need for comparison to "appropriate levels" as part of this project.

Comment 10:

(a) Section 10.4.12 "Fate and Transport for SWMU 39" states that the results of groundwater detections (shallow and deep) have been combined and screened as one. Section 10.4.12.1 "Soil to Groundwater Cross Media Transport", for inorganics includes table 10.4.30 where all the maximum detections for surface soil, subsurface soil and groundwater are compared to the highest of soils (surface or subsurface) and groundwater (shallow or deep) reference concentrations. The purpose and/or rationale for this comparison and for choosing the highest levels is not explained in the report.

Detections in surface soil should be compared to soil ingestion RBCs and/or surface soil reference concentrations. Subsurface soil detections should be compared to SSLs and/or subsurface soil reference concentrations. Detections in groundwater should also be compared to their respective shallow or deep reference concentrations. Since we are trying to assess the transport of contaminants from soil to groundwater, it makes sense to use the values calculated for the media directly related to the process.

It is not understood why inorganics are separated into a different table. The SSLs used for screening differ from generic SSLs. The calculations should be submitted for review and the text should clearly identify that site-specific SSLs were used at this site. None of these has been done. This part of the comment also applies to table 10.4.31.

Table 10.4.30 has not been prepared according to the above stated criteria, which reflects approved NAVBASE procedures. The purpose of this table is unknown and confusing. Refer back to table 10.2.11 for SWMU 2, which reflects the usual screening process followed for soil to groundwater cross-media transport. In addition, the conclusions reached, which are based on this unjustified approach should be revised and modified if

necessary. Table 10.4.30 and related sections should be modified to follow the approved approach.

Response 10:

(a) This comment was a discussion point of the February 9, 1998 meeting following the Technical Subcommittee meeting and subsequent conference calls between Johnny Tapia, Paul Bergstrand, and Ron Severson. In summary, the greater of the shallow and deep background reference concentrations were used for screening in the Fate and Transport and Risk Assessment Sections of the revised report. The rationale for using the greater of the shallow and deep groundwater reference concentrations for screening purposes is provided in Section 6.2 of the revised report. In the Nature and Extent Sections, shallow groundwater data were screened using shallow background reference concentrations and deep groundwater were screened using deep background reference concentrations.

Paragraph 2: Surface soil data were screened as noted in this comment because they were associated with direct contact exposure pathways. When considering indirect exposure pathways, such as soil to groundwater cross media transfer, no distinction is made relative to soil interval since the water has to pass through both, and since there is no physical barrier separating the two soil intervals. Additionally, the soil screening guidance makes no distinction between soil intervals since it considers an evenly contaminated one-half acre parcel where the contamination continues down to the water table in developing SSLs. However, in conference calls following the February 9, 1998 meeting SCDHEC requested that background reference concentrations only be used for comparison purposes, rather than screening purposes, in the soil to groundwater cross-media transfer assessments. For groundwater, since there is no clear physical distinction between the shallow, intermediate, and deep water bearing zones, then no distinction is made between the reference concentration at different water column depths. Since there are no continuous physical barriers to vertical mixing in the aquifer, the highest reference concentration is representative of background conditions regardless of water column depth.

Paragraph 3: The organic and inorganic fate and transport screening tables have been separated to allow for an additional comparison to background reference concentration to be presented on the inorganic screening table. A memo was provided to Johnny Tapia on February 18, 1997, for his review. The memo presented the SSL partitioning equation and identified all of the terms in the equation, giving their equation symbols and their sources. It also provided sample SSL calculations for acetone (a VOC with a low K_{oc} value) and benzo(a)pyrene (an SVOC with a high K_{oc} value). On March 5, 1997, EnSafe informed Johnny Tapia via e-mail that the secondary source of some of the data values (K_{oc} and Henry's law constants) for the SSL calculations had been changed from the source identified in the memo (a TNRCC document) to the Superfund Chemical Data Matrix (SCDM), as recommended in the

USEPA Soil Screening Guidance. The screening process used for fate and transport is provided in Section 6.2 of the revised report.

Paragraph 4: The screening process and table format used in the fate and transport analysis for Zone A was discussed via a conference call between Johnny Tapia of SCDHEC and Ron Severson of EnSafe. SCDHEC requested that additional information (i.e. frequency of detection and mean concentration) be added to the fate and transport screening tables. This was not done because this information is provided in the nature and extent section. Instead, the fate and transport tables refer to the appropriate nature and extent tables for these data.

Comment 11

Section 10.4.12.2 does not present a discussion of the possible groundwater to surface water cross-media transport. Instead this section focuses on groundwater contamination and migration. This section should be more directed towards its purpose with a clear discussion of how contaminated groundwater could affect or has already affected surface water.

Response 11

A detailed discussion of the hydrogeology of the surficial aquifer is presented for SWMU 39 in Section 10.4.11 of the revised report. Potential surface water receptors (Cooper River and Noisette Creek) are provided in Section 10.4.11. Comparison and discussion of AWQCs has been added to Section 10.4.12.2.

Comment 12

Section 10.4.13.2 and table 10.4.32 present the selection process for COPCs in soils. For carcinogenic PAHs, it was noted that for B(a)P and Dibenzo(a,h)anthracene analysis, the lowest sample quantitation limit (SQL) was higher than their respective soil ingestion RBCs. This section needs to note this situation and discuss how detection limits at higher levels than the RBCs would affect sampling results. This section also states that only a few detections happened, but if the SQL is lowered there is the possibility that the frequency of detection would increase. Higher SQLs could also affect the calculation of BEQs, which is the value we use to make remedial decisions. Please provide a complete discussion of this issues on this part of the report.

Response 12

A complete discussion of how sample quantitation limits are managed, including use of estimated concentrations for non-detected analytes, is provided in the Zone A revised report, Section 7.3.3, Management of Site-related Data. It is important to note that the background sections for the Zone A RFI report were submitted with the draft version of the report, and not included with the SWMU 1, 2, and 39 document.

Comment 13

(a) Same as previous comment. On table 10.4.33 the SQL for Arsenic, Antimony and Thallium are higher than their respective Tap water RBC equated to a HQ of 0.1. In the case of Antimony and Thallium the SQLs are higher than their respective MCLs. Include a discussion of how this event would affect the assessment at this site.

(b) In addition , the rational for screening detections in groundwater against the highest of either shallow or deep groundwater reference concentrations should be provided.

(c) The COPCs on table 10.4.33 have not been identified with an asterisk and some of them were not identified as COPCs based on the low frequency of detection, but they also had high detection limits that could have allowed them to escape the screening process. Please provide a complete discussion of this issues. If SQLs are higher that the screening levels we cannot eliminate COPCs based on the low frequency of detection assumption; even more so when some sample locations indicate that such chemical may be present.

Response 13

(a) *It is still possible to detect analytes at concentrations below SQLs, but above method detection limits (MDLs), and report them as "estimated" with a 99 percent confidence level. Depending on matrix interferences, it is also possible to detect analytes at concentrations below the MDL and above the instrument detection limit (IDL). These results would also be flagged as estimated, but at a lower confidence level. For example, the Navy recently requested its laboratories conduct MDL vs. SQL studies. Southwest Laboratory reported that its MDLs for antimony and thallium are 1.6 µg/L (MCL = 6 µg/L) and 5 µg/L (MCL = 2 µg/L), respectively. Thus, the lab could detect antimony at concentrations below the MCL, but not thallium. If matrix interferences prevent the lab from detecting thallium at concentrations between the IDL and MDL or SQL, there is little that can be done about this because it is a matter of limitations of available technology.*

(b) *See Response 10*

(c) *RAGS allows for the elimination of parameters that are reported in less that 5% of samples collected if there is no reason to believe that they are present in other media. The parameters that were eliminated from the formal groundwater risk assessment that had SQLs above screening criteria were not detected in any other media. Additionally, subsequent quarterly sampling did not reproduce these parameters. However, to address the uncertainty resulting from the elimination of these parameters from the formal risk assessment, point risk estimates were provided for all COPCs in the risk summary section. This approach allows the formal risk assessment to focus on the obvious concerns regarding SWMU 39 groundwater while still*

providing risk-based tools for making decisions regarding the less apparent groundwater concerns.

Comment 14

There is a new proposed approach to obtain the Exposure Point Concentrations for chemicals in groundwater at SWMU 39. This "plume approach" should have been first proposed to SCDHEC to allow the Department the opportunity to become familiar with it before it is used in the preparation of a report. The Department has not had the opportunity to review the guidance document mentioned in the report to verify assumptions, site conditions needed, etc.. Averaging the four quarters of data on wells located in "the most concentrated area" of the plume appears to be a less conservative approach than the previously used. At this time, this approach should not be used until the Department has had the opportunity of reviewing the mentioned guidance document. NAVBASE has to remember that any new approach that differs from a previously approved one, and is less conservative, needs previous approval by the Department before is used.

Response 14

Dr. Ted Simon (USEPA Region 4) has indicated that the methods used to determine the groundwater EPCs for SWMU 39 were consistent with USEPA Region 4 guidance. He also mentioned that South Carolina was present at the unveiling of the RAGS Supplemental Guidance which was the basis for the EPCs determination used for SWMU 39 groundwater. It is apparent that the reference to determining groundwater EPCs provided in the guidance is vague at best, and is subject to interpretation. As a result of the Technical Subcommittee meeting on February 9, 1998, 95% UCLs were used as EPCs for COPCs that could not be associated with distinct plumes and the mean in the most concentrated area of the plume was used as EPCs for COPCs that could be associated with a plume. Plume maps have also been provided in the revised report to support "most concentrated area of the plume" determinations. Some plumes were isolated to one monitoring well. In these cases no graphical presentation was provided.

Comment 15

Thallium should be included in the list of COCs for the groundwater ingestion pathway at SWMU 39. The ongoing base-wide study will be considered at the time of making risk management decisions. Detection of chemicals in excess of MCLs should still go to a risk assessment and if meets the criteria, be identified as COC. In this instance, thallium should be a COC, although it may not require remediation based on the results of the base-wide study.

Response 15

Thallium has been added to the list of COCs for SWMU 39 groundwater.

Comment 16

Page 10-360 "Risk Uncertainties" explains the selection of Exposure Point Concentrations (EPCs) for groundwater, based on a "plume approach". It is unclear how the "most concentrated area" is chosen from the total investigated area of a SWMU and how individual plumes areas are separated. How wells contributing to the calculations are chosen? Is there a minimum number of wells needed to have a good "plume" approach?

As stated in previous comments, the Department needs to approve any new method proposed for use at NAVBASE. Until then NAVBASE should continue the use of 95% UCL on the mean to choose a value for the (EPC).

Response 16

See Response 14

Comment 17

Table 10.4.48 contains the point estimates of risk and hazard for all the sampling event at SWMU 39. For groundwater, wells 6-12 seems to have been sampled only during the fourth round of sampling and wells 13, 14, and 15 seem to have been sampled only during the first round of sampling. Other wells show sampling at different quarters.

Since SWMU 39 had a series of groundwater sampling events that started at different times, it should be appropriate to add a table that details rounds of sampling with sampling dates for every shallow, intermediate and deep wells. It also should include projected dates for future quarterly sampling. A table with this condensed, tabulated information will be useful to determine if the report present results based on complete or incomplete quarterly sampling, and when it is expected to be complete. Include in this table wells which data is used on risk calculations.

Response 17

Table 10.4.4 provides a summary of the SWMU 39 groundwater investigation timeline of events (including sampling events). Also, tables 10.4.5 through 10.4.19 summarize data for each well, well pair, or well cluster. The footnotes for each of these tables detail the event in which each was sampled. Since the draft submittal of SWMUs 1, 2, and 39, all quarterly sampling has been completed and the data incorporated into the revised report. Risk and hazard map presentations for SWMU 39 groundwater present the maximum risk and hazard for each location regardless of groundwater sampling round.

Response 3:

Since the review of the draft version of the report, many issues have been resolved by the Project Team, including the issue raised by this comment. The agreed upon background concentrations have been included in the appropriate sections of the revised report.

SPECIFIC COMMENTS:

Comment 4:

On page 5-2 it is stated that (TEQ) dioxin concentrations will be screened using the value 1 $\mu\text{g}/\text{kg}$ for a worker industrial scenario. The Department has always maintained the position of comparing contaminant concentrations to values that will be protective of a residential scenario, as stated in the Bureau Assessment and Remediation criteria. A TEQ concentration that corresponds to a 1 E-6 residential risk value should be used for screening purposes.

Response 4:

The Dioxin cleanup level of 1 $\mu\text{g}/\text{kg}$ was provided by USEPA Region 4 in the "Review of the Final RCRA Facility Investigation Report for Zone H" (South Carolina DHEC Cover Letter Dated May 6, 1996), USEPA general comment # 3 (Attachment 1).

Comment 5:

Section 5.2.10 "Background Values" includes tables 5.2, 5.3, and 5.4 with the calculated UTL reference concentrations for surface soils, subsurface soils and groundwater, respectively. A column with the RBC values should be included in the table that calculates the UTLs for surface soil. A column with the corresponding SSLs should be included in the table that calculates the UTLs for subsurface soils and finally the values of the corresponding MCLs should be included on the table where reference concentration values for groundwater are calculated. The inclusion of these values will help the reviewer to determine if proposed reference concentrations are within a reasonable range of established protective concentrations of contaminants.

Response 5:

Tables 5.2, 5.3, and 5.4 have been amended to include the requested regulatory criteria.

Comment 6:

Table 6.2 lists screening values used to evaluate fate and transport. The value used for Dioxin as TCDD TEQs is 2000 $\mu\text{g}/\text{kg}$ for the soil-to-groundwater transfer pathway and 5 $\mu\text{g}/\text{L}$ for groundwater screening. How these values were obtained? If these values were obtained from

some reference, it should be cited. If these values were calculated, they should be submitted for review.

Response 6:

The values shown in Table 6.2 were 2,000 ng/kg and 5 pg/L. The K_{oc} and H' have been revised since the submittal of the Zone A Draft RFI which has resulted in a slightly different SSL for Dioxin.

The following calculation was used:

$$SSL = C_w (K_d + (\theta_w + H'\theta_a)/P_b) , \text{ where:}$$

C_w	=	3E-08 mg/L (MCL for 2,3,7,8-TCDD equivalent) * DAF
DAF	=	10 (assumes 30-acre site; continuous source, dilution only)
K_d	=	$K_{oc} * f_{oc}$
K_{oc}	=	2,650,000 L/kg
f_{oc}	=	0.002 (default)
θ_w	=	0.3 (default)
H'	=	0.0032
P_b	=	1.5 kg/L (default)
θ_a	=	0.13 (default)

Therefore:

$$SSL = 3E-08 \text{ mg/L} * 10 (5,300 \text{ L/kg} + (0.3 + 0.0032*0.13)/1.5 \text{ kg/L}) = 0.00159 \text{ mg/kg} \\ = 1,600 \text{ ng/kg [to 2 significant figures]}$$

The groundwater screening value of 5 pg/L was obtained from the RBC Table.

Comment 7:

Section 6.2 "Fate and Transport Approach for Zone A."

On this section. on page 6-16 it is stated that generic soil screening levels will be used for comparison to concentrations in soil that will be protective of the soil-to-groundwater pathway. Although the Department agrees that site-specific analysis will produce higher soil screening levels and that some assumptions may apply, it is still expected from the Navy to compare standard assumptions from generic SSLs to the specific conditions of the site. In this section it is stated that SSLs will be chosen with a DAF=10. How has this been determined.

This section should include a table with the comparison of generic SSLs standard conditions and the conditions at the specific site, justifying the soil screening levels chosen.

Response 7:

Following the Technical Subcommittee meeting on February 9, 1998, Johnny Tapia and Paul Bergstrand of SCDHEC and Ron Severson of EnSafe agreed that a DAF of 10 was appropriate for determining soil to groundwater SSLs for Zone A. Section 6.2 of the revised report provides details of the fate and transport screening process. A comparison of site conditions with the Soil Screening Guidance default conditions has been added to the revised report as Section 6.3.

Comment 8:

Page 7-11 "Comparison of Site-Related Data to Background Concentrations:"

This section states, "The statistical method used to determine background concentrations and compare to site related data was approved for use in Zone A on May 12, 1995." This statement is misleading. The statistical approach used to calculate background concentrations was approved to be used in the preparation of the Zone H RFI Report as a test to see if the values obtained were realistic. To date, there are still questions about the values obtained by using this statistical approach. In fact, the review of Zones B and H RFI reports brought up some concerns about the use of the data and calculations. Until a consensus is reached on the values to be used as background reference concentrations this statistical approach should not be considered approved.

Response 8:

Revised background reference values for Zone A were discussed and approved by SCDHEC during project team technical subcommittee meetings on April 7 and April 25, 1997, and in a phone call between Johnny Tapia of DHEC and Barry Doll of EnSafe on April 22, 1997. The background value for thallium in groundwater has not been finalized pending a basewide study by DHEC.

Comment 9:

In Section 8.10, page 8-48:

This Department believes that the analysis of ecological Risk at Zone A has shown a low risk present for soil infaunal organisms and terrestrial wildlife species, specifically the American Robin for inorganic contaminants such as copper, lead, cadmium, and mercury. There is also a possible risk present to vegetation due to copper, lead, and zinc. These risk values, however, were calculated using maximum concentrations present at the Area of Ecological Concern A-1, therefore it is agreed that the calculated risk could have been low if mean concentrations of contaminants

would have been used in the analysis of risk. Therefore, the recommendation of no further work due to only ecological receptors in subzone A-1 is accepted. However, a question is raised according to table 8.2, in which all but two inorganic elements were considered as Ecological Contaminants of Potential Concern (ECPC). Many of them were detected at concentrations above the UTLs for Zone A and are presumed to be related to SWMU 2. Could these concentrations of inorganics affect human populations in any hypothetical scenario?

Response 9:

Since the review of the draft version of the report, the Human Health Risk Assessment for SWMU 2 has been completed and reviewed (SWMUs 1, 2, and 39 submittal). This data has been incorporated into the risk assessment.

Comment 10:

Section 10.1.7.1 Soil Data gaps, confirms that there is a need for completing the approved sampling in the Work Plan. Six soil borings were not collected because of radiological studies happening at that time. These samples should be collected to have a clear picture of the contamination present at the site. In addition, the existing subsurface data gaps should be filled for the sampling event that happened in 1986. Additional sampling may be required to define the nature and extent of contamination at this site.

Response 10:

Since the review of the draft version of the report, the soil data gaps at SWMU 2 have been filled. Data from 16 additional hand auger locations (upper and lower interval sampling) have been incorporated into the site-specific presentation which has been reviewed (SWMUs 1, 2, and 39 submittal).

Comment 11:

The Department agrees with the recommendations in section 10.1.8.

Response 11:

The Navy acknowledges this statement.

Comment 12:

Page 10-78 of the "Exposure Point Concentrations:" section, states that FI/FC terms were applied to the EPCs of contaminants as DDT, DDE, and DDD, as well as for Aroclor-1260 and Beryllium. There is a vague explanation on the obtention of these FI/FC terms. A small table including the parameters used for the calculation of these terms and assumptions should be

included in the report. If values or basic approach are obtained from some reference material, it should be cited in the text.

Response 12:

FI/FC terms were calculated in accordance with Supplemental Guidance to RAGS, Region IV Bulletin. The text has been revised (page 10.3.38) to clarify that the FI/FC calculations are based on the frequency of detections.

Comment 13:

The Department agrees with the recommendation in section 10.3.8. Once all the data are collected, the extent of the plume is defined horizontally and vertically, then Fate and Transport, Human Health Risk Assessment and Corrective Measures Study sections should be submitted, if possible, in the final version of this report.

Response 13:

Since the review of the draft version of the report, these sections for SWMU 39 have been completed and reviewed (SWMUs 1, 2, and 39 submittal).

Comment 14:

On page 10-237, "Frequency of Detection and Spatial Distribution" section:

This section compares the maximum detected concentration of arsenic in SWMU 42/AOC 505 with the background concentration of arsenic in Zone B. What is the purpose of making this comparison? This report is about sites in Zone A and should be compared to background concentrations in Zone A. Zone A characteristics and specific conditions are different than those of Zone B. The statement that makes the above mentioned comparison should be deleted from the report.

Response 14:

The mention of the Zone B arsenic background concentration has been eliminated from the revised report.

Comment 15:

Section 10.4.7 "Corrective Measures Considerations:"

The Department agrees with the COCs identified in soil and shallow groundwater for SWMU 42/AOC 505, and the recommendation to fully delineate the extent of BEQs contamination

in the southern middle portion of the combined area of SWMU 42/AOC 505. In addition the last statement of this section makes reference to SWMU 38; this statement should be corrected or deleted.

Response 15:

The text has been corrected.

Comment 16:

The Department agrees with the recommendation in Section 10.5.8. It is recommended to install a shallow monitoring well downgradient from SWMU 43 that will serve to collect data, as required by Department's policy, and confirm if VOCs are present in the shallow groundwater. The results of this sampling should be included in the final report.

Response 16:

The well has been installed and four-quarters of analytical data have been included in Section 10.6.3 of the revised report.

Comment 17:

Table 10.7.6 shows the results of grid-based inorganics detection in shallow and deep groundwater. Thallium was repeatedly detected in the same well (GDAGW03D) in the three different sampling events for deep groundwater at concentrations ranging from 17 $\mu\text{g/L}$ to 163 $\mu\text{g/L}$, which are much higher than its MCL value of 2 $\mu\text{g/L}$. These results show signs of possible contamination of the deep groundwater for thallium, the that specific well, and therefore cannot be used to calculate a background reference concentration. Additionally, the reference concentration was calculated and was based only on the highest detection. Why were the other sampling events not taken into consideration?

The analytical data and calculations of the reference concentration on the deep groundwater for thallium should be revised and the possibility of contamination considered.

Response 17:

Thallium has been reported in numerous groundwater samples collected throughout NAVBASE at concentrations above its MCL. This issue is currently being discussed by the Project Team. As a result, a thallium background concentration for groundwater was not used in the Zone A report.

Comment 18:

Section 11.6 "AOC 506" includes table 11.4 as the "Conclusion Summary." This table has been labeled as SWMU 38 Conclusion Summary. The header of this table should be corrected.

Response 18:

The table has been corrected.

Paul Bergstrand

GENERAL ISSUES:

Comment 1:

There is an absence of sample of site-specific contaminant tables showing analytical detects only and contaminant maps showing separate or groups of analytical detects only in this document. These tables and contaminant maps are strongly recommended in the EPA RFI Guidance and should be included in this document. Because the RFI does not provide these items it becomes very difficult and time consuming for a reviewer to comprehend and independently confirm site conditions.

Response 1:

The process by which CPSSs are reduced to COPCs was established earlier in the Comprehensive Work Plan.

In an environment such as NAVBASE it is impractical to define the extent of every CPSS, particularly since most of the CPSSs are not present as a result of the past site activities for which the site was sampled. Numerous compounds, particularly polyaromatic hydrocarbons, are present across NAVBASE as a result of being in an industrial area. These are often detected in samples collected during a SWMU or AOC investigation. EnSafe considers the reduction of CPSSs to COPCs through comparison to risk-based screening concentrations and upper tolerance limits to be a practical approach to identifying areas that may present unacceptable risk, and as such, be considered in the risk assessment process.

In order to provide reviewers with more detail regarding all organic CPSSs, a set of tables was prepared and delivered to SCDHEC listing every organic chemical detection for every soil sample collected in the Zone A RFI at that time.

The revised report includes, as an appendix, CPSS tables for all detections in soil and groundwater in Zone A. Also, contaminant distribution maps have been included in the nature and extent sections of the Zone A site-specific discussions for select contaminants.

Comment 2:

Site maps provided do not show the boundaries of SWMUs or AOCs. In addition, important site features such as pipelines, tanks, drainage ditches are not represented.

Response 2:

The RFA and the zone-specific RFI work plans included figures with approximated site boundaries. The intent of the RFI was to define site boundaries based on the results of sample

analyses. As discussed in previous Project Team meetings, the distribution of site-related compounds at most of the SWMUs and AOCs does not lend itself to mapping. Instead, mapping of chemical risk/hazard was proposed as a viable alternative to mapping chemical concentrations. The resulting risk/hazard contours provide the best approximation of site boundaries relative to human health or ecological risk/hazard. Where site features are considered critical to the investigation, they have been presented on the figures.

Comment 3:

Sample analysis was limited in second-round samples from SWMUs, AOCs, and grid-based monitoring wells even though low levels of contaminants might have been detected. This is contradictory to EPA RFI Guidance.

Response 3:

The practice of limiting analytical parameters has been the subject of previous SCDHEC comments which were resolved in previous Project Team meetings. As a result of these meetings, Section 2 of the Comprehensive Project Management Plan was revised July 30, 1996 to explicitly describe the procedure. These revisions were reviewed and approved by both EPA and SCDHEC personnel. The Zone A 60% progress meeting (February 1996) served as the forum for analyte reduction discussion. This was documented in the March 11, 1996 technical memorandum for Zones A and B – Second Round RFI Sampling.

Comment 4:

At some sites, the full extent of contamination has not been defined and at other sites the source of groundwater contamination is unknown. These issues may be resolved with the review of site-specific contaminant tables.

Response 4:

This comment is closely related to the concern raised in comment 1 since there appears to have been a difference in opinion of first defining what constitutes "contamination" and secondly, is it defined by concentration or risk levels.

The Navy was under the impression that the project team will define contamination as described in the Comprehensive RFI Work Plan. The project team has also agreed that the "full" extent of contamination does not mean sampling to non-detect levels so the real question becomes whether the site is "adequately" characterized to make CMS or no further action decisions. With the incorporation of additional data from sampling events subsequent to when these comments were received, the Navy believes the sites have been adequately characterized to make CMS decisions.

Comment 5:

A detailed review and comments on this report will be provided once the general issues are addressed and resolved.

Response 5:

The Navy acknowledges this statement.

Naval Base Charleston
Response to South Carolina Department of Health and Environmental Control
Comments on the Draft Zone A RFI Report
September 12, 1996 Version

SCDHEC Comments Dated April 4, 1997

Johnny Tapia

GENERAL COMMENTS

Comment 1:

The organization of Zone A RFI Report has improved in comparison to previous documents reviewed. By presenting general investigative procedures and concepts in earlier sections of the report and site-specific analysis and interpretation of data in one section, makes easier for the reviewer to follow the flow of information and reach a conclusion on a site-by-site approach. The use of colors in the maps also helps to reflect what is tabulated and gives the reviewer a better idea of the spatial distribution of contaminants across a given site.

Response 1:

No response required.

Comment 2:

If the organization part of the report has improved, there are still questions about justifying certain assumptions and/or the source of certain values proposed to be used for screening purposes. Assumptions should be justified in the text of the report by comparing conditions at the site against conditions required to meet in the corresponding guidance. When assuming that certain value is applicable to a specific site/area it should be shown by calculations, graphs, etc., specially if these values will be used as a screening level to eliminate contaminants from further evaluation.

Response 2:

Where applicable, justification for using comparison values in relation to Zone A sites has been included in the revised report.

Comment 3:

Background reference concentrations values for some inorganic constituents are under review at the moment. Once these reference concentration values are approved by the Department, they should be used in the correction of sections of this document that may be affected by the new values adopted.



Commissioner: Douglas E. Bryant

Board: Richard E. Jabbour, DDS, Chairman
Robert J. Stripling, Jr., Vice Chairman
Sandra J. Molander, Secretary

John H. Burtas
William M. Hull, Jr., MD
Roger Leake, Jr.
Burnet R. Maybank, III

Promoting Health, Protecting the Environment

CERTIFIED MAIL

Return Receipt Requested

May 6, 1996

Commander Phil Dalby
Officer in Charge, Caretaker Site Office
Naval Facilities Engineering Command, Southern Division
Building NH-45
Charleston Naval Base
Charleston, SC 29408-2020

Re: Draft Zone H RCRA Facility Investigation
(RFI) Report, Dated December 27, 1995
Charleston Naval Base
SC0 170 022 560

Dear Commander Dalby:

The South Carolina Department of Health and Environmental Control (Department) and the U.S. Environmental Protection Agency (EPA) have reviewed the above referenced Draft Zone H RFI Report in accordance with applicable State and Federal Regulations, and the Charleston Naval Shipyard's Hazardous Waste Permit, effective June 5, 1990. Based on this review Charleston Naval Base has not adequately fulfilled the requirements of Permit Condition IV.C.4.

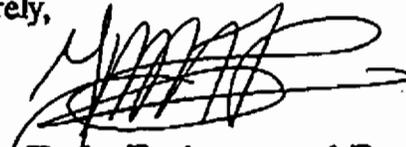
The Department reiterates its commitment to cleanup contaminated sites throughout South Carolina to residential cleanup levels. Industrial cleanup levels will only be acceptable when an agreement has been reached and approved by the Department and the facility can demonstrate that appropriate and effective institutional controls can be maintained at the site.

Attached are comments provided by the U.S. Environmental Protection Agency and the Department. Within thirty (60) days upon receipt of this letter, please make the specified changes and resubmit the Report to the Department and U.S. EPA for review.

Letter dated
May 06, 1996
Page Two

Should you have any questions regarding this issue, please contact me at (803) 896-4179.

Sincerely,



Johnny Tapia, Environmental Engineer Associate
Hazardous Waste Permitting Section
Bureau of Solid & Hazardous Waste Management

Attachments

cc: Paul Bergstrand, Hydrogeology
Rick Richter, Trident EQC
Brian Stockmaster, SOUTHNAVFACENGNCOM
Tony Hunt, SOUTHNAVFACENGNCOM
Doyle Brittain, EPA Region IV

**ENVIRONMENTAL PROTECTION AGENCY COMMENTS ON THE DRAFT
RESOURCE CONSERVATION AND RECOVERY ACT FACILITY INVESTIGATION
REPORT FOR ZONE H**

GENERAL

1. The groundwater sampling forms indicate a number of samples with high levels of turbidity. EPA recommends that samples having a turbidity of 50 NTU or greater be checked against those samples' metals concentrations. If the data indicate that these are correlated, it is recommended that the wells be re-sampled (re-developed if necessary) to determine the actual metals concentrations.

2. The human health risk assessments are greatly improved from the previous submission. This is in no small part credited to the willingness of the Contractor to work closely with EPA in "hammering out" the text and format of these risk assessments in December, 1995. The result is that procedural issues of the risk assessments have been dealt with and, thus, this review will concentrate on substantive risk and policy issues.

3. Cleanup Level for Dioxin (2,3,7,8-TCDD and congeners) Previously, EPA had suggested that a cleanup level of 1 ppb in soil is considered protective in a residential scenario. The basis for this statement was the peer-reviewed paper, Kimbrough RD, Falk H, Stehr P, Fries G (1984) Health Implications of 2,3,7,8-Tetrachlorodibenzodioxin (TCDD) Contamination of Residential Soil. *J. Tox. Env. Health* 14:47-93. The endpoint considered in this study was hepatocellular carcinoma. A slope factor approach was not used; rather, the study compared estimates of the lifetime average daily dose to dose-response relations from specific animal studies.

EPA now considers the slope factor approach to be more appropriate. Therefore, EPA has derived a cleanup level of 1 ppb for a worker/industrial scenario. Although this cleanup level is the same numerically as previously suggested, the derivation is considerably different.

The equation and values used are given below:

$$C_{soil} = \frac{IR \cdot AT \cdot BW}{EF \cdot ED \cdot [(CSP_{oral} \cdot CF \cdot IR_{soil}) + (CSP_{inhalation} \cdot IR_{air} \cdot 1/PEF) + (CSP_{dermal} \cdot CF \cdot SSA \cdot SAP \cdot ABS)]}$$

Assumptions for the Worker Scenario			
C ₁	Concentration in Soil	mg/kg	
TR	Target Risk	(unitless)	
AD	Averaging Time	365 days	
BW	Body Weight	70 kg	
EF	Exposure Frequency	250 day/yr	
ED	Exposure Duration	25 years	
CF	Conversion Factor	1E-06 (mg/kg-day)	
IR ₁	Ingestion Rate for Soil	50 mg/day	
IR ₂	Inhalation Rate	20 m ³ /day	
TEF	Particulate Emission Factor	4.79E-05 (m ³ /kg)	
SSA	Skin Surface Area Exposed	4300 cm ²	
SAF	Skin Adherence Factor	1.0 mg/cm ²	
ABS	Dermal Absorption Factor from Soil	1%	
CSF ₁	Oral Cancer Slope Factor	1.5E+05 (mg/kg-day)	HEAST, 1995
CSF ₂	Inhalation Slope Factor	1.5E+05 (mg/kg-day)	HEAST, 1995
CSF ₃	Dermal Cancer Slope Factor	3.0E+05 (mg/kg-day)	50% absorption efficiency

The dermal CSF was determined using the method in Appendix A of RAGS with the Region 4 default absorption value for SVOCs.

The SSA is considered as the hands, arms and head.

The table below provides the cleanup levels for Dioxin Toxic Equivalents (TEQs) at three levels within the acceptable risk range.

Risk Level	10 ⁻⁶	10 ⁻⁵	10 ⁻⁴
2,3,7,8-TCDD TEQ (µg/kg or ppb)	0.014	0.14	1.4

For convenience, the value at a risk level of 1E-04 has been rounded down to 1 ppb for use as an appropriate cleanup level. None of the dioxin samples obtained in Zone H was above 1 ppb TEQ, and hence, no dioxin-specific cleanup is anticipated.

This value of 1 ppb is quite similar to that of 2.5 ppb presented in the pending Record of Decision at the Koppers site, also in Charleston, South Carolina. The cleanup level at the Koppers site is also based on a worker/industrial scenario.

In anticipation of questions raised regarding the use of the upper end of the risk range, this risk management option seems a prudent course in light of the uncertainty about dioxin exposure levels at which adverse effects occur. EPA

Region 4 has sanctioned 1E-04, the upper end of the risk range, as a risk management option at other sites in the region. The same decision is typically made by hazardous waste managers in other EPA Regions.

4. **The Use of Summaries in Chapter 9**
These summaries were very good for providing a precis of each SWMU or AOC. They should be repeated in the CMS, and in lieu of providing information on unacceptable risks in the residential scenario, they should indicate the estimated risks in the worker/industrial scenario. Based on the estimated risks in the worker/industrial scenario, the treatment in the CMS may be abbreviated. For example, SWMU 14, SWMU 15, AOC 670, AOC 684, SWMU 19, SWMU 20, SWMU 121, AOC 656, AOC 653, AOC 654, AOC 659, AOC 660, AOC 662, AOC 665, AOC 667/SWMU 138, and SWMU 159 need only minimal treatment in the CMS.
5. **Methods for Background Comparison**
The background comparison was performed according to the method previously agreed to in the Technical Memorandum dated June 8, 1995. EPA has had several conversations with the Contractor in this regard and the document has been improved in this area.
6. **The Ecological Risk Assessment (ERA) for Zone H follows the basic approach that the Contractor and EPA agreed to during a meeting in Atlanta. However, the main concern is that the ecological risk assessment does not present sufficient information to make a decision concerning the possible need for corrective action at different Areas of Concern (AOCs) or SWMUs (Solid Waste Management Units). Some of the comments given below recommend steps needed to make the ERA more useful as a decision-making tool.**
7. **A few of the comments given below address the need for a more adequate response to EPA's comments on the previous draft of the Zone H RFI Report. Most of the remaining comments pertain to the Ecological Risk Assessment (ERA), since an ERA was not included in the previous draft.**

SPECIFIC

1. Page 4-147, Section 4.6.1.5 - Given the operational history of SWMU 20, additional soil samples should be collected and analyzed for metals.
2. Page 9-30, Section 9.17 - The last paragraph states that:

Due to the hydrophobic nature of dioxins, they would be expected to migrate from soil to groundwater.



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
17 August 1998

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: SUBMITTAL OF DRAFT ZONE A RCRA FACILITY INVESTIGATION REPORT

Dear Mr. Litton:

The purpose of this letter is to submit the Draft Zone E 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.

Previous comments have been discussed with Department and EPA personnel and responses prepared based on those discussions. 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 (843) 743-9985 and (843) 820-5525 respectively.

Sincerely,

A handwritten signature in cursive script that reads "W. A. Drawdy for".

H.N. SHEPARD II, P.E.
Caretaker Site Officer
By direction

Encl: (1) Draft Zone A RCRA Facility Investigation Report
Copy to:
SCDHEC (Paul Bergstrand, Johnny Tapia), USEPA (Dann Spariosu)
SOUTHDIV (Matthew A. Hunt),
SPORTENVDETCNASN (Bobby Dearhart)

**ZONE A
RCRA FACILITY INVESTIGATION REPORT
NAVBASE CHARLESTON
NORTH CHARLESTON, SOUTH CAROLINA**

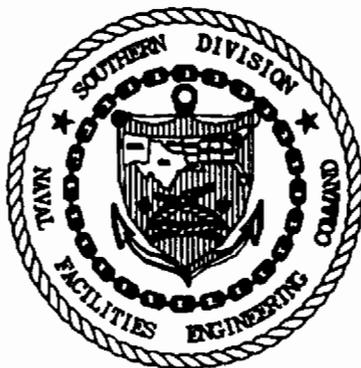


**Volume I of V
Sections 1 to 9**

**CTO-029
Contract Number: N62467-89-D-0318**

Prepared for:

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



Prepared by:

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

**August 7, 1998
Revision: 0**

Release of this document requires prior notification of the Commanding Officer of the Southern Division, Naval Facilities Engineering Command, North Charleston, South Carolina.

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Source: RCRA Facility Investigation Report
 Zone A (April 14, 1998)

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE A

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
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
BCT	Base Closure Team
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	Benzene hexachloride
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
CEERD	Charleston Environmental and Engineering Remediation Detachment
CERCLA Liability Act	Comprehensive Environmental Response, Compensation, and
CF	Calibration Factor
CFR	Code of Federal Regulations

Abbreviations, Acronyms, and Symbols for NAVBASE Zone A (Continued)

CLEAN	Comprehensive Long-Term Environmental Action Navy
CLP	Contract Laboratory Program
cm/sec	Centimeters per second
CMI	Corrective Measures Implementation
CMS	Corrective Measures Study
CNS	Central Nervous System
CNSY	Charleston Naval Shipyard
COC	Chemical of Concern
COPC	Chemical of Potential Concern
cPAH	Carcinogenenic 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
DAF	Dilution Attenuation Factor
DCAA	2,4-Dichlorophenylacetic acid
DCE	Cis-1,2-dichloroethene
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyl-trichloroethane
DNAPL	Dense Non-Aqueous Phase Liquid
DOD	Department of Defense
DQO	Data Quality Objectives
DRMO	Defense Reutilization Marketing Office
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
ED	Exposure Duration
EF	Exposure Frequency
EMPC	Estimated Maximum Possible Concentration
EOD	Explosive Ordnance Disposal
EPC	Exposure Point Concentration
ERA	Ecological Risk Assessment
ESA	Ecological Study Area
ESDSOPQAM	Environmental Services Division Standard Operating Procedures and Quality Assurance Manual

Abbreviations, Acronyms, and Symbols for NAVBASE Zone A (Continued)

FC	Fraction Contacted
FFI	Focused Field Investigation
FI	Fraction Ingested
FID	Flame ionization detector
ft ² /day	Square feet per day
GC/MS	Gas Chromatography/Mass Spectrometry
gpm	Gallons per minute
g/cm ³	Grams per cubic centimeter
g/mole	Grams per mole
GPS	Global Positioning System
GRO	Gasoline Range Organics
HASP	Health and Safety Plan
HEAST	Health Effects Assessment Summary Tables
HHRA	Human Health Risk Assessment
HI	Hazard Index
HL	Henry's Law Constant
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
IDW	Industrial Derived Waste
ILCR	Incremental Lifetime Excess Cancer Risk
ILO	Indeterminate Lubricating Oil
IRIS	Integrated Risk Information System
IRP	Installation Restoration Program
IS	Internal Standard
kg/mg	Kilogram per milligram
kg/hr	Kilogram per hour
kph	Kilometers per hour
LC ₅₀	Lethal Concentration to 50 percent of test population
LCS	Laboratory Control Sample

Abbreviations, Acronyms, and Symbols for NAVBASE Zone A (Continued)

LD ₅₀	Lethal Dose to 50 percent of test population
LDR	Land Disposal Restriction
L/kg	Liter per kilogram
LMW	Low Molecular Weight
LNAPL	Light Nonaqueous Phase Liquid
LQAC	Laboratory QA Coordinator
LTTD	Low-Temperature Thermal Desorption
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
meq/L	Milliequivalent per liter
mg/kg	Milligram per kilogram
mg/L	Milligram per liter
mg/cm ²	Milligram per square centimeter
mg/m ³	Milligram per cubic meter
ml	Milliliter
mph	Miles per hour
msl	Mean sea level
MS/MSD	Matrix Spike/Matrix Spike Duplicate
MW	Molecular Weight
NA	Not Applicable
NAD	North American Datum
NAVBASE	Naval Base Charleston
NCEA	National Center for Environmental Assessment
NCR	NEESA Contract Representative
ND	Nondetect
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 Observed Adverse Effect Level
NPDES	National Pollutant Discharge Elimination System
NR	Not Reported
NRC	National Research Council
NTP	National Toxicology Program
NTU	Nephelometric Turbidity Unit

Abbreviations, Acronyms, and Symbols for NAVBASE Zone A (Continued)

OERR	Office of Emergency and Remedial Response
OIA	Other Impacted Area
OP	Organophosphorus
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
PCT	Porphyria Cutanea Tarda
PDE	Potential Dietary Exposure
PE	Performance Evaluation
PEM	Performance Evaluation Mixture
pg/g	Picogram per gram
pg/L	Picogram per liter
POL	Petroleum, oil, and lubricant
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
QA/QC	Quality Assurance/Quality Control
Qc	Quaternary clayey sand
Qdm	Quaternary dewatered marsh clay
Qg	Quaternary gravel
Qm	Quaternary marsh clay
Qp	Quaternary peat
Qs	Quaternary sand
RAB	Restoration Advisory Board
RADCON	Radiological Control
RAGS	Risk Assessment Guidance for Superfund
RBC	Risk-Based Concentration
RBSL	Risk-Based Screening Level
RC	Reference Concentration
RCRA	Resource Conservation and Recovery Act

Abbreviations, Acronyms, and Symbols for NAVBASE Zone A (Continued)

RDA	Recommended Daily Allowance
RFA	RCRA Facility Assessment
RfC	Reference Concentration
RfD	Reference Dose
RFI	RCRA Facility Investigation
RGO	Remedial Goal Option
RME	Reasonable Maximum Exposure
ROC	Run of Crush
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
SFF	Site Foraging Factor
SMCL	Secondary Maximum Contaminant Level
SOP	Standard Operating Procedure
SOUTHDIV	Southern Division Naval Facilities Engineering Command
SPLP	Synthetic Precipitation Leachate Procedure
SQL	Sample Quantitation Limit
SRL	Significant Risk Level
SSL	Soil Screening Levels
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
TCE	Trichloroethene
TCL/TAL	Target Compound List/Target Analyte List
TD-GS/MS	Thermal Desorption-Gas Chromatography/Mass Spectrometry
TD/MS	Thermal Desorption/Mass Spectrometry
TDS	Total Dissolved Solids
TEF	Toxic Equivalency Factor
TEQ	TCDD Equivalency Quotient
TIC	Tentatively Identified Compounds

Abbreviations, Acronyms, and Symbols for NAVBASE Zone A (Continued)

TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TRV	Toxicity Reference Values
TSCA	Toxic Substances Control Act
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
VP	Vapor Pressure
WBZ	Water-Bearing Zone
WQC	Water Quality Criteria
$\mu\text{g}/\text{cm}^2$	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
%R	Percent Recovery
%RSD	Percent Relative Standard Deviation
%D	Percent Difference
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

Abbreviations, Acronyms, and Symbols for NAVBASE Zone A (Continued)

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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 RCRA Corrective Action Program objectives 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 A RFI Report, prepared by EnSafe Inc., 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.

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 occupied areas of the base included Charleston Naval Shipyard, Fleet Ballistic Missile Submarine Training Center, Fleet and Industrial Supply Center, Fleet and Mine Warfare Training Center, Naval Regional Medical Center Charleston, and Naval Station Charleston (Figure 1.2). NAVBASE also included the degaussing station in downtown Charleston, the Shipboard Electronics System Evaluation Facility on Sullivan's Island, and the Naval Station Annex next to the Charleston Air Force Base.

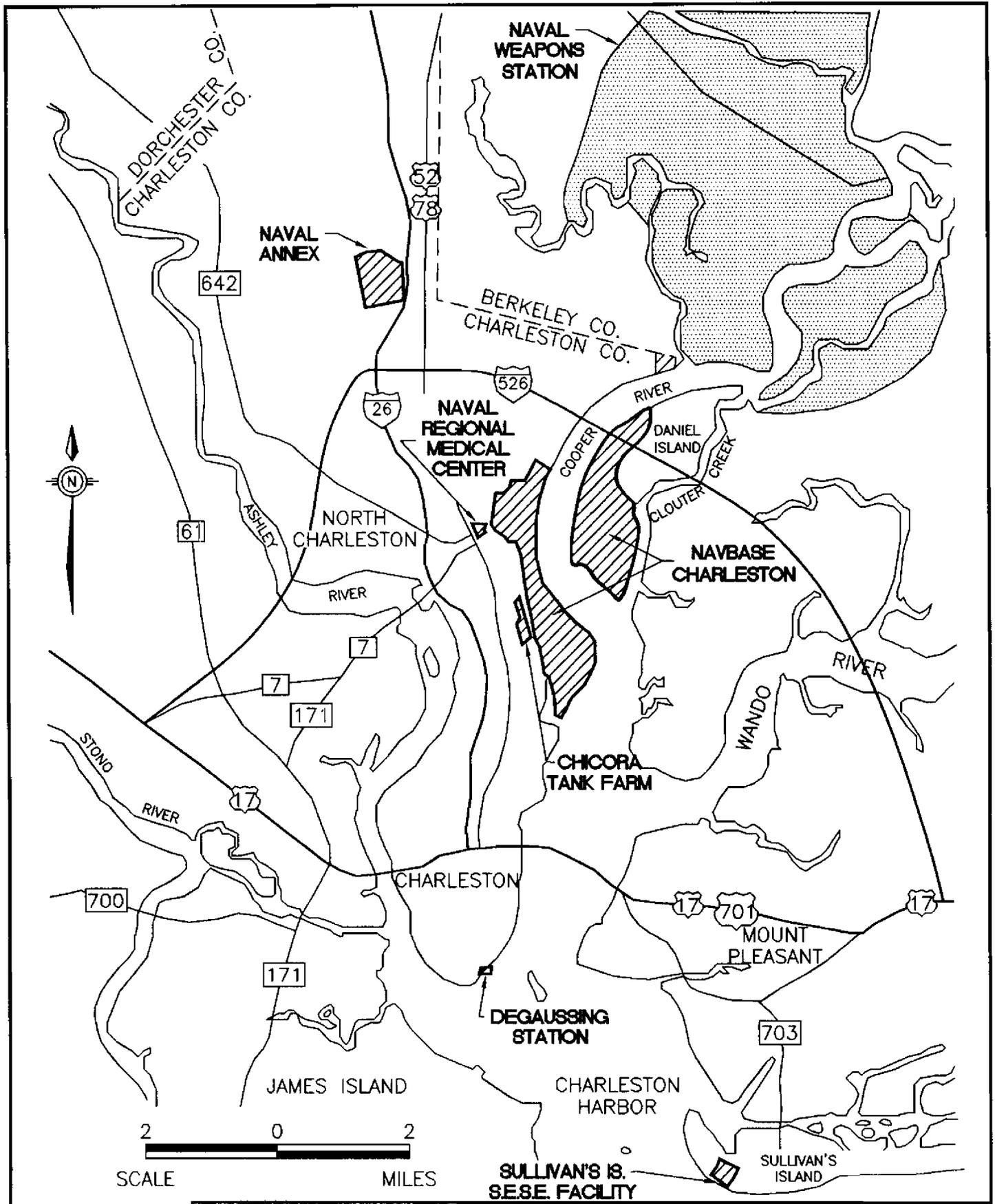
The areas surrounding NAVBASE are *mature urban*, having long been developed with commercial, industrial, and residential land uses. Commercial areas are primarily west of NAVBASE; industrial areas lie primarily north of NAVBASE and along the west bank of Shipyard Creek.

The area west of Shipyard Creek is concentrated with industrial users and has been 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 over 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.

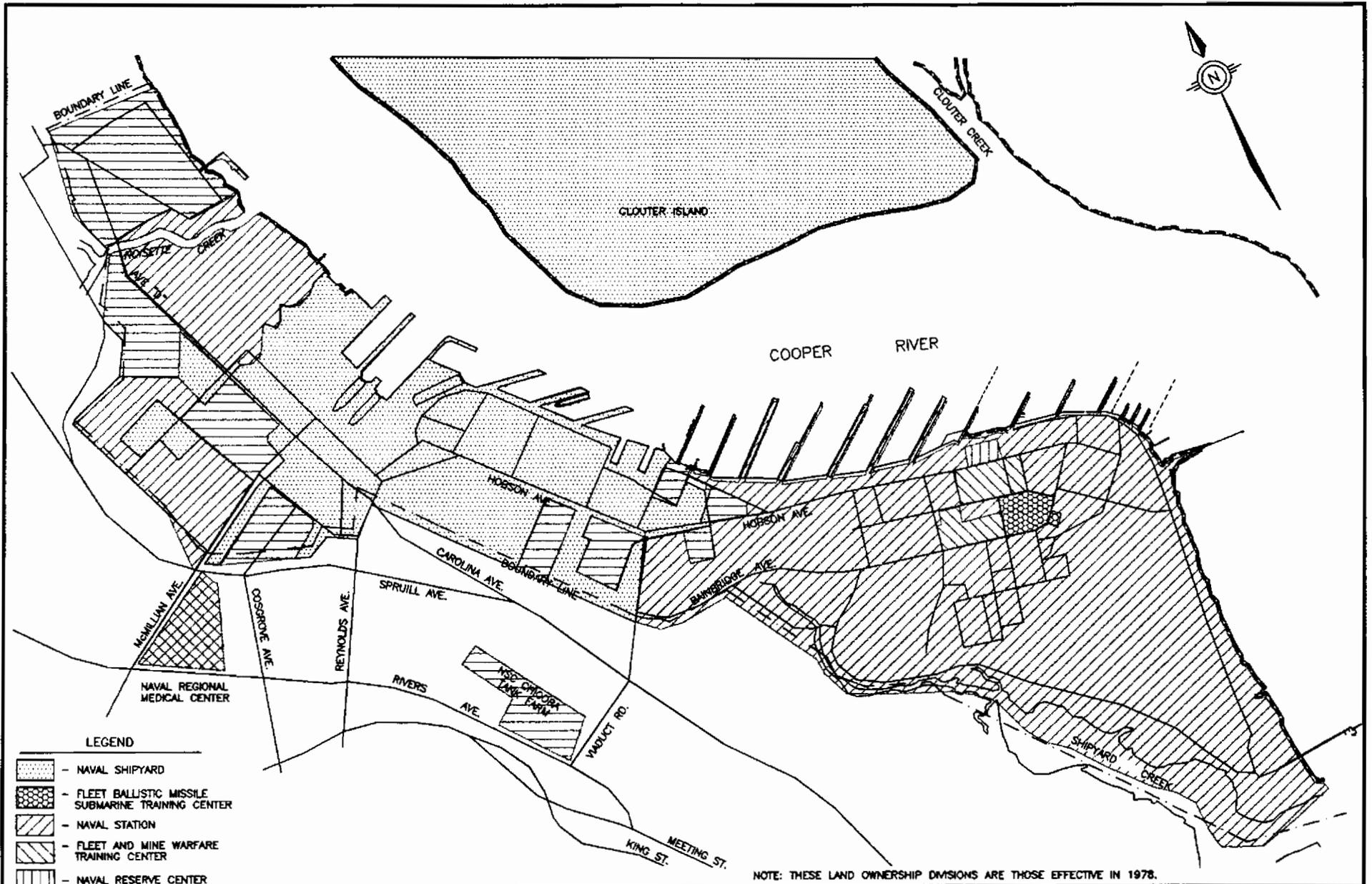
History

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. 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.



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

FIGURE 1.1
 NAVBASE LOCATION MAP
 NAVAL BASE CHARLESTON
 CHARLESTON, SOUTH CAROLINA



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

FIGURE 1.2
 LOCATIONS OF
 LAND HOLDINGS AND OCCUPANTS

DWG DATE: 05/07/98 | DWG NAME: 29EBSLOA

2000 0 2000
 SCALE FEET
 SOURCES: SOUTH DIV, n.d. ESE, 1981.

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 home port for combatant ships and submarines of the U.S. Atlantic Fleet.

Base Closure

In 1993, NAVBASE Charleston was added to the list of bases scheduled for closure under the Defense Base Closure and Realignment Act (BRAC), which regulates the closure and transition of property to the community. Since the April 1, 1996, closure, operations have ceased and environmental cleanup has begun to make the property available for redevelopment.

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

Most NAVBASE environmental cleanup activities are being implemented under RCRA, which was passed by Congress to control handling hazardous materials and wastes and to set standards for hazardous waste generation, transportation, treatment, storage, and disposal.

NAVBASE received 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) and areas of concern (AOCs), resulting from past hazardous waste releases. 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.
- *Corrective Measures Implementation (CMI)*. During this step, 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 (RAB) and the Building Economic Solutions Together (BEST) 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

replaced by the Charleston Naval Complex Redevelopment Authority, which has authority to establish leases for the transferred property.

Zone A is on the northwestern edge of NAVBASE. As shown in Figure 1.4, the zone is bounded by Zone B to the south; the Cooper River to the east; and the NAVBASE property boundary to the west and north. Zone A consisted primarily of light industrial and commercial properties, including the Defense Reutilization Marketing Office (DRMO), and a portion of the former NAVBASE golf course. Zone A properties identified in the *Final Environmental Impact Statement for Disposal and Reuse of the Charleston Naval Base* (Ecology and Environment Inc., June 1995) are to be used for warehouse/storage space, cargo terminal, or maritime industrial.

1.4 Current Investigation

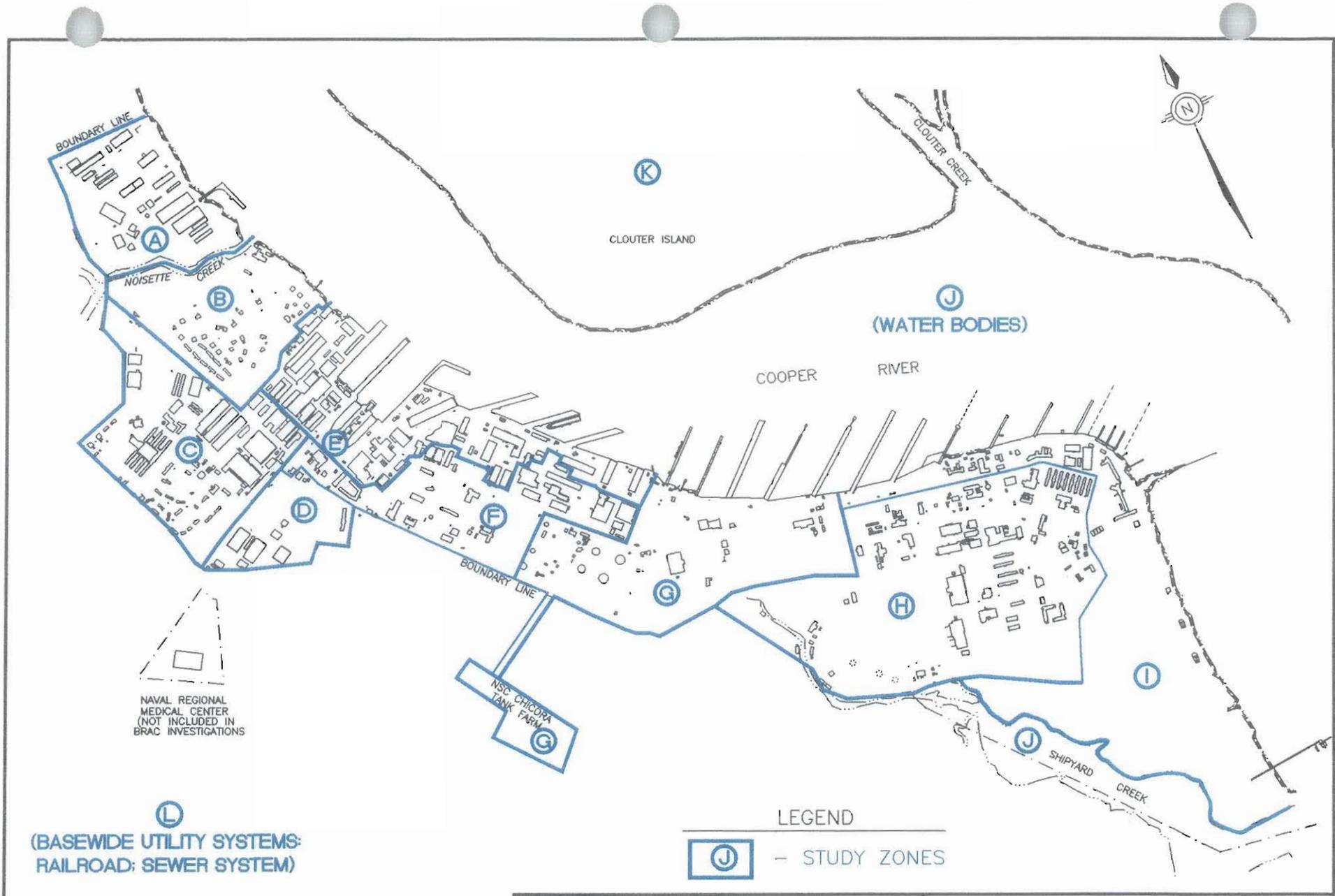
Objective

RFI objectives 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 determined by conducting human health and ecological risk assessments to assess the risks posed to human health and the environment by individual sites or groups of sites within a zone.

Scope

Ten sites were identified in Zone A through the RFA process. Each Zone A site is discussed in detail in the *Final RCRA Facility Assessment* (E/A&H, June 6, 1995).

Recommendations for the investigative approach to be taken at each site were based on the best information available at that time and may have changed as more information became available.



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



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

FIGURE 1.3
INVESTIGATIVE
ZONE BOUNDARIES

DWG DATE: 05/07/98 DWG NAME: 29ZONEA

J WATER BODIES

HESS
TANK FARM



COOPER RIVER

LEGEND

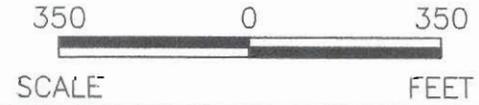
E - RCRA INVESTIGATION ZONES

A

COOPER RIVER

MOORING PILES

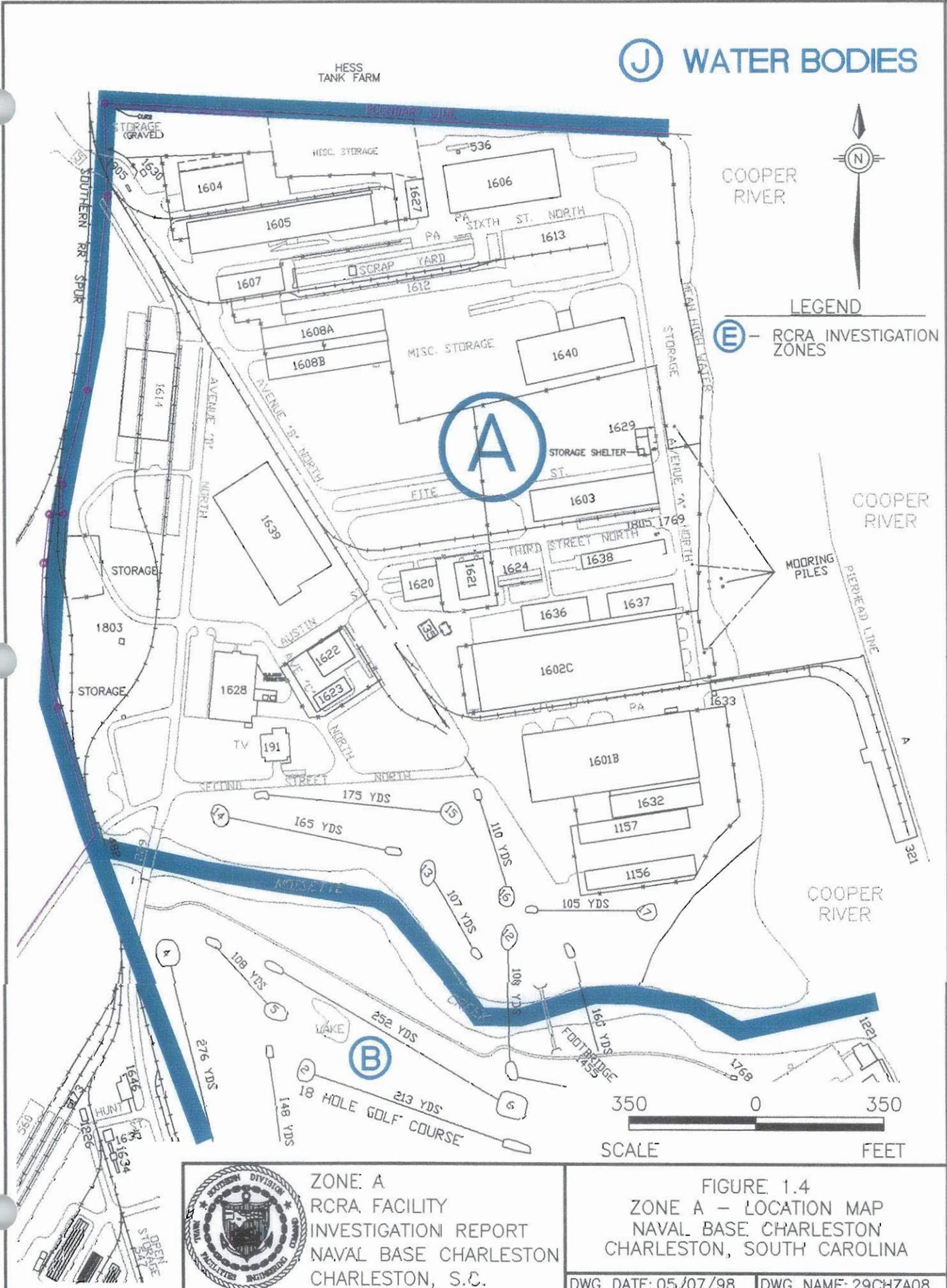
COOPER RIVER



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

FIGURE 1.4
ZONE A - LOCATION MAP
NAVAL BASE CHARLESTON
CHARLESTON, SOUTH CAROLINA

DWG DATE: 05/07/98 | DWG NAME: 29CHZA08



The investigatory designations were 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 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 were needed to determine whether a hazard exists. Confirmatory sampling results were used to determine whether a "no further investigation" designation was appropriate or a full-scale RFI was warranted.

- *RFI* – This approach was used for AOCs or SWMUs if visual evidence, historical information such as spill reports, or analytical data indicated that hazardous substances had been released to the environment. An RFI was used to characterize the site to determine the nature and extent of contamination, to identify migration pathways, to identify actual and potential receptors, and to evaluate ecological and human health risks posed by the site.

Of the 10 SWMUs and AOCs identified, eight required further investigation. The *Final Zones A and B RFI Work Plan* (E/A&H, September 1995) outlined an investigative strategy for each of the eight sites designated for a CSI or RFI. This RFI report only addresses the eight sites included in the work plan. Table 1.1 summarizes each Zone A SWMU and AOC requiring further investigation and its investigative approach.

Table 1.1
 Zone A
 SWMUs and AOCs with Investigatory Designations

Zone A AOCs and SWMUs	Site Description	Investigative Approach	Investigation Grouping
SWMU 1	DRMO Storage Area	RFI	Investigated independently
SWMU 2	Lead Contamination Area	RFI	Investigated independently
SWMU 38	Miscellaneous Storage, North of Building 1605	CSI	Investigated independently
SWMU 39	Former POL Drum Storage, Building 1604	RFI	Investigated independently
SWMU 42 and AOC 505	Former Asphalt Plant and Tanks Creosote Cross-Tie/Ballast Storage Area and Golf Course Maintenance Building	CSI RFI	Sites were investigated together
SWMU 43	Publications and Printing Plant, Building 1628	CSI	Investigated independently
AOC 506	Flammable Storage Shelter, Building 1629	CSI	Investigated independently

Note:

POL = Petroleum, oil, and lubricants

1.5 Previous Investigations

In addition to data generated during this investigation, information from previous Zone A investigations was reviewed for this report and incorporated where appropriate. Previous investigations at SWMU 1 culminated in the certification of clean closure for soil of the DRMO Storage Area. Additional samples were collected during 1993 to corroborate the earlier sampling results. Two soil borings, with two samples each, and one groundwater sample location were sampled for the complete USEPA Contract Laboratory Program (CLP) Target Compound

List/Target Analyte List (TCL/TAL) list. The 1993 data are presented with the data collected during the RFI in this report.

SWMU 2, the Lead Contamination Area, has been the subject of two investigations in which extensive soil, sediment, and groundwater sampling was conducted to delineate the extent of contamination migrating from SWMU 2. In 1986, 71 samples (35 surface and 36 at various depths) were collected. Also, the 1993 investigation included sampling 23 soil borings, five additional monitoring wells, and 11 sediment locations in the storm sewer system and Cooper River. Both datasets are presented in Section 10.1 of this report. The 1986 data are presented as "screening" level data.

Also, several of the six monitoring wells installed in 1993 are in areas that support the investigation of other Zone A sites. Where applicable, these wells were sampled for the site-specific parameters being investigated.

1.6 RFI Report Organization

To facilitate review of the RFI report, sections have been organized to discuss zonewide information, overall technical approach, and evaluation methodologies first. These general sections are sequenced according to the natural progression of an RFI investigation. The zonewide sections are:

- 1.0 INTRODUCTION
- 2.0 PHYSICAL SETTING
- 3.0 FIELD INVESTIGATION
- 4.0 DATA VALIDATION
- 5.0 METHODOLOGY FOR DETERMINING NATURE AND EXTENT OF CONTAMINATION
- 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 RISK MANAGEMENT DECISIONS

followed by:

12.0 REFERENCES

13.0 SIGNATORY REQUIREMENT

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

Section 11 summarizes the conclusions and risk-management considerations from each Section 10 site-specific summary. This organization makes it easy to determine which sites have been recommended for the CMS and which are recommended for no further action. Section 12 is a compilation of references.

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 increments of both solid wastes and dredged materials (primarily the latter) 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 Quaternary-age sands, silts, and clays of high organic content (Weems and Lemon, 1993). Tertiary-age sediments immediately underlie the younger Quaternary-age deposits. Erosional remnants of late Tertiary (Pliocene to Miocene) formations may be encountered at various locations. However, the mid Tertiary-age (Oligocene to Eocene) Cooper Group is pervasive beneath the study area. The Cooper Group consists of the following in increasing age: the Ashley, Parker's Ferry, and Harleyville formations. The formation of particular importance in the Cooper Group is the Ashley Formation, which was previously referred to as the Cooper Marl

in most NAVBASE reports and regional geologic literature. The Ashley Formation is a pale green to olive-brown, sandy, phosphatic limestone or marl, locally muddy and/or sandy. In the Charleston vicinity, the Ashley Formation 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 Group, 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. Much of NAVBASE, particularly the southern portion, 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. Most of the remainder of the base has been either filled or reworked. Native soil is the fine-grained silt, silty sand, and clay typical of terrigenous tidal marsh environments. Sand lenses are present in localized areas, but are generally only a few feet thick in the upper 5 to 10 feet of the subsurface.

2.1.2 Zone A Geologic Investigation

Geological and stratigraphic information for Zone A has been obtained from soil and monitoring well borings installed during the RFI. Similar information has been collected in association with RFI work for Zones H, I, C, E, and B. Lithologic samples acquired using hollow-stem auger, wet/mud rotary, and rotasonic drilling methods were classified and logged by an EnSafe geologist as described in the *Final Comprehensive Sampling and Analysis Plan RCRA Facility Investigation* (E/A&H, August 1994) (CSAP).

The following background discussion of the geologic investigation in Zone A is a summary of the first round well installation, as set forth in the Zone A and B RFI Work Plan, and the second round well installation based on Geoprobe investigation results at SWMU 39. This discussion was initially compiled in September 1996, before the third and fourth rounds of well installation specific to delineating a chlorinated solvent plume at SWMU 39 had begun. Due

to the site-specific nature of these field events, subsequent findings in the geologic and hydrogeologic setting at SWMU 39 are contextually pertinent in Section 10.4. As a result, Section 2.0 remains a summary of the overall geologic and hydrogeologic setting of Zone A as a whole. For additional geologic/hydrogeologic data and interpretation from the third and fourth rounds of well installation, the reader should refer to the discussion of SWMU 39 in Section 10.4.

Twenty monitoring wells (15 shallow and five deep) were installed in Zone A between October and November 1995 during the initial phase of the RFI. Based on the results of a shallow soil and groundwater contamination study using direct-push technology (Geoprobe), seven shallow, one intermediate, and two deep monitoring wells were installed in July 1996 during the second round of well installation. Table 2.1 lists the monitoring wells installed during the first two well installation rounds in Zone A with pertinent information regarding well construction. Third and fourth round well construction data are presented in Table 10.4.27 in Section 10.4.9, since they pertain to SWMU 39. Although installed during the fourth round, shallow well NBCA-043-001 is presented in Table 2.1 as it is unrelated to the SWMU 39 field investigation.

Table 2.1
Zone A Monitoring Well Construction Data

Monitoring Well ID	Date Installed	TOC elevation (msl)	Ground elevation (msl)	Drilled Data (bgs)			Depth to Groundwater* (below TOC)	Groundwater elevation (msl)
				TOS	BOS	BOW		
RFI WELLS								
NBCA-038-001	10/6/95	7.13	7.3	2.6	12.1	12.6	1.27 ^a	5.86 ^a
NBCA-038-01D	11/15/95	7.63	7.8	40.3	49.7	50.2	6.00 ^a	1.63 ^a
NBCA-038-002	10/6/95	8.42	8.6	3.0	12.5	13.0	2.97 ^a	5.45 ^a
NBCA-039-001	10/3/95	13.47	11.1	3.1	12.6	13.1	4.71 ^a	8.76 ^a
NBCA-039-002	10/4/95	14.35	12.1	2.6	12.1	12.6	6.43 ^a	7.92 ^a

Final Zone A RCRA Facility Investigation Report
 NAVBASE Charleston
 Section 2 — NAVBASE Physical Setting
 Revision: 0

Table 2.1
Zone A Monitoring Well Construction Data

Monitoring Well ID	Date Installed	TOC elevation (msl)	Ground elevation (msl)	Drilled Data (bgs)			Depth to Groundwater* (below TOC)	Groundwater elevation (msl)
				TOS	BOS	BOW		
NBCA-039-003	10/4/95	8.64	8.8	2.8	12.3	12.6	2.78 ^a	5.86 ^a
NBCA-039-004	10/5/95	11.72	9.4	3.0	12.5	13.0	5.26 ^a	6.46 ^a
NBCA-039-04D	11/16/95	9.77	9.9	44.6	54.0	54.5	7.62 ^a	2.15 ^a
NBCA-039-005	10/5/95	12.67	10.2	3.0	12.5	13.0	6.12 ^a	6.55 ^a
NBCA-039-006	7/15/96	8.93	9.0	3.0	12.5	13.0	5.02 ^a	3.91 ^a
NBCA-039-007	7/10/96	8.49	8.5	4.5	14.0	14.5	1.61 ^a	6.88 ^a
NBCA-039-008	7/16/96	10.08	7.6	4.0	13.5	14.0	6.15 ^a	3.93 ^a
NBCA-039-08D	7/17/96	10.06	7.6	40.1	49.6	50.1	8.15 ^a	1.91 ^a
NBCA-039-009	7/15/96	9.72	7.4	3.0	12.5	13.0	4.42 ^a	5.30 ^a
NBCA-039-010	7/10/96	13.74	11.2	3.2	12.7	13.2	7.47 ^a	6.27 ^a
NBCA-039-011	7/10/96	15.20	12.7	3.3	12.8	13.3	5.85 ^a Oil 6.20 ^a Water	9.35 ^a Oil 8.99 ^a Water
NBCA-039-012	7/16/96	8.54	8.6	2.6	12.1	12.6	2.52 ^a	6.02 ^a
NBCA-039-12I	7/22/96	8.66	8.7	22.0	31.5	32.0	2.90 ^a	5.76 ^a
NBCA-039-12D	7/22/96	8.56	8.7	46.3	55.8	56.3	6.39 ^a	2.17 ^a
NBCA-042-001	10/7/95	10.09	7.6	2.6	12.1	12.6	6.24 ^a	3.85 ^a
NBCA-042-002	10/7/95	10.47	8.0	2.6	12.1	12.6	6.80 ^a	3.67
NBCA-042-003	10/7/95	10.26	7.7	2.6	12.1	12.6	6.67 ^a	3.59
NBCA-043-001	1/10/97	5.91	6.4	2.5	12.0	12.5	5.22 ^b	0.69 ^b
NBCA-505-001	10/6/95	10.39	7.7	2.6	12.1	12.6	6.88 ^a	3.51 ^a
NBCA-506-001	10/11/95	9.71	9.9	2.8	12.3	12.5	7.99 ^a	1.72 ^a
NBCA-GDA-001	10/11/95	11.45	9.1	2.8	12.3	12.5	9.19 ^a	2.26 ^a
NBCA-GDA-01D	11/15/95	11.33	9.0	25.6	35.0	35.5	9.52 ^a	1.81 ^a
NBCA-GDA-002	10/10/95	8.61	8.8	2.8	12.3	12.5	2.73 ^a	5.88 ^a

Table 2.1
Zone A Monitoring Well Construction Data

Monitoring Well ID	Date Installed	TOC elevation (msl)	Ground elevation (msl)	Drilled Data (bgs)			Depth to Groundwater* (below TOC)	Groundwater elevation (msl)
				TOS	BOS	BOW		
NBCA-GDA-02D	11/17/95	8.53	8.8	39.8	49.2	49.7	7.23 ^a	1.30 ^a
NBCA-GDA-003	10/10/95	9.12	6.6	2.8	12.3	12.5	4.79 ^a	4.33 ^a
NBCA-GDA-03D	11/14/95	8.77	6.3	24.0	33.9	34.4	7.70 ^a	1.07 ^a
RFA WELLS								
NBCA-002-001 ^c	10/5/93	11.54	8.8	4.0	14.0	14.0	9.72 ^a	1.82 ^a
NBCA-002-002 ^c	10/6/93	8.88	8.9	5.0	15.0	15.0	7.76 ^a	1.12 ^a
NBCA-002-003 ^c	10/6/93	11.53	6.8	3.9	13.9	13.9	10.81 ^a	0.72 ^a
NBCA-002-004 ^c	10/6/93	8.00	8.2	3.8	13.8	13.8	3.91 ^a	4.09 ^a
NBCA-002-005 ^c	10/6/93	8.89	8.2	5.4	15.4	15.4	6.70 ^a	2.19 ^a
NBCA-002-006 ^c	10/7/93	11.53	8.6	5.3	15.3	15.3	5.71 ^a	5.82 ^a

Notes:

- TOC = Top of well casing
- TOS = Top of screened interval
- msl = mean sea level
- bgs = below ground surface
- BOS = Bottom of screened interval
- BOW = Bottom of well (end cap)
- * = Depths to groundwater vary seasonally and diurnally. These depths should only be considered approximate.
- a = August 7, 1996 data
- b = January 22, 1997 data
- c = Wells installed in 1993 during the RFA were formerly designated CNSY-02-01 through CNSY-02-06.

Figure 2.1 depicts all Zone A RFI and RFA monitoring well locations listed in Table 2.1. Monitoring well construction diagrams and associated lithologic boring logs are included in Appendix A.

2.1.2.1 Geotechnical

Shelby tubes, collected as part of the RFI drilling program, were analyzed for porosity, bulk density, grain size distribution, specific gravity, percent moisture, and vertical permeability. Thin-wall steel tubes were pushed into undisturbed soil using a truck-mounted drill rig. The steel tubes were recovered, sealed, labeled, and retained onsite until transported to the laboratory for analysis. Shelby tube sample intervals were selected for geotechnical analysis based upon areal distribution, lithology type, and uniformity of sample in order to develop a range of coverage for characterizing the predominant lithologies encountered at Zone A. Additional geotechnical information was obtained from borings advanced at SWMU 39 to provide supplemental grain-size distribution data for greater site-specific evaluation.

Shelby tube sample laboratory data reports are presented as Appendix B. Table 2.2 summarizes the Zone A geotechnical data.

Table 2.2
Zone A Geotechnical Summary

Type	Location ID	Depth (bgs)	Lith Type	K_v (cm/s)	K_v (ft/day)	n	% sand	% silt	% clay
ST	042-003	10-12.5	Qc	5.89E-05	0.167	0.37	—	—	—
ST	GDA-002	10-12.5	Qc	2.82E-05	0.080	0.39	78.0	9.5	12.5
ST	039-008	10-12	Qc	5.41E-08	1.53E-04	0.57	26.0	50.0	24.0
ST	039-012	6-8	Qc	3.85E-06	0.011	0.38	79.0	4.0	17.0
ST	039-12D	32-34	Qc*	2.51E-06	7.11E-03	0.38	73.0	3.0	24.0
MEAN				3.87E-06	0.011	0.42	64.0	16.6	19.4
ST	038-002	11-13.5	Qs	1.54E-03	4.37	0.40	91.3	1.7	7.0
ST	039-001	10-12.2	Qs	1.34E-03	3.80	0.38	91.0	3.6	5.4
ST	039-009	11-13	Qs	9.00E-05	0.255	0.29	91.0	2.5	6.5
J	039-12D	40-42	Qs	—	—	—	96.0	1.5	2.5

Table 2.2
Zone A Geotechnical Summary

Type	Location ID	Depth (bgs)	Lith Type	K_v (cm/s)	K_v (ft/day)	n	% sand	% silt	% clay
J	039-12D	50-52	Qs	—	—	—	88.5	5.0	6.5
J	039-08D	44-46	Qs	—	—	—	95.0	3.0	2.0
J	039-08D	46-48	Qs	—	—	—	95.5	3.0	1.5
<i>MEAN</i>				5.71E-04	1.62	0.35	92.6	2.9	4.5
ST	039-009	11-13	Qp	1.28E-06	3.63E-03	0.80	—	—	—

Notes:

- K_v = vertical permeability
- n = porosity as decimal percentage
- * = Classified Qcs lithology type in Section 10.4.
- ST = Shelby Tube sample
- J = Jar sample

Of the stratigraphic formations described in Section 2.1.1, only the Quaternary and upper Tertiary age sediments were encountered during the Zone A RFI. The lowermost stratigraphic unit identified is the Oligocene-age Ashley Formation of the Tertiary Cooper Group. Above the Ashley lies what are believed to be sediments of the Quaternary Wando Formation and Holocene-age (recent) sediments. These stratigraphic relationships are more clearly defined in four lithologic cross sections constructed across Zone A (Figure 2.2). The cross sections are labeled A-A' (Figure 2.3), B-B' (Figure 2.4), C-C' (Figure 2.5), and D-D' (Figure 2.6) and will be referred to frequently throughout Section 2.0 of this report. A more detailed lithologic cross section was constructed to focus on the subsurface in the vicinity of SWMU 39. This cross section is included in the site-specific discussion of SWMU 39 in Section 10.4.10 (Figure 10.4.30).

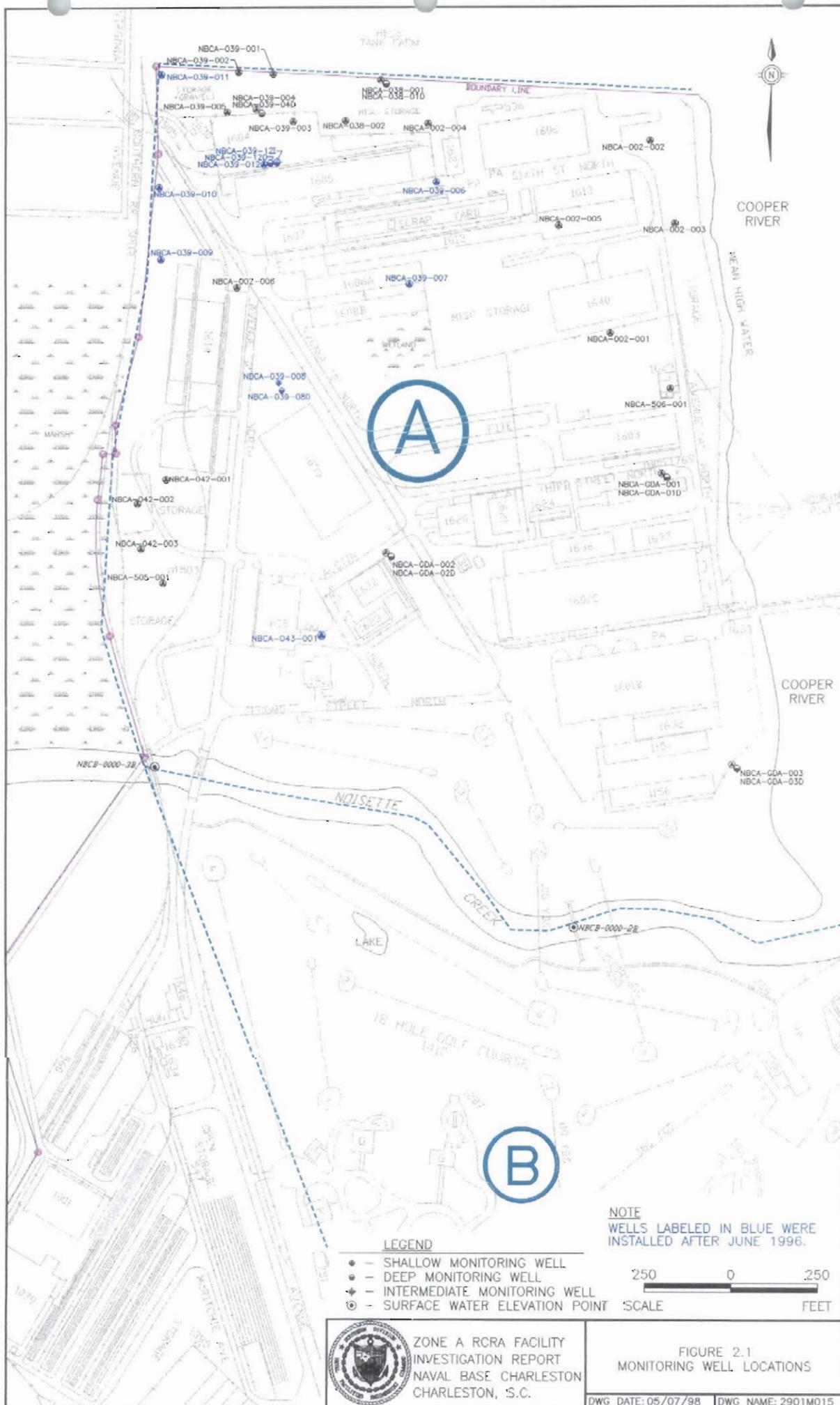
2.1.3 Tertiary-Age Sediments

2.1.3.1 Ashley Formation

The oldest sediment encountered during the Zone A RFI investigation has been the Ashley Formation, the youngest member of the Eocene-Oligocene-age Cooper Group. The Ashley Formation (Ta) was deposited in an open-marine shelf environment during a rise in sea level in the late Oligocene (Weems and Lemon, 1993). The Ashley Formation is an olive-yellow to olive-brown, tight, slightly calcareous, clayey silt with varying amounts of very fine to fine grained sand that decrease rapidly with depth. It is firm to stiff, low in plasticity, and moist to wet. No Shelby tube samples from the Ashley Formation were taken in Zone A; however, seven Shelby tubes were collected from this unit during the Zone E RFI. The average porosity of these samples was 47% with a mean grain size distribution of 30.6% very fine grained sand and 69.4% silt and clay.

Due to successive sea level transgression-regression (rise and fall) sequences during late Tertiary and early Quaternary time, extensive erosion has removed many of the marine and terrigenous deposits overlying the Ashley Formation (Weems and Lemon, 1993). The scoured nature of the upper Ashley Formation is plainly evident in the lithologic cross sections (Figures 2.3 to 2.6) and Figure 2.7, a contour map of its surface. Elevations of the Ashley Formation decrease from east to west away from the Cooper River. The overall relief across the unit's surface in Zone A is 21 feet.

The additional drilling and cone penetrometer (CPT) data collected at SWMU 39 allowed for a more detailed inspection of the Ashley Formation's surface. A contour map using this data is included in the site-specific discussion of SWMU 39 (Section 10.4.10; Figure 10.4.31).



LEGEND

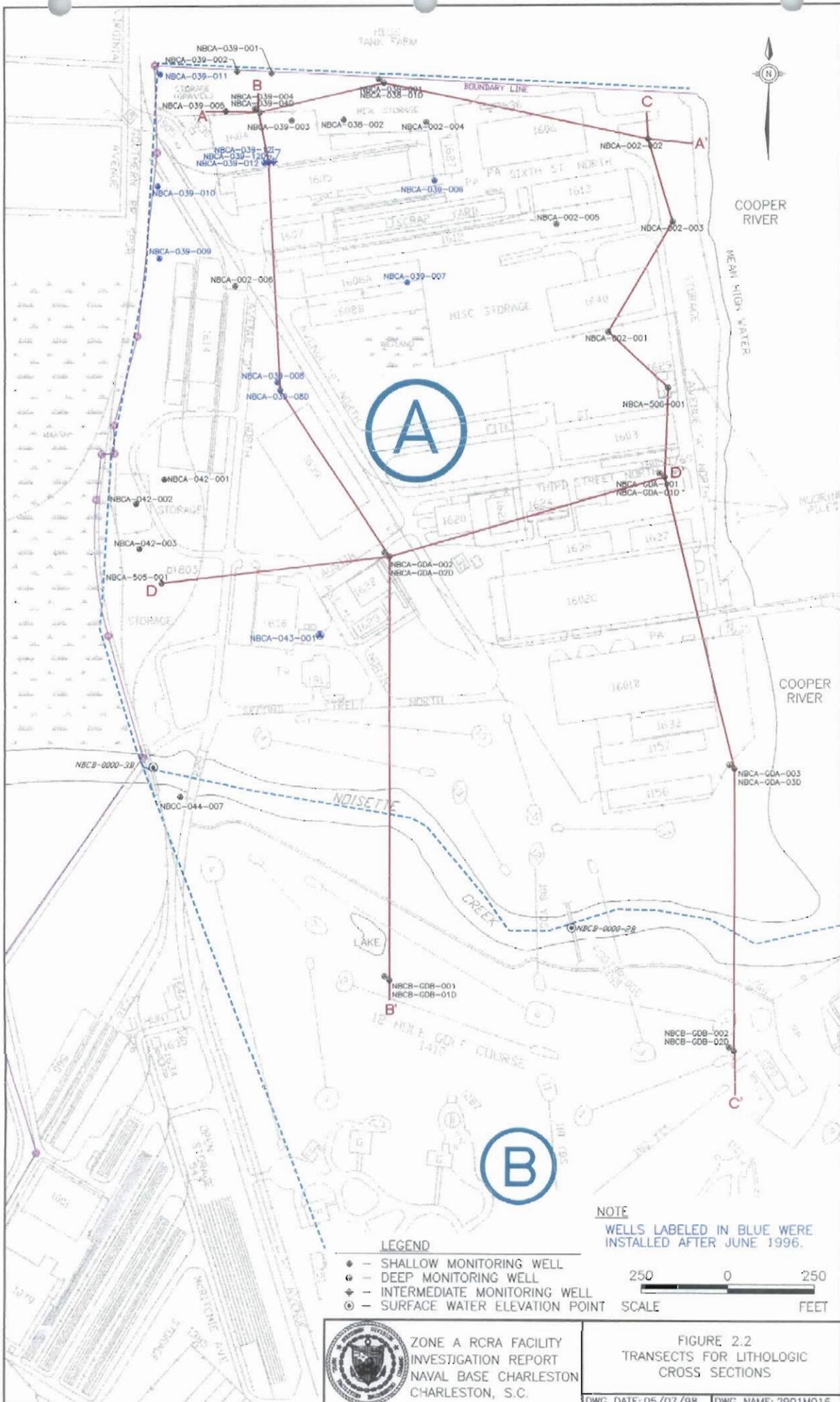
- - SHALLOW MONITORING WELL
- - DEEP MONITORING WELL
- - INTERMEDIATE MONITORING WELL
- ⊙ - SURFACE WATER ELEVATION POINT

NOTE
WELLS LABELED IN BLUE WERE
INSTALLED AFTER JUNE 1996.



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

FIGURE 2.1
MONITORING WELL LOCATIONS



LEGEND

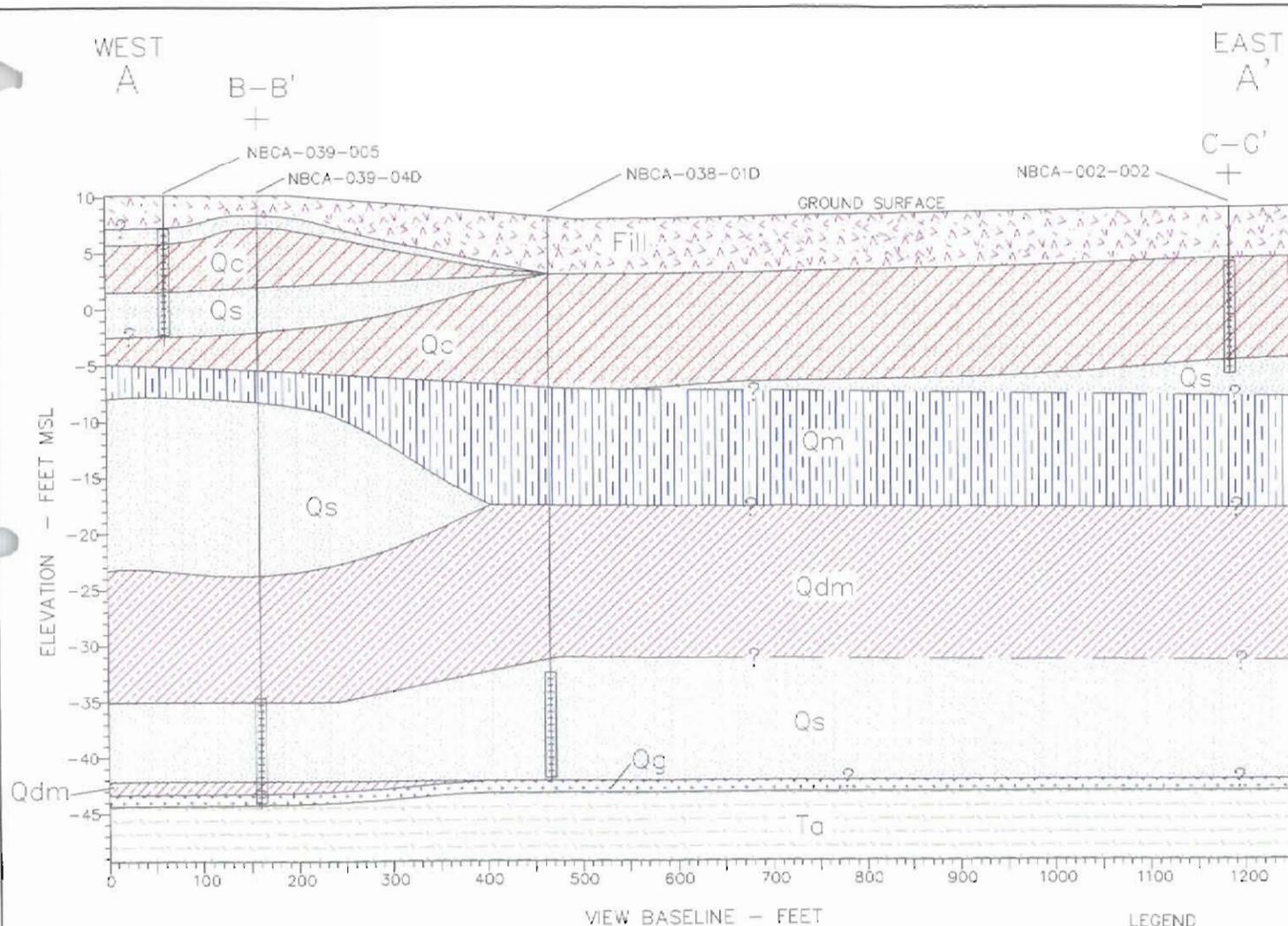
- ◆ - SHALLOW MONITORING WELL
- - DEEP MONITORING WELL
- ⊕ - INTERMEDIATE MONITORING WELL
- - SURFACE WATER ELEVATION POINT

NOTE
WELLS LABELED IN BLUE WERE INSTALLED AFTER JUNE 1996.



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

FIGURE 2.2
TRANSECTS FOR LITHOLOGIC
CROSS SECTIONS



Fill	Undifferentiated mixture of medium to high plasticity clays; fine sand, silt, gravel and ROC. Varies greatly with location.
Up	UNSATURATED PEAT--brown, silty, trace very fine sand, grasses and fibrous woody pieces, soft.
Qc	QUATERNARY CLAYEY SAND AND SILTY SAND--brown, orange-brown, gray, green, and tan, very fine to fine sand often with trace medium grains, varying amounts of silt and inorganic gray clay; often interbedded with medium plasticity, soft gray clay laminae; sand occasionally unconsolidated and loose. AQUIFER
Qm	QUATERNARY MARSH CLAY--dark gray to black, silty, high organic content, with brown grasses and occasional peat; very soft, low plasticity, sticky; occasionally interbedded with very fine to fine sand laminae and pods. AQUITARD
Qs	QUATERNARY SAND--undifferentiated olive-brown, gray, and orange sand; primarily very fine to fine and moderately to well-sorted but typically increases in grain size with depth (from fine to medium with some coarse); clean to silty sand. AQUIFER.
Qdm	QUATERNARY DEWATERED MARSH CLAY--dark green to dark gray, silty, high plasticity, firm to stiff clay; occasionally very fine sand present in very thin laminae and pods. AQUITARD.
Qg	QUATERNARY GRAVEL--gray to dark gray; typically grain-supported subrounded phosphate pebbles up to 2 cm in size and fine to coarse shell hash, silty and clayey fine to coarse sand matrix. AQUIFER.
Tm	TERTIARY MARKS HEAD FORMATION--olive-gray to gray-green silt with varying amounts of very fine to fine quartz and phosphate sand with some clay; low plasticity, soft; intermixed with small subrounded phosphate pebbles, coarse shell hash, and oyster shells.
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.

- LEGEND
- WELL SCREEN INTERVAL NOT INCLUDING FILTERPACK
 - CROSS SECTION INTERSECTION
 - GEOLOGIC CONTACT INFERRED



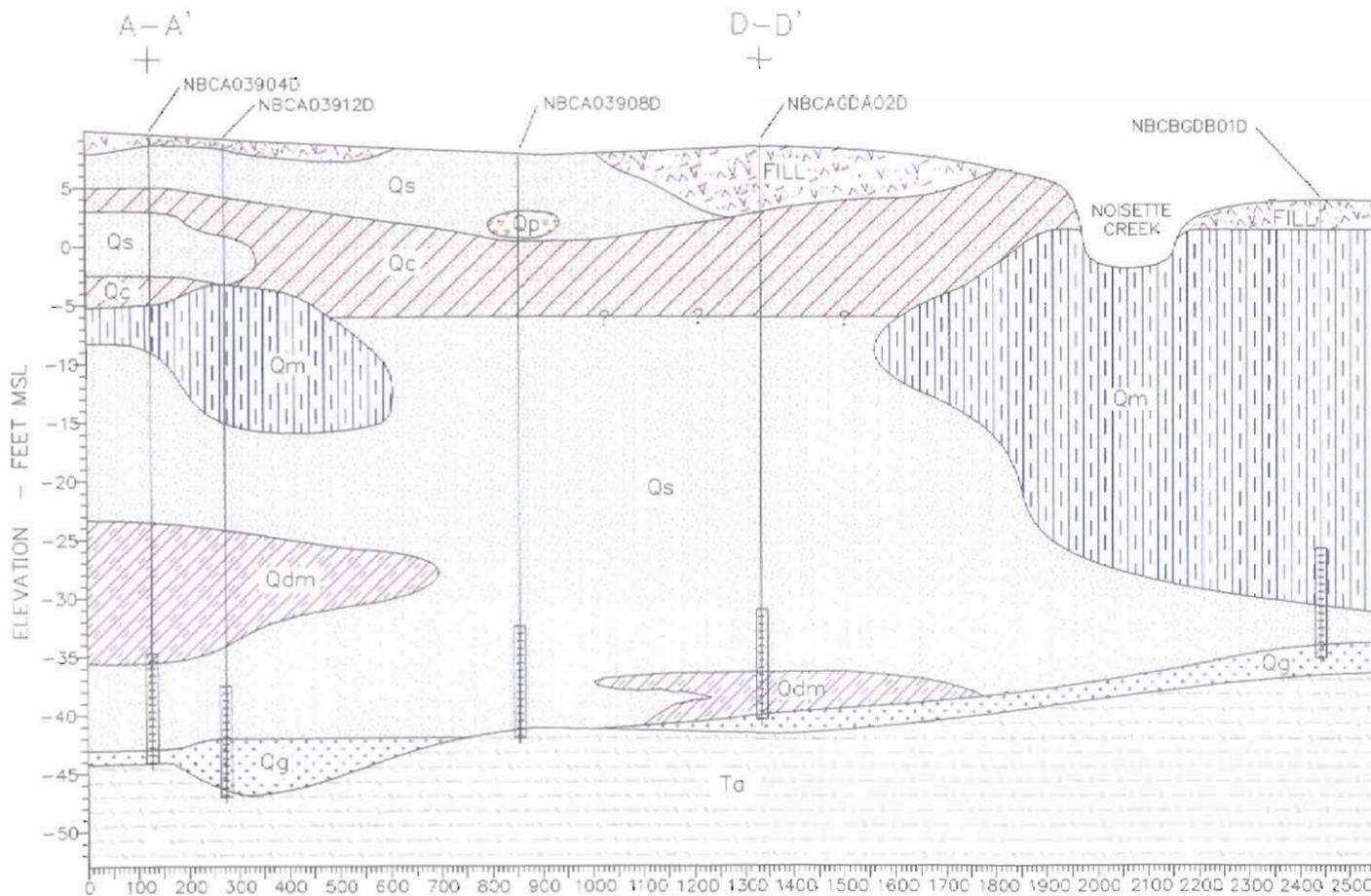
ZONE A RCRA FACILITY
INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.

FIGURE 2.3
LITHOLOGIC CROSS SECTION
A - A'

DWG DATE: 02/25/98 DWG NAME: 2901M017

NORTH
B

SOUTH
B'



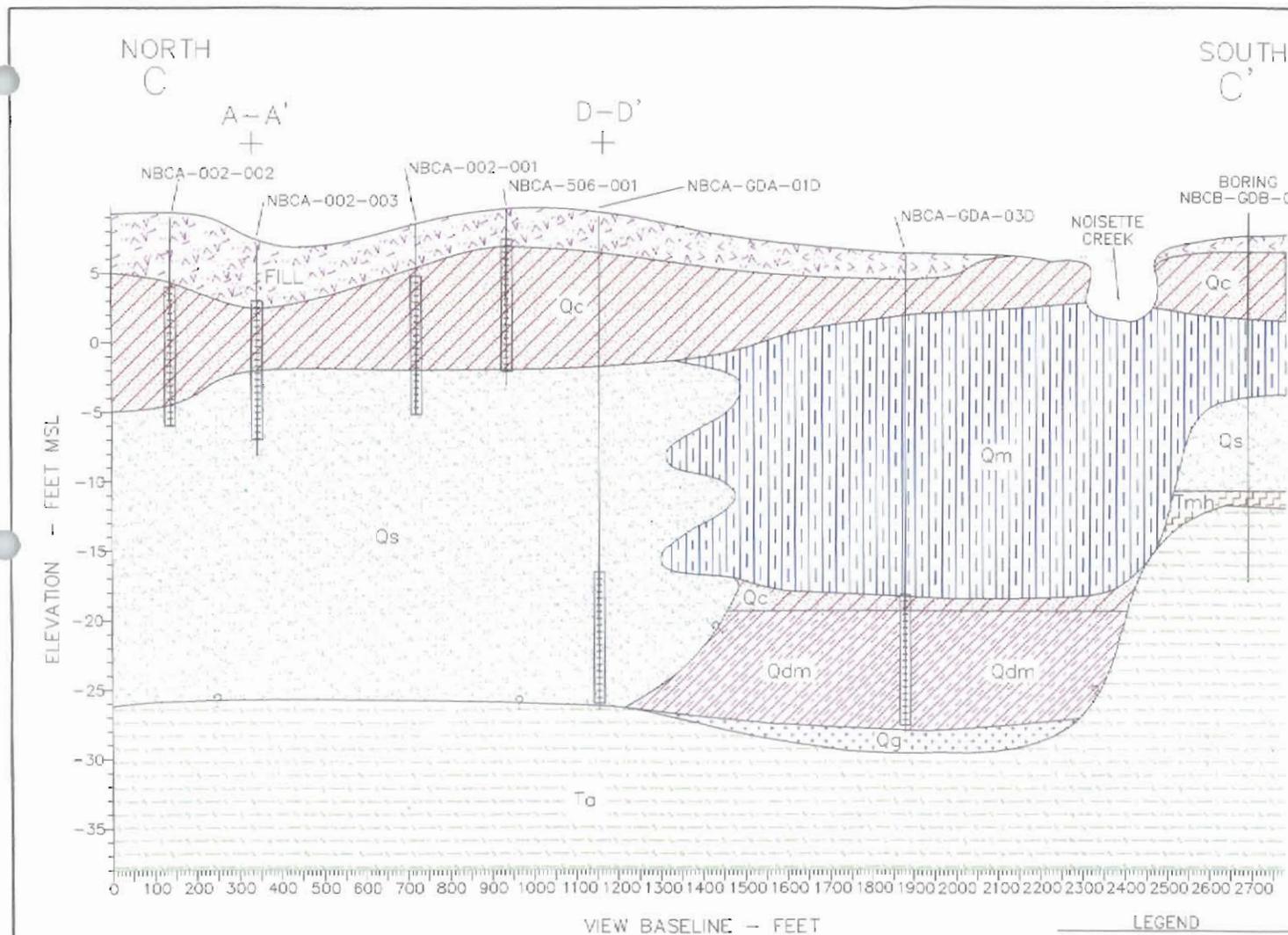
	FILL--Undifferentiated mixture of medium to high plasticity clays, fine sand, silt, gravel and ROC. Varies greatly with location.
	Qp--QUATERNARY PEAT--brown, silty, trace very fine sand, grasses and fibrous woody pieces, soft.
	Qc--QUATERNARY CLAYEY SAND AND SILTY SAND--brown, orange-brown, gray green, and tan, very fine to fine sand often with trace medium grains, varying amount of silt and inorganic gray clay; often interbedded with medium plasticity, soft gray clay laminae; sand occasionally unconsolidated and loose. AQUIFER
	Qm--QUATERNARY MARSH CLAY--dark gray to black, silty, high organic content, with brown grasses and occasional peat; very soft, low plasticity, sticky; occasionally interbedded with very fine to fine sand laminae and pods. AQUITARD
	Qs--QUATERNARY SAND--undifferentiated olive-brown, gray and orange sand; primarily very fine to fine and moderately to well-sorted but typically increases in grain size with depth (from fine to medium with some coarse); clean to silty sand. AQUIFER.
	Qdm--QUATERNARY DEWATERED MARSH CLAY--dark green, dark gray, silty, high plasticity, firm to stiff clay, occasionally very fine sand present in very thin laminae and pods. AQUITARD.
	Qg--QUATERNARY GRAVEL--gray to dark gray, typically grain-supported subrounded phosphate pebbles up to 2 cm in size and fine to coarse shell hash; silty and clayey fine to coarse sand matrix. AQUIFER.
	Tm--TERTIARY MARKS HEAD FORMATION--olive-gray to gray-green silt with varying amounts of very fine to fine quartz and phosphate sand with some clay; low plasticity; soft; intermixed with small subrounded phosphate pebbles, coarse shell hash, and oyster shells.
	Ta--TERTIARY ASHLEY FORMATION--olive-brown to olive-brown silt with varying amounts of clay and very fine sand, medium plasticity, firm to stiff, trace calcareous. CONFINING UNIT.

- LEGEND
- WELL SCREEN INTERVAL NOT INCLUDING FILTERPACK
 - CROSS SECTION INTERSECTION
 - GEOLOGIC CONTACT INFERRED

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

FIGURE 2.4
LITHOLOGIC CROSS SECTION
B - B'

DWG DATE: 02/28/98 DWG NAME: 2901M01

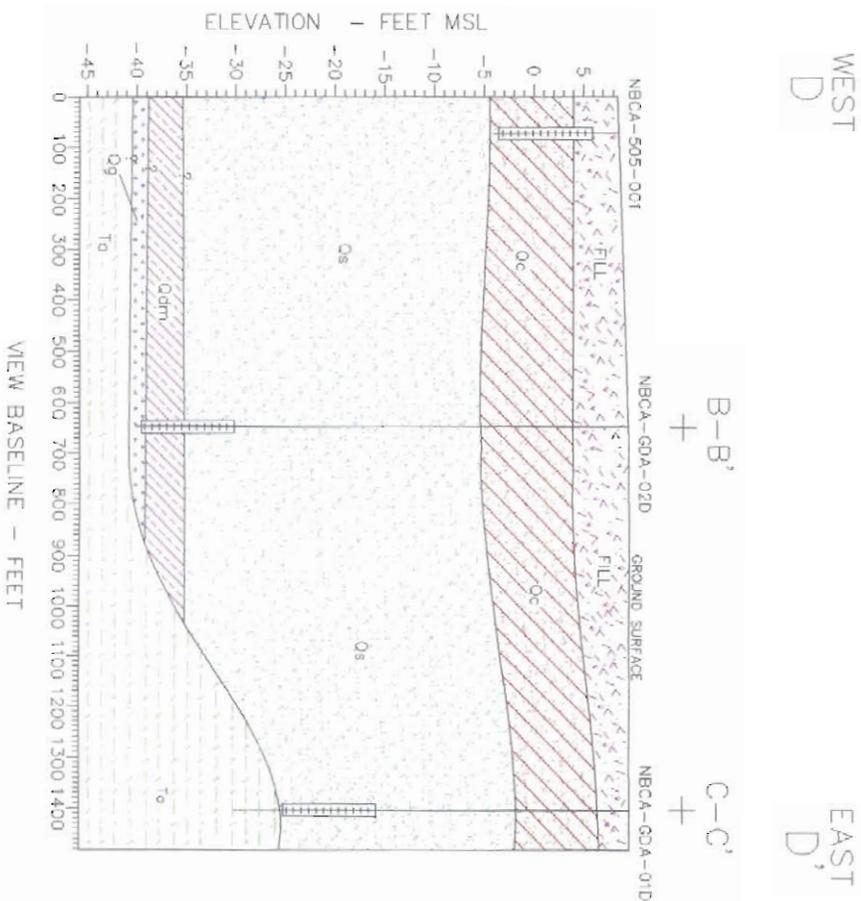


	FILL -- Undifferentiated mixture of medium to high plasticity clays, fine sand, silt, gravel and ROC. Varies greatly with location.
	Qp -- QUATERNARY PEAT -- brown, silty, trace very fine sand, grasses and fibrous woody pieces, soft.
	Qc -- QUATERNARY CLAYEY SAND AND SILTY SAND -- brown, orange-brown, gray, green, and tan, very fine to fine sand often with trace medium grains, varying amounts of silt and inorganic gray clay, often interbedded with medium plasticity, soft gray clay laminae; sand occasionally unconsolidated and loose. AQUIFER
	Qm -- QUATERNARY MARSH CLAY -- dark gray to black, silty, high organic content, with brown grasses and occasional peat; very soft, low plasticity, sticky; occasionally interbedded with very fine to fine sand laminae and pods. AQUITARD
	Qs -- QUATERNARY SAND -- undifferentiated olive-brown, gray, and orange sand; primarily very fine to fine and moderately to well-sorted but typically increases in grain size with depth (from fine to medium with some coarse); clean to silty sand. AQUIFER.
	Qdm -- QUATERNARY DEWATERED MARSH CLAY -- dark green to dark gray, silty, high plasticity, firm to stiff clay; occasionally very fine sand present in very thin laminae and pods. AQUITARD.
	Qg -- QUATERNARY GRAVEL -- gray to dark gray, typically grain-supported subrounded phosphatic pebbles up to 2 cm in size and fine to coarse shell hash; silty and clayey fine to coarse sand matrix. AQUIFER.
	Tmh -- TERTIARY MARKS HEAD FORMATION -- olive-gray to gray-green silt with varying amounts of very fine to fine quartz and phosphate sand with some clay; low plasticity, soft, intermixed with small subrounded phosphate pebbles, coarse shell hash, and oyster shells.
	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.

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**FIGURE 2.5
LITHOLOGIC CROSS SECTION
C - C'**

DWG DATE: 02/25/98 DWG NAME: 2901M019



VIEW BASELINE - FEET

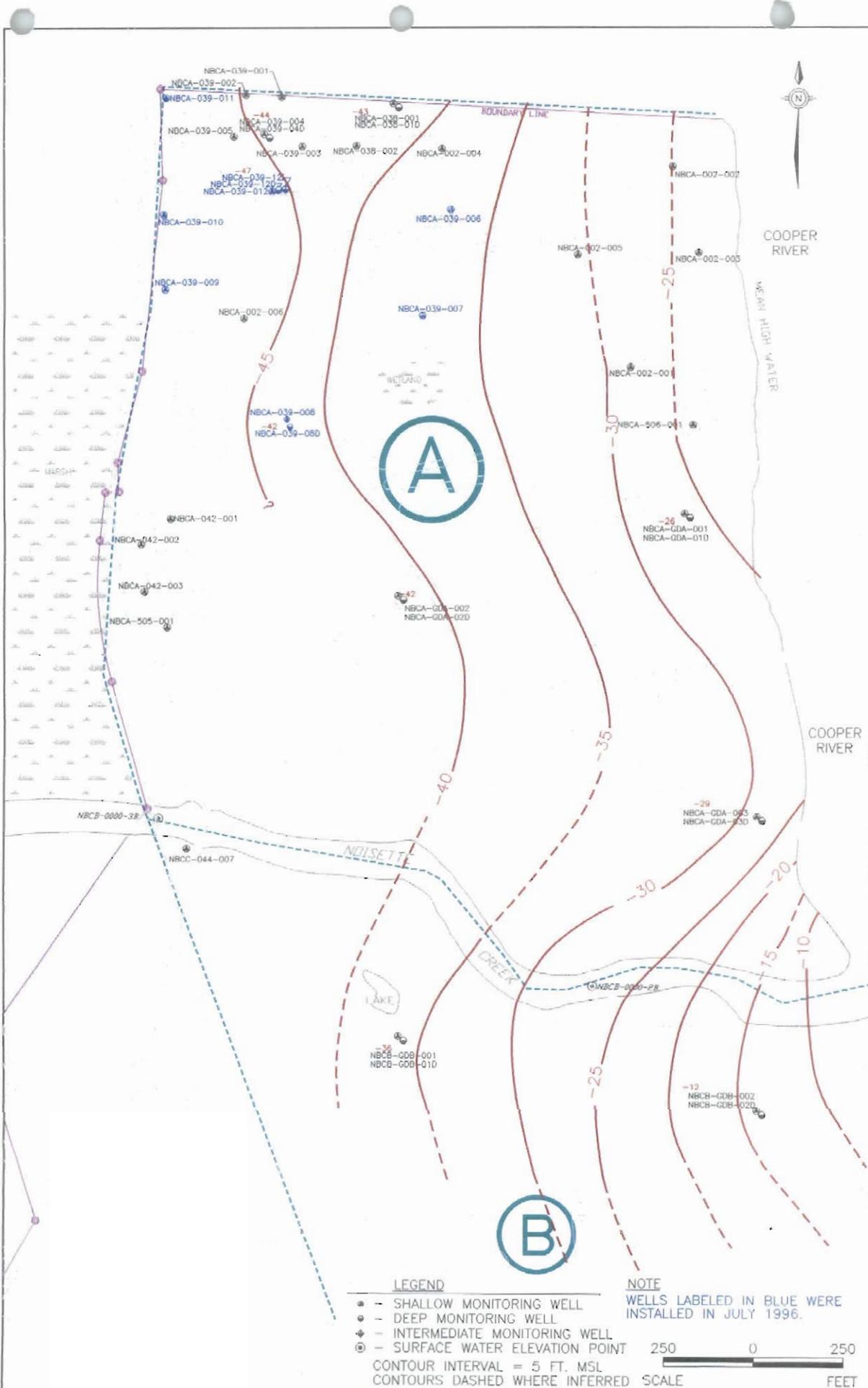
- LEGEND
- WELL SCREEN INTERVAL
 - NOT INCLUDING FILTERPACK
 - + — CROSS SECTION INTERSECTION
 - ? — GEOLOGIC CONTACT INFERRED

Fill	Undifferentiated mixture of medium to high plasticity clay, fine sand, silt, gravel and ROC. Varies greatly with location.
Qc	QUATERNARY PEAT—brown, silty, trace very fine sand, grasses and fibrous woody pieces, soft.
Qs	QUATERNARY CLAYEY SAND AND SILTY SAND—brown, orange-brown, gray, green, and tan, very fine to fine sand often with trace medium grinds, varying amounts of silt and inorganic gray clay, often interbedded with medium plasticity, soft gray clay laminae, sand occasionally unconsolidated and loose. AQUIFER
Qdm	QUATERNARY MARSH CLAY—dark gray to black, silty, high organic content, with brown grasses and occasional peat, very soft, low plasticity, silty; laminae and pods. AQUIFARD
Qg	QUATERNARY SAND—undifferentiated olive-brown/gray, fine orange sand; primarily very fine to fine and moderately to well-sorted but typically increases in grain size with depth (from fine to medium with some coarse); clean to silty sand. AQUIFER
Qdm	QUATERNARY DEWATERED MARSH CLAY—dark green to dark gray, silty, high plasticity, firm to stiff clay; laminae and pods. AQUIFARD
Qg	QUATERNARY GRAVEL—gray to dark gray, typically grain-supported subrounded phosphate pebbles up to 2 cm in size and fine to coarse shell hash, silty and clayey fine to coarse sand matrix. AQUIFER
Qg	QUATERNARY HEAD FORMATION—olive-gray to gray-green silt with varying amounts of very fine to fine quartz and phosphate sand with some clay, low plasticity, soft, interbedded with small subrounded phosphate pebbles, coarse shell hash, and oyster shells.
To	TERTIARY ASHLEY FORMATION—olive-green to olive-brown silt with varying amounts of clay, and very fine sand, medium plasticity, firm to stiff, trace colorless CONFINING UNIT.



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FIGURE 2.6
LITHOLOGIC CROSS SECTION
D - D'



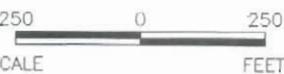
LEGEND

- - SHALLOW MONITORING WELL
- - DEEP MONITORING WELL
- ⊕ - INTERMEDIATE MONITORING WELL
- ⊙ - SURFACE WATER ELEVATION POINT

CONTOUR INTERVAL = 5 FT. MSL
 CONTOURS DASHED WHERE INFERRED

NOTE

WELLS LABELED IN BLUE WERE INSTALLED IN JULY 1996.



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 CHARLESTON, S.C.

FIGURE 2.7
 TOP OF ASHLEY FORMATION
 ELEVATION (MSL)

2.1.4 Quaternary-Age Sediments

The Quaternary Period began 1.6 million years ago with the Pleistocene Epoch and continues with the Holocene (recent) Epoch from 65,000 years ago to the present. During Quaternary time, several sea transgressions-regressions resulted in a jumbled network of terrace complexes composed of varied depositional environments such as barrier islands, back barrier lagoons, tidal inlets, and shallow-ocean-marine shelf systems. Due to regional crustal uplift that occurred in the Charleston region during the Quaternary, many barrier to back barrier deposits from high sea-level stands are preserved as terraces; however, succeeding transgressions reworked the shallow-marine shelf deposits on the seaward side of each older barrier ridge or island (Weems and Lemon, 1993). The result of this erosional and redepositional process of older sediments is that a subsequently younger sequence of deposits may exist on the seaward side and laterally adjacent to the previous (older) coastal deposit (Weems and Lemon, 1993). Therefore, it can be difficult to determine discrete formational units within the Quaternary system. Weems and Lemon (1993) have identified and correlated several formations of Quaternary-age sediments. However, field identification of these formational units is difficult since many characteristics may only be evident at the microscopic level.

Throughout Zone A, Quaternary-age sediments extend from the top of the Ashley Formation to just below ground surface. Based on the 12 deep well borings drilled in Zone A, these sediments range from approximately 36 feet thick at NBCA-GDA-03D to 56 feet thick at NBCA-039-12D. These sediments primarily comprise the Pleistocene-age Wando Formation (deposited 70,000 to 130,000 years ago), which are in turn overlain by Holocene-age sand and clay deposits.

In general, the Wando deposition encompasses three distinct high sea-level stands in the late Pleistocene (Weems and Lemon, 1993). As a result, Wando composition consists of repeating sequences of clayey sand and clay deposits overlying barrier sand deposits which, in turn, overlie fossiliferous shelf-sand deposits. In Holocene time, rivers and streams have down-cut these

sediment sequences, leaving scours that have become filled with clay and silty sand deposits typical of low energy environments. These younger deposits may resemble Wando-age deposits and further complicate the interpretation of local geology.

Consequently, only six distinct Quaternary-age stratigraphic units have been correlated in the lithologic cross sections presented in Figures 2.3 through 2.6. These units were selected because of their generally consistent lithologic characteristics throughout Zone A. The stratigraphic units are designated Qp (Quaternary peat), Qc (Quaternary clayey sand), Qm (Quaternary marsh clay), Qs (Quaternary sand), Qdm (Quaternary dewatered marsh clay), and Qg (Quaternary gravel). These units were subsequently refined to reflect the additional findings associated with the site-specific geologic investigation at SWMU 39, and are presented in Section 10.4.10.

2.1.4.1 Description of Zone A Quaternary-Age Stratigraphic Units

Quaternary peat (Qp): This sediment was encountered in well locations NBCA-039-008, NBCA-039-08D, NBCA-039-007, and NBCA-039-009 as shown in cross section B-B' (Figure 2.4). The peat deposit is brown, silty with a trace of very fine-grained sand, with a high percentage of grass, fibrous wood, and other fine pieces of organic matter. It is soft, moist, and low in plasticity. The shallow Qp deposit is generally found in the upper 13 feet of the subsurface.

One Shelby tube sample of Qp was obtained from the 11 to 13 ft bgs interval at well location NBCA-039-009 (Table 2.2). This sample had a porosity of 80%, but no grain-size distribution data was obtained.

Quaternary clayey sand (Qc): This sediment is prevalent in Zone A and can be seen in each of the lithologic cross sections (Figures 2.3 through 2.6). In general, the Qc deposit is a brown to gray, very fine to fine-grained, silty, clayey sand that is occasionally loose and unconsolidated. This unit is often interbedded with gray clay lenses and laminae of low to medium plasticity and

low organic content. The Qc deposits were typically in the upper 10 to 15 feet of the shallow subsurface.

Five Shelby tube samples of Qc sediment were obtained during drilling in Zone A (Table 2.2). Four of these samples were taken from the shallow subsurface at less than 13 feet bgs, while the fifth was taken from the 32 to 34 ft. bgs interval. The average porosity of these samples was 42% with a mean grain size distribution of 64.0% sand, 16.6% silt, and 19.4% clay.

Quaternary marsh clay (Qm): The marsh clay deposits are dark gray to black, silty clays of high organic content often intermixed with grass and wood fragments. The soft marsh clay has low plasticity, is sticky and occasionally interbedded with very fine sand laminae and pods. Often the marsh clay has a distinctive "rotten egg" hydrogen sulfide odor due to an oxygen-poor environment.

No Qm geotechnical samples were obtained during the Zone A RFI. Six Qm Shelby tube samples, collected during the Zone E RFI, were found to have an average porosity of 56.2% and mean grain-size distribution of 19.8% sand and 80.2% silt and clay (E/A&H, November, 1997).

Quaternary sand (Qs): The Quaternary sand is an undifferentiated olive-brown to gray and orange sand that is typically very fine to fine-grained. The grain size may increase with depth to fine to medium with some coarse. The Qs unit varies from clean to silty sand and generally lacks the clay content associated with the Qc deposits.

Three Shelby tube samples of Qs material were collected from near surface sediments at depths less than 13.5 ft bgs. The average porosity from these samples is 35.7%. Four additional samples were taken from deeper Qs deposits (32-52 feet bgs) for grain size distribution analyses only. The mean grain size distribution of all seven Qs samples is 92.6% sand, 2.9% silt, and 4.5% clay.

Quaternary dewatered marsh clay (Qdm): The dewatered marsh clay is a moist, dark green to gray, silty clay of high plasticity and strikingly firm to stiff. Very thin, very fine-grained sand laminae and pods occasionally are present. In general, the dewatered marsh clay is encountered deeper than the Holocene-age marsh clay deposits and may lie unconformably on top of the Ashley Formation. This deposit is thought to be a channel-fill deposit that lies in scours of the Ashley Formation, best seen in cross sections C-C' and D-D' (Figures 2.5 and 2.6).

No Qdm Shelby tube samples were obtained during the Zone A RFI. However, four Shelby tube samples of Qco (older Quaternary clay that is synonymous with Qdm in this report) were obtained during the Zone E RFI. The reported average porosity was found to be 54.4%, and mean grain-size distribution was 4.5% sand and 95.4% silt and clay (E/A&H, November, 1997).

Quaternary gravel (Qg): This unit is characterized as gray to dark gray, grain-supported phosphate pebbles intermixed with fine to coarse shell hash, and a silty, clayey, fine to coarse sand matrix. The Quaternary-age designation may be questionable since each of the Tertiary-age units typically have phosphate gravel beds at their basal contacts (i.e., Marks Head Formation). However, the presence of the poorly sorted sand and shell hash is thought to be more indicative of lower Wando Formation sediments which are of Quaternary-age. The Qg unit can be seen in all four lithologic cross sections presented in Figures 2.3 through 2.6.

No Qg geotechnical samples were obtained during the RFI.

2.1.5 Soil

Due to extensive surface soil disturbance at NAVBASE during its operational history, approximately the upper 5 feet of the subsurface is typically a mixture of artificial fill and native sediments. Much of NAVBASE, including areas within Zones A and B along Noisette Creek, has been filled using dredge materials from the Cooper River and Shipyard Creek.

Artificial fill was designated as FILL on the lithologic cross sections (Figures 2.3 through 2.6) and is described as an unsorted mixture of medium to high plasticity clays, fine sand, silt, gravel, and ROC (run of crusher) that varies greatly in depth and distribution throughout NAVBASE. Native soil is the fine-grained silt, silty sand, and clay typical of tidal marsh environments. Due to limited recovery during drilling of the upper 5 feet at many locations, it is difficult to delineate the transition from fill to native sediments. As a result, the FILL unit was used to group deposits that were indistinguishable in the upper 5 feet of the subsurface in Zone A.

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 are tributaries of the Cooper River, which include areas other than NAVBASE. Surface drainage over the remainder of NAVBASE flows directly into the Cooper River, which discharges into Charleston Harbor.

Shipyard Creek, a small tidal tributary approximately two 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 Cooper River'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 and separates Zones A and B, 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. Surface water elevations in the creek, recorded during February and August 1996 groundwater-level measurement events, showed an average of 5 feet change in elevation from low to high tide.

Groundwater occurs under water table or poorly confined conditions within the Quaternary deposits overlying the Tertiary-age Cooper Group. Aquifer transmissivities are generally less than 1,000 square feet per day (ft²/day), and well yields range 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 Cooper Group 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 Zone A Hydrogeologic Investigation

Hydrogeological information was obtained from slug test analyses and water-level measurements conducted during the Zone A RFI. Estimates of vertical permeability, grain-size distribution, and porosity were obtained from laboratory analysis of Shelby tube samples collected during drilling. Only data pertinent to the Quaternary deposits and Tertiary Ashley Formation deposits are discussed since they were the only deposits encountered in Zone A.

2.2.3 Tertiary-Age Sediments

2.2.3.1 Ashley Formation

The Ashley Formation is important because of its role as a confining unit between the lower members of the Cooper Group and Eocene-age Santee Limestone, and the overlying water-bearing Quaternary-age sediments (Park, 1985). Lithologic cross sections presented by Weems and Lemon (1993) show the Ashley Formation as having a laterally consistent overall thickness. Samples taken from this unit at NAVBASE have shown high clay and silt contents and varying

sand contents depending greatly upon depth. Seven Shelby tube samples, collected from the Ashley during the Zone E RFI, exhibited vertical permeabilities ranging from 1.6E-06 to 3.0E-04 centimeters per second (cm/sec) (4.6E-03 to 0.84 feet/day) with a geometric mean of 1.7E-05 cm/sec (0.05 feet/day) (E/A&H, November, 1997). These ranges reflect the sand content of the depths sampled: the highest permeability (3.0E-04 cm/sec) had a sand content of 39% whereas the lowest permeability (1.6E-06 cm/sec) had a sand content of 14.5%. According to Fetter (1988), sediments with permeabilities of 10^{-5} cm/sec (0.03 feet/day) or less can be considered confining units. All deep borings in Zone A were terminated when the Ashley Formation was encountered.

2.2.4 Quaternary-Age Sediments

The hydrogeologic role of the Quaternary-age sediments is as a single surficial aquifer overlying the Ashley Formation. However, the hydraulic conditions within the surficial aquifer vary significantly at the local scale. This is largely influenced by the range of stratigraphic units that comprise the Quaternary-age sediments, as previously discussed in Section 2.1.4.

The heterogeneity of the hydraulic properties of these stratigraphic units in Zone A is most plainly evident in their vertical permeabilities (Table 2.2). Qs samples reveal the greatest vertical permeability (K_v) of the stratigraphic units in Zone A with a mean K_v of 5.71E-04 cm/sec (1.62 ft/day). Zone A Qc samples reveal a mean K_v of 3.87E-06 cm/sec (1.10E-02 ft/day), while a single Qp sample in Zone A has a K_v of 1.28E-06 cm/sec (3.63E-03 ft/day). No Qm vertical permeabilities were obtained during the Zone A RFI; however, the mean K_v from six Qm samples in Zone E was reported as 1.15E-06 cm/sec (3.30E-03 ft/day), the lowest of the Quaternary-age stratigraphic units sampled (E/A&H, November, 1997). Similarly, the vertical permeability geometric mean of Qco Shelby tube samples in Zone E, synonymous with Zone A Qdm sediments, was 2.16E-06 cm/sec (6.1E-03 ft/day). Comparatively, it has been reported by Anderson (1990)

and Fetter (1988) that sediments with permeabilities between 1 and 10 ft/day and greater than 0.03 ft/day are defined as unconfining fine sand with water-transporting capabilities.

These large ranges in vertical permeability suggest various hydrogeologic roles for each of the Quaternary-age stratigraphic units within the hydrogeologic system. The most obvious of these are the marsh clay (Qm) and dewatered marsh clay (Qdm) deposits. Both units exhibit high silt and clay contents and low vertical permeabilities, making them viable aquitards. The thicknesses of Qm and Qdm deposits will restrict vertical groundwater flow while their areal distribution will greatly impact horizontal groundwater flow.

Marsh clay deposits have been encountered throughout NAVBASE; in fact, the consistent relationship of marsh clay deposits intervening between permeable sand bodies in Zones H and I led to the unit's demarcation as a boundary between an "upper sand" and "lower sand," which were the targets for shallow well and deep well installation, respectively. A similar scenario occurs in the northern portion of Zone A at wells NBCA-039-04D and NBCA-039-12D where discontinuous Qm and Qdm lenses separate three distinct sand units, leading to the localized development of three groundwater flow zones (Figure 2.4; cross section B-B'). Consequently, shallow, intermediate, and deep wells at several SWMU 39 locations were installed to monitor these separate units. However, the Qm and Qdm pinch out to the south, as evidenced by the lack of marsh clay deposits encountered in deep well boring locations NBCA-039-08D, NBCA-GDA-02D, and NBCA-GDA-01D (Figure 2.4). The three sand units evident in the northern portion of the zone appear to commingle and coalesce in the central to southern portions of the zone. A more detailed discussion of and investigation into the complex geology and hydrogeology of SWMU 39 is presented in Section 10.4.11 of this report.

2.2.4.1 Surficial Aquifer

The surficial aquifer extends from the water table to the top of the confining unit. Deeper sand units that overlie the Ashley Formation are considered unconfined, such as those encountered in the southern portion of the zone at NBCA-039-08D and NBCA-GDA-02D. In other locales, the presence of discontinuous aquitards of Qc, Qm, or Qdm deposits may act to semi-confine underlying sand lenses.

Water levels in the shallow wells reflect the position of the water table and typically monitor shallow Qs, Qc, Qp or Fill deposits. Although water table elevations generally mimic topographic elevations, the topographic relief in Zone A is fairly subdued due to extensive man-made surface features such as paved surfaces, gravel fill, and concrete foundations. As a result, anomalous but localized variations in water table elevation may reflect other factors such as perching of groundwater in higher permeable units (Qs) over lower permeable units (Qm), or interactions with the storm sewer system. Water table elevations are also influenced by seasonal variations in precipitation and evapotranspiration rates, barometric pressure changes, and recharge rates.

The deep monitoring wells in Zone A primarily monitor Qs deposits, which tend to be moderately well to poorly sorted, clean to silty sands, and occasional Qg and Qdm deposits. At certain locations such as NBCA-038-01D, NBCA-039-04D, NBCA-039-12D, and NBCA-GDA-03D, overlying Qm and/or Qdm deposits may provide semi-confined conditions on top of the Ashley Formation. Initial water level elevations in these wells were all above the top of the aquifer, a characteristic typical of a confined aquifer system in which the water-bearing formation is under artesian conditions. There are no Qm or Qdm deposits at deep well locations NBCA-GDA-01D, NBCA-GDA-02D, and NBCA-039-08D, such that unconfined conditions exist at the base of the surficial aquifer. However, water levels in these three wells are of the same magnitude as those in wells NBCA-038-01D, NBCA-039-04D, NBCA-039-12D, and NBCA-GDA-03D, the potentially semi-confined locations. It is likely that the Qm and Qdm aquitards, where present,

are either leaky or of such limited lateral extent that the hydraulic conditions do not appear to vary greatly from unconfined conditions. The hydraulic heads measured in all Zone A deep wells are therefore treated as representing the hydraulic conditions overlying the Ashley regardless of the presence of any overlying aquitards.

2.2.5 Groundwater Flow Direction

Water levels in the shallow and deep wells were measured during low and high tides on February 13, and August 7, 1996, in Zone A and at selected locations in Zones B and C. The August water level data were contoured for this report due to the addition of 10 new wells in July 1996, which provided better resolution of the groundwater flow pattern. A subsequent water level event was conducted in January 1997 after the fourth round well installation at SWMU 39 was completed, and is presented in Section 10.4.11.

The August 7, 1996 elevation data revealed that the maximum relief of the water table surface was 8.17 ft. as measured from a maximum of 8.99 ft. msl at NBCA-039-011, to a low of 0.72 ft. msl at NBCA-002-003 during low tide (Table 2.1). The maximum relief of water levels in the deep wells was 1.10 ft. as measured from a maximum of 2.17 ft. msl at NBCA-039-12D, to a low of 1.07 ft. msl at NBCA-GDA-03D during low tide.

Tidal data collected for the *Final RCRA Facility Investigation Report for Zone H* (E/A&H, 1996) showed that tidal changes in surface water bodies exert greater influence on wells closer to tidal sources than those inland. Moreover, aquifer heterogeneity greatly affects its tidal response since well-sorted, coarse-grained deposits are more transmissive than poorly sorted, fine-grained deposits. The location of many Zone A wells near the Cooper River and Noisette Creek warranted the measurement of surface water elevations at three locations: two on Noisette Creek (one at the railroad bridge west of the junction of Zones A, B, and C and one on the golf course footbridge

between Zones A and B) and one in the southeastern section of Zone B on Pier B in the Cooper River.

2.2.5.1 Shallow Groundwater

Figures 2.8 and 2.9 depict groundwater elevation contours in shallow wells for low and high tides, respectively. These figures represent the water table elevation across Zone A. Despite the 4- to 5-foot surface water elevation difference between low and high tide, no significant change in groundwater flow direction occurs within most of Zone A, except along its northeastern portion closest to the Cooper River (Figures 2.8 and 2.9). In that area, three wells drilled during the 1993 RFA (NBCA-002-002, NBCA-002-003, and NBCA-002-005) showed significant tidal fluctuations of 0.79, 1.47, and 0.55 feet, respectively. These variations are most likely associated with the lithology, which really consists of well-sorted, clean to silty sand and clayey sand with no distinct clay lenses or layers. Tidal fluctuations produced less than 0.3-foot variations for the remainder of the shallow wells installed in Zone A.

Figures 2.8 and 2.9 show that a northwest to southeast trending recharge zone lies in the central portion of Zone A, forming a groundwater flow divide. This recharge zone is in the vicinity of the former small wetland in Zone A. Groundwater to the east of this divide flows east toward the Cooper River. To the south, groundwater flows south toward Noisette Creek; to the west, groundwater flows either west into the marsh and former wetland north of Noisette Creek or to the south directly toward Noisette Creek.

Groundwater flow is more complex north of the recharge zone. The highest groundwater elevations were measured in the northwest corner of Zone A and suggest that higher hydraulic heads exist northwest of the NAVBASE boundaries. Groundwater initially flows south to southeast from the northwest corner of Zone A, but then may follow one of two general paths: One is to the south, west of the recharge zone in the central portion of Zone A where it encounters

the flatter portion of the water table; the second is to the east, north of the groundwater high associated with recharge in the central portion of Zone A, toward the Cooper River.

For a site-specific discussion of groundwater flow in the shallow, intermediate, and deep portions of the surficial aquifer at SWMU 39, refer to Section 10.4.11.

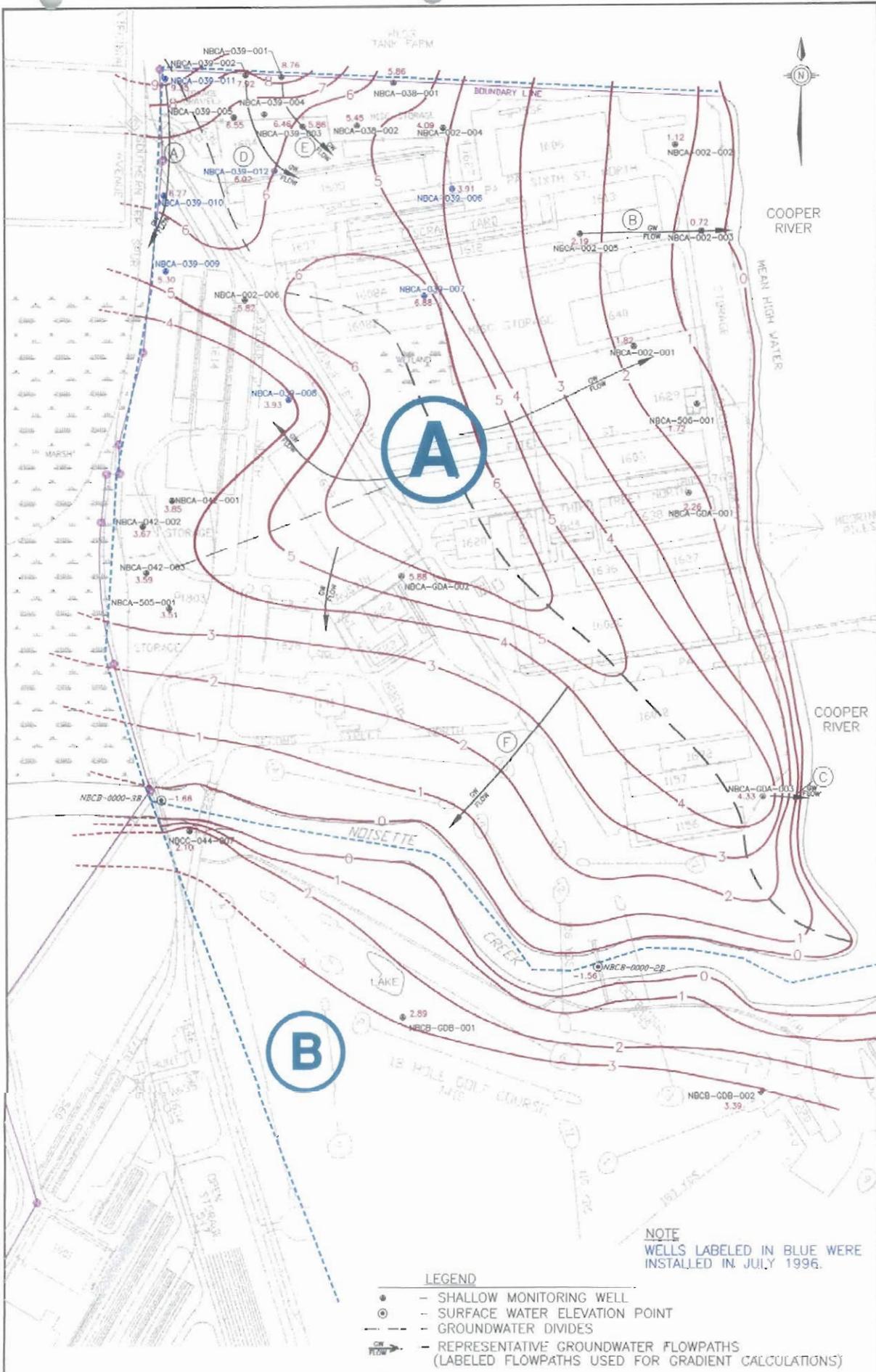
2.2.5.2 Deep Groundwater

Figures 2.10 and 2.11 are contour maps of groundwater elevation data from the deep wells during low and high tide, respectively. It is quickly evident that the potentiometric surface representing conditions at the bottom of the surficial aquifer is of more subdued relief than the water table surface. The general direction of groundwater flow at the bottom of the surficial aquifer is east to the Cooper River. Tidal variation does not alter groundwater flow direction. A small zone of high hydraulic heads in the east-central portion of Zone A reflects the consistently higher groundwater elevations measured in well NBCA-GDA-01D.

2.2.6 Vertical Hydraulic Gradient

The vertical hydraulic gradient is a mathematical expression that indicates the potential for vertical groundwater flow. The vertical gradient was calculated at each well pair in Zone A by dividing the differences between water levels in the shallow and deep wells by the vertical distance between the bottoms of the respective well screens. Positive gradients indicate a downward potential for vertical flow whereas negative gradients indicate potential for upward flow.

Table 2.3 presents the calculated vertical hydraulic gradients between the shallow/deep well pairs and shallow/intermediate/deep well cluster for the zone-wide groundwater level measurement events in February 13, 1996, and August 7, 1996 for low and high tide.



A

B

NOTE
WELLS LABELED IN BLUE WERE
INSTALLED IN JULY 1996.

LEGEND

- - SHALLOW MONITORING WELL
- ⊙ - SURFACE WATER ELEVATION POINT
- - - - GROUNDWATER DIVIDES
- - - - REPRESENTATIVE GROUNDWATER FLOWPATHS
(LABELED FLOWPATHS USED FOR GRADIENT CALCULATIONS)

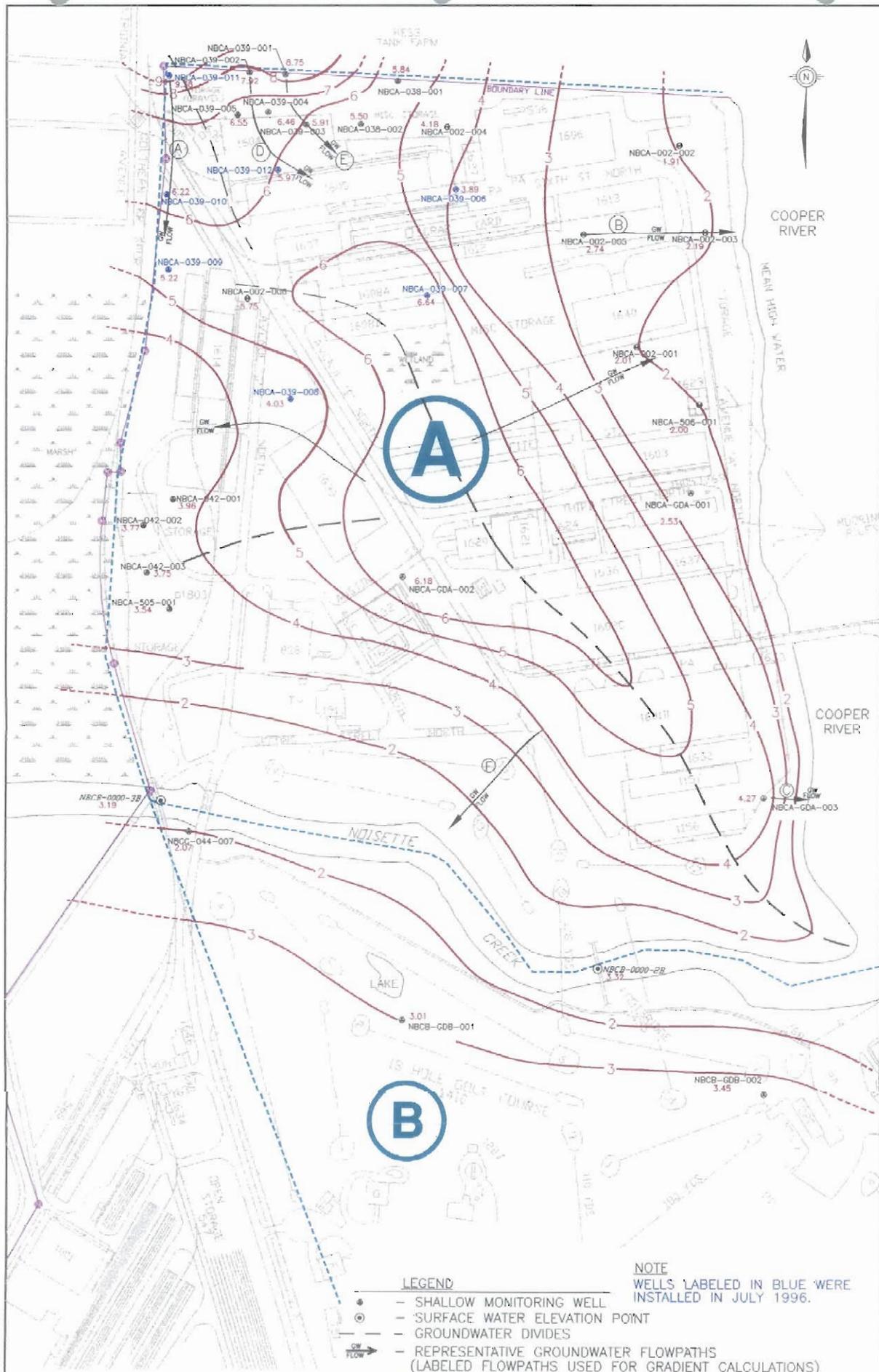
CONTOUR INT. = 1 FOOT
250 0 250
SCALE FEET



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FIGURE 2.8
GROUNDWATER ELEVATIONS IN SHALLOW
WELLS AT LOW TIDE ON 8-7-96

DWG DATE: 05/08/98 DWG NAME: 200110021

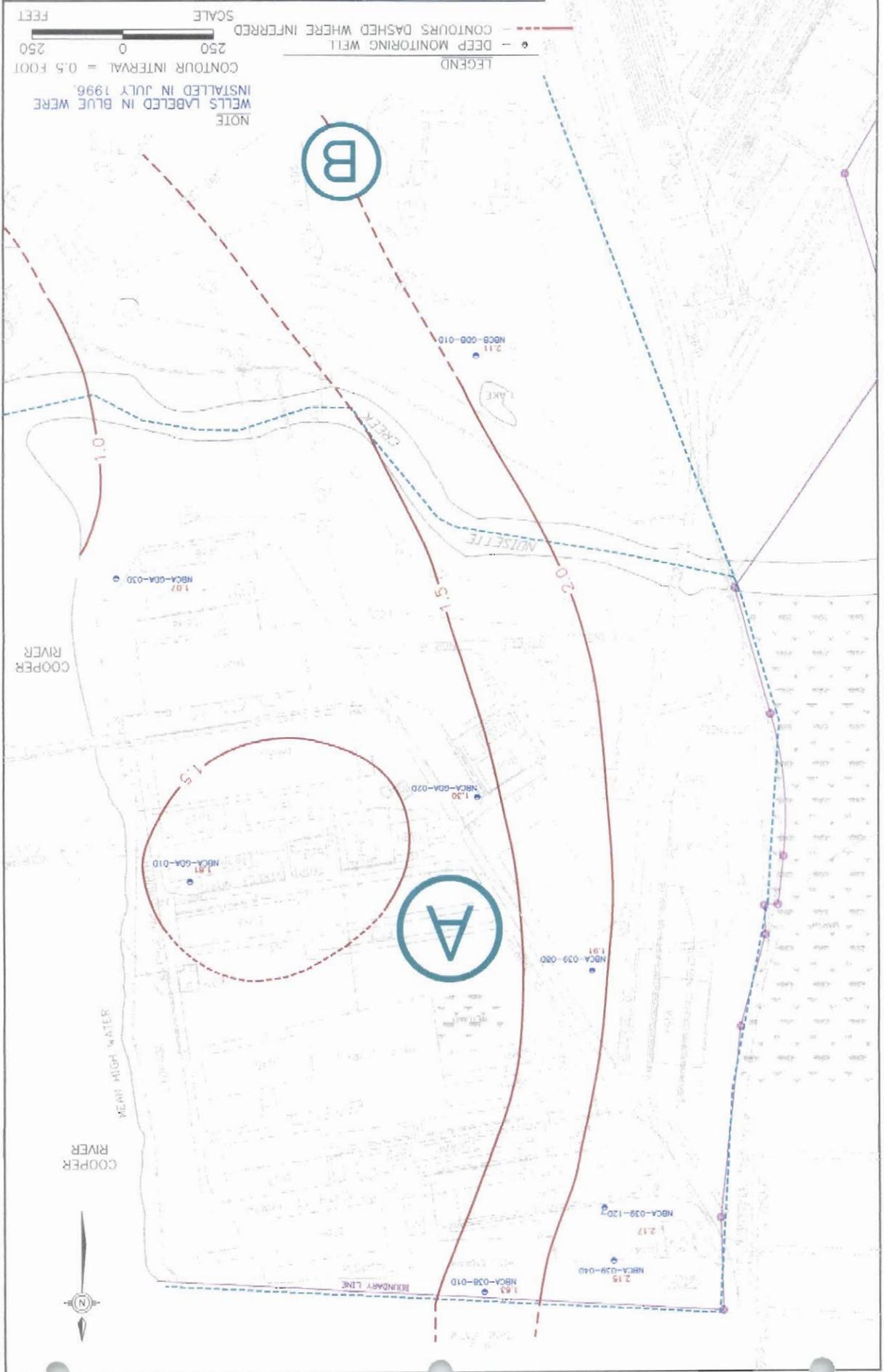


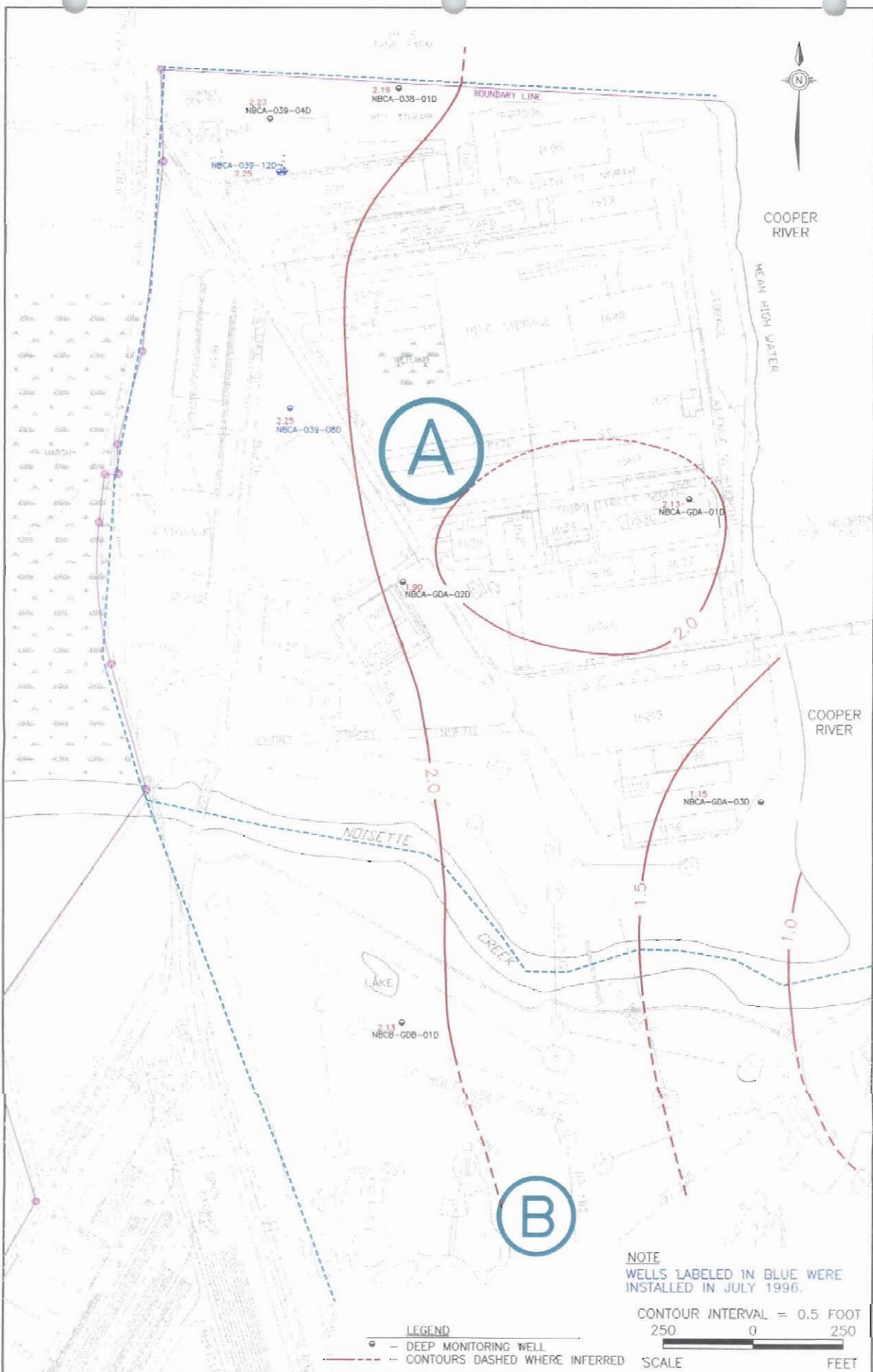
CONTOUR INT. = 1 FOOT
 250 0 250
 SCALE FEET



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 CHARLESTON, S.C.

FIGURE 2.9
 GROUNDWATER ELEVATIONS IN SHALLOW
 WELLS AT HIGH TIDE ON 8-7-96





NOTE
 WELLS LABELED IN BLUE WERE
 INSTALLED IN JULY 1996.

CONTOUR INTERVAL = 0.5 FOOT
 250 0 250

- LEGEND
- - DEEP MONITORING WELL
 - - - CONTOURS DASHED WHERE INFERRED

SCALE FEET



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FIGURE 2.11
 GROUNDWATER ELEVATIONS IN
 DEEP WELLS
 AT HIGH TIDE ON 8-7-96

Table 2.3
Vertical Hydraulic Gradients
Measured Winter and Summer 1996

Well Pair	Vertical Distance (ft)	Date	LOW TIDE		HIGH TIDE	
			GW Elevation Difference (ft)	Vertical Hyd. grad. (ft/ft)	GW Elevation Difference (ft)	Vertical Hyd. grad. (ft/ft)
NBCA-038-001 and -01D	37.6	2/13/96	2.96	0.079	2.25	0.060
		8/7/96	4.23	0.113	3.65	0.097
NBCA-039-004 and -04D	41.5	2/13/96	4.52	0.109	4.41	0.106
		8/7/96	4.31	0.104	4.23	0.102
NBCA-039-008 and -08D	36.1	8/7/96	2.02	0.056	1.78	0.049
NBCA-039-012 and -12I	19.4	8/7/96	0.25	0.013	0.20	0.010
NBCA-039-12I and -12D	24.3	8/7/96	3.59	0.148	3.52	0.145
NBCA-GDA-001 and -01D	23.0	2/13/96	0.23	0.010	0.17	0.007
		8/7/96	0.45	0.020	0.40	0.017
NBCA-GDA-002 and -02D	37.2	2/13/96	4.39	0.118	3.95	0.106
		8/7/96	4.59	0.123	4.29	0.115
NBCA-GDA-003 and -03D	21.9	2/13/96	3.58	0.163	—	—
		8/7/96	3.26	0.149	3.12	0.142

All well pairs in Zone A have positive vertical gradients, indicating downward groundwater flow potential during both low and high tides. The addition of several intermediate and deep wells during third and fourth round well installation events at SWMU 39 provided additional data from which to calculate vertical gradients. These data are presented in the site-specific discussion of groundwater flow at SWMU 39 in Section 10.4.11.

2.2.7 Horizontal Hydraulic Gradient

The horizontal hydraulic gradient (i) is a measurement of the change in hydraulic head (Δh) (i.e., change in groundwater elevation) of two points over the distance between the points (Δx). It is a dimensionless value which is generally used to quantitatively determine the magnitude of groundwater flow in a given region. Groundwater contour maps for the shallow aquifer (Figures 2.8 and 2.9) were examined to find the highest and lowest horizontal hydraulic gradient for the shallow wells at both low and high tide.

Because monitoring well placement during the Zone A RFI was based solely on SWMU and AOC locations and historical land uses at NAVBASE, it is coincidental when monitoring wells are aligned with each other along a groundwater flowpath. Since groundwater flowpath lines must be perpendicular to groundwater contours or equipotential lines (lines of equal hydraulic head), the contour pattern of hydraulic head dictates the orientation of groundwater flowpaths. However, four pairs of wells in Zone A are situated so that they closely reflect groundwater flowpaths. These four pairs were used in estimating hydraulic gradients in the northern portion of the zone and are labeled "A," "B," "D," and "E" in Figures 2-8 and 2-9. In addition a hypothetical flowpath, labeled "F" in Figures 2-8 and 2-9, was drawn as an estimate in the southern portion of the zone along the golf course. A final flowpath, labeled "C" in Figures 2-8 and 2-9, was drawn from well NBGA-GDA-003 towards the Cooper River as an estimate of the steep gradient in the southeastern tip of Zone A. These computed hydraulic gradients along these flowpaths are presented in Table 2.4.

Table 2.4
Horizontal Hydraulic Gradients
Measurements taken 8/7/96

Measurement Points	Tide	Δh	ΔX	i
A	Low	3.08	319	0.010
	High	3.16	325	0.010
B (shallowest gradient)	Low	1.47	373	0.004
	High	0.55	373	0.002
C (steepest gradient)	Low	4.33	100	0.043
	High	2.27	88	0.026
D	Low	1.90	275	0.007
	High	1.95	288	0.007
E	Low	2.90	150	0.019
	High	2.84	145	0.020
F	Low	3.0	445	0.007
	High	2.0	275	0.007

The horizontal hydraulic gradient results indicated that the greatest gradient lies along flowpath "C" which is primarily influenced by the anomalously high groundwater elevation found at NBCA-GDA-03D. The prevalence of Qm and Qdm deposits at this location is likely responsible for its high hydraulic head (Figure 2.5). The shallowest gradient was calculated along flowpath "B" in the region of Zone A where significant tidal influence was noted.

2.2.8 Horizontal Hydraulic Conductivity

Slug tests were used to evaluate the horizontal hydraulic conductivity of an aquifer at a single point. A slug test is initiated by inserting a 1-7/8" diameter Teflon cylinder below the static water level in the well, creating an instantaneous change in the water level. The change in water level over time is monitored as the aquifer attempts to reach equilibrium in response to the perturbation. This procedure is known as a falling head slug test since the water level (hydraulic head) declines back to its original static level. Once equilibrium is re-established, the slug is quickly removed,

dropping the static water level. This procedure is a rising head slug test since the water level in the well rises back to its original static level as the test progresses. The resulting horizontal hydraulic conductivity (K_h) values of the falling and rising head slug tests are presented below in Tables 2.5 and 2.6 for both the shallow and deep wells, respectively. The lithologic type considered to be most responsible for the test response is also presented. Additional tests were performed on third and fourth round SWMU 39 wells. These data are presented and discussed in Section 10.4.11.

Table 2.5
Zone A
Shallow-Well Slug Test Horizontal Hydraulic
Conductivity Results in feet/day

Well	Lith. Type	Falling Head Hydraulic Conductivity	Rising Head Hydraulic Conductivity	Geometric Mean ^a
NBCA-039-001	Qs	0.96	Not Used	0.96
NBCA-039-002	Qs	0.36	Not Used	0.36
NBCA-039-004	Qs	1.1	3.5	2.0
NBCA-042-003	Qs	1.1	1.3	1.2
NBCA-506-001	Qc	1.3	1.0	1.1
NBCA-GDA-003	Qc/Fill	Not Used	0.29	0.29
NBCA-002-002	Qs	7.2	12	9.3
NBCA-002-005	Qc	0.07	0.06	0.065

Note:

^a = Average calculated using the falling and rising head values.

Table 2.6
Zone A
Deep-Well Slug Test Horizontal Hydraulic
Conductivity Results in feet/day

Well	Lith. Type	Falling Head Hydraulic Conductivity	Rising Head Hydraulic Conductivity	Geometric Mean ^a
NBCA-038-01D*	Qs	0.56	1.1	0.78
NBCA-039-04D	Qs	Not Used	24	24
NBCA-GDA-03D	Qs	2.1	2.8	2.4

Notes:

- ^a = Average calculated using the falling and rising head values.
- * = Bouwer and Rice (1976) solution used.

Data from the slug tests were first 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 shallow aquifer were plotted using an unconfined aquifer solution. For this solution, elapsed time versus displacement (change in water levels) was plotted on a semilogarithmic graph. Horizontal hydraulic conductivity (K_h) was computed by the program using an equation developed by Bouwer and Rice (1976) for wells that partially penetrate unconfined aquifers (i.e., the well does not fully screen the saturated interval). This method assumes that the aquifer is homogeneous, isotropic (vertical hydraulic conductivity equals horizontal hydraulic conductivity), in steady-state equilibrium, and that flow into the well is solely through the well screen. The analyses were later evaluated using the techniques provided in an update paper from Bouwer (1989) that incorporates the porosity of the filter pack material so that filter pack drainage effects can be considered. While this analysis results in a more reliable estimate of the aquifer's true hydraulic conductivity, it is important to recognize that these values are estimates of aquifer characteristics only at that specific well location and depth, and should be used carefully in discussing the overall characteristics of an aquifer. There were some data sets that did not provide

adequate responses for evaluation, and as a result were not used in the slug test analyses (Table 2.5). The shallow well slug test analyses are presented as Appendix C.

The slug test data collected from the deep wells were plotted using a solution developed by Cooper et al. (1967) to generate a value for transmissivity in a confined aquifer. The Cooper method requires that the confined aquifer be infinite in areal extent, homogeneous, isotropic, of uniform thickness over the area of influence during the test, and fully penetrated by the monitoring well. Although boring logs and other geologic evidence indicate a confined condition in this zone and wells fully penetrating the lower aquifer, the data from several of the wells could not be used to find a solution with this method. An unconfined Bouwer and Rice solution was applied to the data and a fit was made. Consequently, conductivity values for the deep wells may not be as reliable. Only one data set did not provide an adequate response for evaluation and was not used in the slug test analyses (Table 2.6). The deep well slug test analyses are included in Appendix C. Both rising and falling head slug tests were conducted on 31% of the total wells currently installed in Zone A.

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 when applicable.

The geometric means of hydraulic conductivity based upon slug-tested shallow wells varies from 6.5E-02 to 9.3 feet/day. The corresponding variation in the slug-tested deep wells was 0.77 to 24 feet/day. Some of this variation may be accounted for by lithologic heterogeneity in the shallow subsurface (i.e., Qc-dominated responses compared to Qs-dominated responses). However, the range of values from Qs-dominated responses is over 2.5 orders of magnitude. This variation may be accounted for by varied silt and clay content in the matrix or as discrete lenses.

It is also possible that other non-native factors may influence slug test results such as well construction, slug test procedures, and well development practices.

The mean hydraulic conductivities from Tables 2.5 and 2.6 were plotted next to their respective wells to produce Figure 2.12.

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:

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

Where:

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

Groundwater velocities were computed for the groundwater flow paths used to calculate horizontal hydraulic gradients (Figures 2.8 and 2.9; Table 2.4). Since effective porosity values are difficult to obtain, the lowest of all total porosities from the eight Zone A Shelby tube samples, 29%, was used for effective porosity in groundwater velocity calculations. Choosing the lowest total porosity value will result in higher, more conservative groundwater velocities.

Due to the limited differences in the horizontal hydraulic gradient (*i*) with respect to tidal ranges as seen in Table 2.4, only the highest value for each measurement point was used to compute groundwater velocities. When no spatially discrete horizontal hydraulic conductivity (K_h) data were available for either endpoints along a groundwater flow path, the geometric mean of those

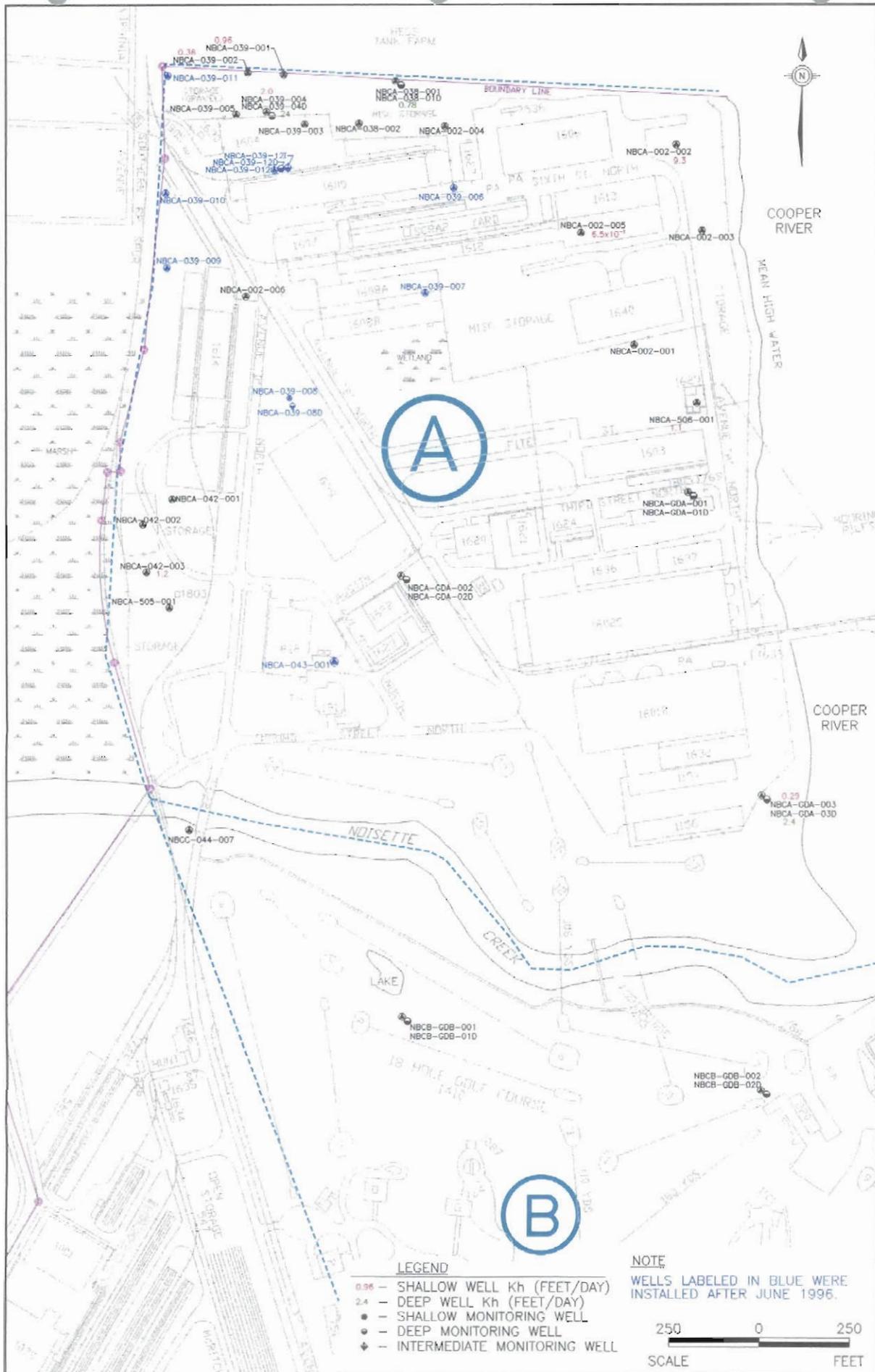
K_h values from locations in the vicinity of the flow path was used. For example, the geometric mean of the K_h values from well locations NBCA-039-004, NBCA-039-002, and NBCA-039-001 was used to represent an average K_h along flowpath "A." Similarly, a geometric mean of the K_h values from well locations NBCA-042-003 and NBCA-GDA-003 was used as a representative K_h value along flowpath "F." Table 2.7 presents estimated maximum groundwater velocities for each of the groundwater flow paths.

Table 2.7
Groundwater Velocity Results

Flow path	n_e (decimal %)	K_h (ft/day)	Maximum i (ft/ft)	Estimated Maximum Velocity (ft/day)
A	0.29	1.1	0.010	0.0380
B	0.29	0.065	0.004	0.0009
C	0.29	0.29	0.043	0.0430
D	0.29	0.36	0.007	0.0090
E	0.29	0.96	0.020	0.0660
F	0.29	0.64	0.007	0.0154

2.3 Climate

Data in this section, including temperature and wind data in Tables 2.8 and 2.9 are from the S.C. SEA Grant Consortium, 1992. Charleston Harbor area climate is typically mild compared to other areas farther inland. The mountains in the northern portion of the state block 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.



LEGEND

- 0.96 - SHALLOW WELL Kh (FEET/DAY)
- 2.4 - DEEP WELL Kh (FEET/DAY)
- - SHALLOW MONITORING WELL
- - DEEP MONITORING WELL
- ◆ - INTERMEDIATE MONITORING WELL

NOTE
WELLS LABELED IN BLUE WERE INSTALLED AFTER JUNE 1996.

250 0 250
SCALE FEET

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FIGURE 2.12
AREAL DISTRIBUTION OF
HYDRAULIC CONDUCTIVITY (kh)
IN SURFICIAL AQUIFER

The average monthly air temperatures for the Charleston area are presented in Table 2.8. 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 2.8
Mean Temperature and Wind Data
for Charleston Harbor between 1970 and 1985

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

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. Winds prevail to the north in the fall and winter, and to the south 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 2.9.

The Charleston area averages 124.9 centimeters (cm) of precipitation annually, which is 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.

Relative humidity in the Charleston Harbor area is normally very high and fluctuates greatly. Generally, it is higher during the summer months than at 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 is presented in Table 2.9.

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 2.9.

The primary concern in climate extremes 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.

Table 2.9
Monthly and Annual Mean Precipitation, Relative Humidity, and Cloud Cover
for Charleston Harbor between 1960 and 1985

Month	Precipitation (cm)	Relative % Humidity (by Time of Day)				Cloud Cover % Number of Days		
		0100 hrs.	0700 hrs.	1300 hrs.	1900 hrs.	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

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3.0 FIELD INVESTIGATION

The following section lists the field investigation objectives and describes the technical sampling methods, procedures, and protocols implemented for Zone A data collection. Fieldwork was conducted in accordance with the CSAP and the USEPA Region IV, Environmental Services Division, *Standard Operating Procedures and Quality Assurance Manual* (February 1991) (ESDSOPQAM) which was subsequently revised with the title *Environmental Investigations Standard Operating Procedures and Quality Assurance Manual* (May 1996). Sampling and investigatory methods used in the Zone A RFI 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 detailed in Section 10, Site-Specific Evaluations.

3.1 Investigation Objectives

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

- Characterize the Zone A sites.
- Define contaminant pathways and potential receptors (on and offsite, where applicable).
- Define the nature and extent of contamination, if any, at Zone A sites.
- Assess human health and ecological risk.
- Assess the need for corrective measures.

3.2 Sampling Procedures, Protocols, and Analyses

3.2.1 Sample Identification

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 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 interval. For example: sample ID 039SB00802 is a second-interval soil sample from Boring B008 at SWMU 39. For the groundwater samples, the ninth and tenth characters identify the sampling sequence. For example, 505GW00101 would be the first groundwater sample collected from monitoring well W001 at AOC 505, and 505GW00102 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 these procedures.

3.2.2.1 Soil Sample Locations

Soil samples were collected from locations proposed in the *Final Zones A and B RFI Work Plan*, which were based on the investigation strategy outlined in Section 1.2 of that plan. 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 obstructions.

As outlined in Section 2 of the *Final Zones A and B RFI Work Plan*, the Charleston Naval Shipyard (CNSY) Radiological Control (RADCON) Office performed detailed radiological surveys at Zone A sites with a low potential for radioactivity. Collection of samples from six of the proposed boring locations at SWMU 2 and one grid-based soil boring was postponed until closure of the DRMO facility, due to the potential for encountering low-level radiologically contaminated material. After the closure of DRMO, RADCON returned to SWMU 2 to complete the survey. Samples were collected from these locations during the second-round soil sampling event (January 1997).

At some sites, additional samples were required to adequately characterize contaminant distribution. After the analytical data were interpreted for the initial round of soil samples, a second and third sampling round were proposed in some areas. 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 collected for laboratory analysis from 0- to 1-foot bgs and from 3- to 5-foot bgs. The 0- to 1-foot bgs interval is referred to in this report as the “first” or “upper interval.” 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.” One other interval, unique to Zone A, was sampled during the Geoprobe investigation. A subsurface soil sample (2' to 4') was collected from each Geoprobe boring. This 2- to 4-foot bgs interval is referred to as the “Geoprobe” interval.

No other intervals were sampled due to the relatively shallow depth to groundwater in Zone A, typically from 3 to 6 feet bgs. No saturated soil samples were retained for laboratory analysis.

Stainless-steel hand augers were used to collect soil samples. At grassy locations, the vegetative root zone (generally less than 2 inches thick) overlying the soil 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 the portion for volatile organic analysis (VOA) was immediately collected with a stainless-steel spoon. The remaining sample was placed in a stainless-steel mixing bowl. This process was repeated until the entire interval had been collected. The hole was then augered to approximately 3 feet bgs, and a new, decontaminated auger bucket was used. The lower interval sample was then collected, following the same sample collection procedures as the upper interval. A coring

machine was used at numerous locations within Zone A 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. The following is a brief overview of the procedures for soil samples.

Sample material was transferred from the stainless-steel bowl to glass sample jars using a stainless-steel spoon. VOA samples were not homogenized, but were containerized immediately with zero headspace to reduce volatilization. Soil for all other analyses was homogenized with a stainless-steel spoon and placed into appropriate containers. Any remaining soil was returned to the auger hole. Bentonite pellets, hydrated in place with American Society for Testing and Materials (ASTM) Type III water, 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. Information such as weather conditions, date and time of collection, sampling team, and a sketch of the location was recorded in a Zones A and B soil sampling logbook.

Soil sample containers were individually custody-sealed, encased in protective bubble wrap, double-bagged in waterproof resealable plastic bags, and placed on ice in a cooler to ensure proper preservation at 4°C during shipment. A temperature blank was included inside each cooler that contained samples during shipment. Information for all samples was recorded on a preprinted chain-of-custody form, which was then affixed to the top inside surface of the sample cooler.

After recording sample numbers, analyses, times, date, and an air-bill shipping number on 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
- Semivolatile organic compounds (SVOCs) USEPA Method 8270
- Pesticides/polychlorinated biphenyls (PCBs) USEPA Method 8080
- Cyanide USEPA Method 9010
- Appendix IX Metals USEPA Method 6010/7000 series
- Total petroleum hydrocarbons (TPH) USEPA Method 418.1

Approximately 10% of the soil samples collected at Zone A 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, Appendix IX parameters analyzed for included:

- Hexavalent chromium USEPA Method 218.4
- Dioxins USEPA Method 8290
- Herbicides USEPA Method 8150
- Organophosphorus (OP) pesticides USEPA Method 8140

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 shallow monitoring well depth was 11 to 13 feet bgs.

For each monitoring well borehole, 2-foot split-spoon samples were typically 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. Shelby tube samples representing the lithology of the typical screened interval for each SWMU/AOC were retained for grain-size analysis.

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 not to raise the hollow-stem auger sections higher than the filter pack level in the borehole, in order to prevent the formation from collapsing on the well screen. Bentonite pellets were placed from the top of the filter pack to ground surface, then hydrated with potable water. After allowing for 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 Intermediate Monitoring Well Installation

Five intermediate monitoring wells were installed in Zone A (SWMU 39) to allow groundwater sampling of a discrete sand interval between the shallow and deep monitoring wells. The monitoring wells were installed using mud-rotary drilling methods and were continuously sampled using standard 2-inch diameter split-spoons. Mud-rotary drilling uses a recirculated mixture of potable water and bentonite powder. The recirculated fluid is pumped down the inside of the rotating drill string and exits at the bit. The fluid carries the drill cuttings from the bottom of the hole to the surface as the bit is advanced. Cuttings settle out of the fluid as it enters the circulation tank situated over the top of the boring at ground surface. Cuttings are removed from the tank as they accumulate and are placed in labeled Investigation-Derived Waste (IDW) containers. The intermediate monitoring wells were installed in borings advanced through 6" ID PVC surface casings. The casings had been installed into the top of the clay unit which separates the intermediate sand from the shallow aquifer. The 6" ID surface casings were cemented in place to stabilize them and to seal the annular space from potential downward migration of contaminant fluids from the shallow aquifer. No fluids were allowed to enter the surface casings prior to advancing the well boring through the casings. A 10-foot section of 2-inch ID, 0.010-inch factory slot PVC screen was installed in the target interval. Attached to the screen was an appropriate length of 2-inch ID PVC riser pipe. Filter pack sand was tremied into place to a level approximately 2 feet above the screened interval. A bentonite seal at least 2 feet thick was then tremied into place on top of the filter pack. The remaining interval of borehole was then tremied to the surface with a high density solids bentonite grout.

3.2.3.3 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. Three grid-based and nine site-specific

deep monitoring wells were installed in Zone A to allow groundwater sampling where the shallow aquifer's base contacts the underlying Ashley Formation.

Rotasonic drilling methods were used to install five of the deep monitoring wells, and mud rotary was used for the other seven (Section 3.2.3.2). Rotasonic drilling combines standard rotary action with sonic vibration. The sonic vibration created at the surface is directed to the subsurface through the drill string, displacing formation material rather than forcing cuttings back to the surface as do more traditional drilling methods. The Rotasonic method produces a continuous core sample that can be used to precisely characterize the lithology. Soil samples were logged and classified as described in Section 4.2 of the CSAP. Ten- to 20-foot core sections were typically produced, depending on anticipated proximity to the target formation.

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

3.2.3.4 Monitoring Well Protector Construction

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

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

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

3.2.3.5 Monitoring Well Development

Monitoring well development consisted of initially stressing the filter pack by surging and pumping, then pumping until turbidity was reduced as much as practical and specific conductance, pH, and temperature were stabilized as described below. Monitoring 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 20 minutes per well.
5. The surge block was removed from the well for decontamination.

Shallow Well Pumping Procedures:

1. Decontaminated Teflon 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 $\pm 1.0^{\circ}\text{C}$

pH: within ± 0.5 standard unit

Conductivity: within $\pm 10\%$ from the previous reading

Turbidity: generally between 10 and 30 nephelometric turbidity units (NTUs) or relatively stable (± 15 NTU)

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

3.2.4 Groundwater Sampling

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

3.2.4.1 Groundwater Sample Locations

Groundwater samples were collected from well locations based on the approved locations identified in the *Final Zones A and B RFI Work Plan*. No proposed locations were adjusted during field activities.

3.2.4.2 Groundwater Sample Collection

Groundwater sample collection followed these steps:

1. Wells were allowed to recover for at least two weeks after being developed.
2. Decontaminated sampling equipment and supplies were transported to the monitoring well.

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

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.

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. Otherwise, a water-level meter was used. All measurements were recorded to the nearest 0.01 foot. Static water level was measured 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.

6. New decontaminated Teflon 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 measure volume removed, which was recorded in the field logbook.

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 when three consecutive temperature, specific conductance, and pH readings met the criteria outlined

for well development as described in Section 3.2.3.4. Turbidity was monitored until the reading was less than 10 NTUs or it 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. Lithologic variabilities prevented purging some wells to a turbidity of less than 10 NTUs. For example, in wells installed in areas with increased silt content, it was 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 monitoring well. Samples for VOC analyses were collected first by capping the tubing and raising it from the well and then allowing the contents to drain into the sample containers. A precleaned transfer bottle equipped with an airtight cap containing an inlet and outlet was then assembled to collect all other sample containers. Once this system was established, the vacuum created allowed collection of groundwater which was directly poured into the appropriate sample container. Where additional volumes were needed, the transfer bottle was filled repeatedly. Samples for organic analyses were poured prior to inorganics. Samples were collected for pesticides/PCBs, herbicides, metals, cyanide, sulfates, chlorides, total dissolved solids (TDS), dioxin, hexavalent chromium, OP pesticides, TPH, and SVOC analyses.

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 preparing, packaging, and shipping groundwater samples collected during the Zone A RFI. The following briefly summarizes those activities.

Groundwater samples were preserved according to laboratory criteria for parameters being analyzed. Appropriate labels and custody seals were completed and affixed to each sample bottle. Immediately after sample collection and identification, sample containers were placed on ice in coolers. Records of sampling were entered in 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, double-bagged in waterproof resealable plastic bags, and placed on ice in a cooler to ensure proper preservation at 4°C during shipment. All sample information was recorded on a preprinted 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.

After recording sample numbers, analyses, times, date, and an air-bill shipping number on an official shipping log, the coolers were shipped priority overnight via FedEx to the laboratory for analyses.

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
- Appendix IX Metals USEPA Methods 6010/7000 Series

- TPH
(diesel range organics — DRO) USEPA Method 3550/Modified 8015
(gasoline range organics — GRO) USEPA Method 5030/Modified 8015

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

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

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

The zone-wide second, third, and fourth rounds of quarterly groundwater sampling were conducted in April, June, and October 1996, respectively. These results are included in this report rather than a separate quarterly groundwater summary report.

3.2.5 Sediment Sampling

Sediment was sampled in accordance with Section 7 of the CSAP. The following subsections briefly summarize those methods as applied in Zone A.

3.2.5.1 Sediment Sample Locations

Sediment samples were collected from the approved locations identified in the *Final Zones A and B RFI Work Plan*. All sediment sample locations were accessible by land.

3.2.5.2 Sediment 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.

Stainless-steel spoons and bowls were used to collect sediment samples. After the sample location was determined, 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 remainder was homogenized in the bowl and placed into the appropriate sample containers.

3.2.5.3 Sediment Sample Preparation, Packaging, and Shipment

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

Sediment 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 of this RFI report. Appropriate labels and custody seals were completed and affixed to each sample bottle. Immediately after sample collection and identification, sample containers were placed on ice in coolers. Sampling information was recorded in a dedicated field logbook and in a master logbook placed in a fireproof safe in the site trailer.

Sediment sample containers were individually custody-sealed, encased in protective bubble wrap, double-bagged in waterproof resealable plastic bags, and placed on ice in a cooler to ensure proper preservation at 4°C during shipment. All sample information was entered on a preprinted 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.

3.2.5.4 Sediment Sample Analysis

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

- Metals 40 CFR Part 264 Appendix IX

In addition to metals analyses, selected sediment samples were analyzed using the following methods:

- VOC USEPA Method 8240
- SVOC USEPA Method 8270
- Pesticides/PCBs USEPA Method 8080
- Cyanide USEPA Method 9010
- Organotins Per Triangle Laboratories, Research Triangle Park, North Carolina Standard Operating Procedure
- Dioxins USEPA Method 8290
- Hexavalent Chromium USEPA Method 218.4
- Organophosphorus pesticides USEPA Method 8140

3.2.6 Geoprobe Sampling

A Geoprobe investigation was completed in June 1996 at three sites within Zone A to further delineate the extent of VOC contamination in groundwater. Sampling was performed in accordance with Section 6.1.3 included in Revision No. 01 of the CSAP. Although this document had not received final regulatory approval at the time of the investigation, the applicable sections

did not receive comments requiring modifications. The following sections detail the Geoprobe sampling conducted in Zone A.

3.2.6.1 Geoprobe Sample Locations

Thirty-two borings were pushed in Zone A: 21 at SWMU 39, five at SWMU 42/AOC 505, three at SWMU 42, and three at AOC 506. All locations were permitted in accordance with SCDHEC well standards and regulations.

3.2.6.2 Geoprobe Sample Collection

Subsurface soil (2' to 4') and groundwater samples from the shallow aquifer were collected at each location. Approximate collection depths for groundwater samples were 5 to 10 feet below ground surface. Each sample was rapidly analyzed by an onsite laboratory using a GC/MS (Method 5030/8260), and 25% of any samples analyzed onsite were sent to an offsite lab. After sampling, each borehole was abandoned using either bentonite pellets or a high-solids bentonite grout.

3.2.6.3 Geoprobe Sample Preparation, Packaging, and Shipment

Samples analyzed onsite were labeled and placed on ice in a cooler immediately after collection, then delivered to the onsite laboratory in groups approximately every 2 hours. The duplicate offsite samples were handled in a similar manner to other soil (Section 3.2.2.3) and groundwater samples (Section 3.2.4.3) collected in Zone A.

3.2.6.4 Geoprobe Sample Analysis

Geoprobe samples (soil and groundwater) were analyzed per USEPA SW-846 at DQO Level III as follows:

- VOC USEPA Method 5030/8260

3.2.7 Cone Penetrometer (CPT) Sampling

A cone penetrometer study was conducted in September 1996 in the vicinity of SWMU 39 in the northern portion of Zone A. The CPT investigation goals were three-fold:

- 1) To obtain lithologic data on NAVBASE property to facilitate mapping of permeable and impermeable geologic units.

- 2) To obtain lithologic data beyond the perimeter of NAVBASE property for extending the boundaries for geologic mapping.

- 2) To sample groundwater at several locations and intervals beyond the perimeter of NAVBASE property to assess groundwater quality.

All sampling was performed in accordance with Section 6.1.3 included in Revision No. 01 of the CSAP.

3.2.7.1 CPT Sample Locations

Thirteen cone penetrometer borings for lithologic data were advanced within the vicinity of SWMU 39. The maximum depth of these borings was 68 feet below ground surface.

Sixteen borings were advanced in the neighborhood streets outside the Virginia Avenue entrance to NAVBASE. Of the sixteen locations, two locations were only sampled for lithologic data, eight were sampled for lithologic data and groundwater, and six were sampled for groundwater only. The deepest boring off-base was 60 feet below ground surface.

All on-base and off-base sampling locations were permitted in accordance with SCDHEC well standards and regulations. All borings were abandoned from bottom to ground surface upon probe extraction using a high solids bentonite grout.

3.2.7.2 CPT Groundwater Sample Collection (off-base)

At locations where lithologic and groundwater samples were to be obtained, the cone penetrometer was first advanced to provide a lithologic data sounding from which intervals could be targeted for groundwater sampling. This borehole was abandoned, and the CPT rig offset at least five feet before advancing the groundwater sampling probe. The groundwater sampling probe generally obtained samples over a two foot interval at each location. At locations where only groundwater samples were obtained, the lithologic data from adjacent borings was extrapolated to assist in targeting groundwater sampling intervals. Groundwater samples were not obtained at two locations due to a lack of groundwater recharge into the sampler. Groundwater samples were generally taken from shallow intervals (between 8-12 feet bgs) and intermediate intervals (between 18-30 feet bgs). All groundwater samples were analyzed by an offsite laboratory for VOCs.

3.2.7.3 CPT Groundwater Sample Preparation, Packaging, and Shipment

Samples were labeled on-site and stored on ice in a cooler immediately after collection. Samples were shipped to the laboratory at the end of each day.

3.2.8 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 North American Datum 1983 and vertical datum of 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).

3.2.9 Aquifer Characterization

Rising and falling head slug tests were conducted according to Section 10.6.1 of the CSAP on 13 shallow, five intermediate, and seven 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 abruptly introduced into the well, at which time the water level and the start time were recorded. Periodically, water level/elapsed-time measurements were recorded using an electronic data logger. 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 slugs consisted of 3-foot long and 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 two-channel Hermit 1000C data loggers were used to record water level and elapsed-time measurements. To facilitate graphing of 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.

3.2.10 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. The detergent used on this project was Liquinox, which contains powerful chelating agents to bind and remove trace metals

from sampling equipment. 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 water pressure and temperature. All wastes generated during decontamination were containerized in a tanker for disposal by the Navy in accordance with Section 16 of the CSAP.

3.2.10.1 Decontamination Area Setup

The decontamination area is a concrete pad sloped to direct water runoff into a catch basin, from which liquids were pumped regularly into the tanker. Equipment was cleaned on sawhorses or auger racks above the concrete surface. When field cleaning of equipment (i.e., hand augers) at a location other than the decontamination area was necessary, plastic sheeting was placed on the ground to contain any spills.

3.2.10.2 Cross-Contamination Prevention

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

- Fresh disposable outer gloves were donned before handling sampling equipment.
- Only Teflon, glass, or stainless-steel spray bottles/pressurized containers were used to apply decontamination fluids. Each solution was kept in a separate container.
- All necessary decontaminated field equipment was transported to the sampling location to minimize the need for field cleaning.

3.2.10.3 Nonsampling Equipment

Nonsampling equipment used in Zone A included only drill rigs. The rigs were decontaminated using the following procedures:

1. Equipment was decontaminated with high-pressure hot water and/or steam.
2. Portions of the equipment coming in contact with material to be sampled were scrubbed with a laboratory-grade detergent and clean water wash solution.
3. Equipment was rinsed with clean water as necessary.

3.2.10.4 Sampling Equipment

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, etc.), 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:

1. Protective gloves were donned before decontaminating the equipment.
2. Items were washed and scrubbed with a laboratory-grade detergent and clean water wash solution or sprayed with high-pressure steam.
3. Equipment was rinsed with ASTM Type III water.
4. Equipment was rinsed twice with pesticide-grade isopropyl alcohol.

5. Equipment was rinsed with ASTM Type III water.
6. Equipment was air dried. If weather prohibited air drying, the isopropyl alcohol rinse was repeated and the item was rinsed with ASTM Type III water twice.
7. Items were wrapped in aluminum foil or plastic sheeting if the sampling equipment was stored or transported.
8. Augers and drill rods were covered in clean plastic after decontamination.

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4.0 DATA VALIDATION

4.1 Introduction

DQOs are qualitative and quantitative statements specifying the quality of data required to support decisions during environmental response actions. The level of certainty regarding data precision varies with their intended end use. According to USEPA guidance, *Data Quality Objectives for Remedial Response Activities, Development Process*, EPA/540/G-87/003 (USEPA, March 1987), analytical data levels are 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 an onsite mobile laboratory. The quality of the data generated depends on the use of suitable calibration standards, reference materials, and sample preparation equipment in addition to operator training. 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 does not need to be a CLP laboratory.

- Level IV — All analyses are performed in an offsite analytical laboratory following rigorous QA/QC protocols and documentation meeting or exceeding CLP requirements.

- Level V — Analysis by nonstandard methods. All analyses are performed by an offsite analytical laboratory that does not need to be a CLP laboratory. Method development or method modification may be required for specific constituents or detection limits. CLP special analytical services are classified as Level V.

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

In September 1993, USEPA replaced its 1987 guidance with an updated manual, *Data Quality Objectives Process for Superfund, Interim Final Guidance*, EPA/540/G-93/071 (USEPA, September 1993) which reduced the five analytical levels introduced in that document to two — screening data and definitive data.

Definitive data (formerly Levels 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 can be used to produce tangible raw data (e.g., chromatograms, spectra, digital values) in paper printouts or computer-generated electronic files. Analytical or total measurement error (precision) must be determined for the data to be definitive (USEPA, September 1993). As a result, the data collected at NAVBASE 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 produced from the analysis of environmental media samples collected in Zone A during the RFI. This evaluation will 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 for 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

RFI environmental samples were collected at Zone A from September 1995 to October 1997. Samples were analyzed by Lockheed Analytical Services, Ceimic Corporation, and Southwest Laboratories of Oklahoma. Triangle Laboratories of Research Triangle Park, North Carolina, conducted analyses for dioxins and dibenzofurans. Analytical Mobile Services performed onsite VOC analyses during the geoprobe investigation. In accordance with the approved CSAP, sample analyses followed the guidance in the *USEPA Test Methods for Evaluating Solid Waste, SW-846* (USEPA, 1992) and Title 40 CFR Part 264. Table 4.1 summarizes the analytical methods and DQO laboratory deliverables.

Table 4.1
NAVBASE Analytical Program

Full Scan/Appendix IX Analytical Methods	Data Quality Level	Method Reference
VOCs	III/IV	SW-846 8240
SVOCs	III/IV	SW-846 8270
Pesticides/PCBs	III/IV	SW-846 8080
Chlorinated Herbicides	III/IV	SW-846 8150
OP Pesticides	III/IV	SW-846 8140
TPH	III/IV	USEPA 3550 & 5030/Modified 8015
Cyanide	III/IV	USEPA 9012
Appendix IX Metals	III/IV	SW-846 6010/7060/7421/7470/7740/7841
Hexavalent Chromium	III/IV	USEPA 218.4
Polychlorinated dibenzo-p-dioxins	III/IV	USEPA 8290
Organotins	III/IV	Triangle Laboratories SOP

Notes:

Full Scan parameters include: VOCs, SVOCs, pesticides/PCBs, metals, and cyanide (Level III). *Appendix IX* parameters include: VOCs, SVOCs, pesticides/PCBs, herbicides, OP pesticides, metals, cyanide, hexavalent chromium, and dioxins (Level IV). The water field duplicate sample and the groundwater rinsate blank were analyzed for TPH as an additional QA/QC measure.

SOP = Standard Operating Procedures

The methods listed in Table 4.1 are from:

- USEPA 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.

- *Title 40 Code of Federal Regulations Part 264, Appendix IX (52 Federal Register 25947), July 1987.*

Third-party independent data validation of all analytical work performed under the CSAP was conducted by Heartland Environmental Services, Inc., St. Peters, Missouri, based on the QC criteria developed for CLP. 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.

4.2.1 Organic Evaluation Criteria

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 Program National Functional Guidelines for Organic Data Review* (February 1994) (Organic Functional Guidelines). For Zone A, these guidelines were used throughout the data evaluation process for this purpose.

Data evaluation included the following parameters:

- Holding times
- Gas Chromatography/Mass Spectroscopy (GC/MS) instrument performance checks
- Surrogate spike recoveries
- Instrument calibration
- Matrix spike and matrix spike duplicates (MS/MSD)
- Blank analysis
- Internal standard (IS) performance

- Compound quantitation
- Field duplicate precision
- Calculations

When the QC parameters did 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:

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.

J Estimated Value — One or more QC parameters were outside control limits or the compound was detected at a concentration less than the practical quantitation limit.

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.

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

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

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

4.2.1.1 Holding Times

Acceptable technical holding times are specified in the CSAP. The sample holding time depends on the type of analysis. For water and soil samples, the holding time for VOC analysis is 14 days from the collection date. SVOC, pesticide/PCB, OP pesticide, and chlorinated herbicide water samples must be extracted within seven days from the collection date and analyzed within 40 days after extraction. Soil samples must be extracted within 14 days of sample collection and analyzed within 40 days of collection. Dioxin water and soil samples require extraction within 30 days from date of collection and analysis within 45 days of collection. The holding time for TPH analysis is 28 days from the date of collection for both water samples that are preserved and refrigerated and soil samples that are refrigerated.

4.2.1.2 GC/MS Instrument Performance Checks

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

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 not normally found in environmental samples. Three surrogate compounds are added 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 OP pesticide and chlorinated herbicide samples. Percent recovery (%R) 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 below in Table 4.2.

Table 4.2
 Surrogate Compound Summary

VOC Surrogates	SVOC Surrogates	Pesticide/PCB Surrogates	Herbicide Surrogate	OP Pesticide Surrogate
Toluene-d8	Nitrobenzene-d5 (NBZ)	Tetrachloro-m-xylene (TCMX)	2,4-Dichloro-phenylacetic acid (DCAA)	Tributyl phosphate
Bromofluorobenzene (BFB)	2-Fluorobiphenyl (FBP)	Decachlorobiphenyl (DCB)		
1,2-Dichloroethane (DCA)	Terphenyl-d14 (TPH)			
	2,4,6-Tribromophenol (TBP)			
	Phenol-d5 (PHL)			
	2-Fluorophenol (2FP)			
Dioxin Surrogates				
¹² 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 multicomponent 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 multicomponent compounds are to verify that these steps were taken.

A five-point initial calibration is analyzed for herbicides, OP pesticides, and TPH. Two calibration methods 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, 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. Multicomponent compounds do not require continuing calibration.

For herbicides and OP 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 rather than a low bias.

4.2.1.5 Matrix Spike/Matrix Spike Duplicate

An MS, which is used to determine the accuracy of the analysis for a given matrix, 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 %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 (RPD) 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 the Organic Functional Guidelines.

4.2.1.6 Laboratory Control Samples and Laboratory Duplicates

TPH and other GC methods may require laboratory control samples (LCSs) 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 presence and magnitude of potential contamination introduced during analysis. Additionally, field blanks may be collected to assess any contamination introduced while collecting samples. 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 Organic 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 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 less than the quantitation limit and less than the AL, the quantitation limit is reported as nondetect *U*.
- If the sample concentration is between the quantitation limit and the AL, the concentration is reported as nondetect *U*.
- If the sample concentration is greater than the AL, the concentration may be used unqualified.

4.2.1.8 Field-Derived Blanks

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 in the laboratory before the containers are shipped to the field. It is used to assess cross-contamination during VOC sample container handling, storage, and shipment.

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

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

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

4.2.1.9 Internal Standard Performance

A GC/MS IS is 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 IS compounds recommended by the methods.

VOC IS Compounds	SVOC IS Compounds	Dioxin
Bromochloromethane (BCM)	1,4-Dichlorobenzene-d4 (DCB)	¹³ C ₁₂ - 2,3,7,8-TCDD
1,4-Difluorobenzene (DFB)	Naphthalene-d8 (NPT)	¹³ C ₁₂ - 2,3,7,8-TCDF
Chlorobenzene-d5 (CBZ)	Acenaphthene-d10 (ANT)	¹³ C ₁₂ - 1,2,3,7,8-PeCDD
	Phenanthrene-d10 (PHN)	¹³ C ₁₂ - 1,2,3,7,8-PeCDF
	Chrysene-d12 (CRY)	¹³ C ₁₂ - 1,2,3,6,7,8-HxCDD
	Perylene-d12 (PRY)	¹³ C ₁₂ -1,2,3,4,7,8-HxCDF
		¹³ C ₁₂ -1,2,3,4,6,7,8-HpCDD
		¹³ C ₁₂ -1,2,3,4,6,7,8-HpCDF
		¹³ C ₁₂ -OCDD

Notes:

TCDD (Tetrachlorodibenzo-p-dioxin)	HpCDF (Heptachlorodibenzofuran)
TCDF (Tetrachlorodibenzofuran)	HxCDD (Hexachlorodibenzo-p-dioxin)
PeCDD (Pentachlorodibenzo-p-dioxin)	HxCDF (Hexachlorodibenzofuran)
PeCDF (Pentachlorodibenzofuran)	OCDD (Octachlorodibenzo-p-dioxin)
HpCDD (Heptachlorodibenzo-p-dioxin)	

4.2.1.10 Diluted Samples

A special evaluation was performed for diluted samples to determine if method detection limits were sufficiently low to be compared with reference concentrations (e.g., Maximum Contaminant

Levels [MCLs], Risk-Based Concentrations [RBCs]). Table 4.3 lists all diluted samples from Zone A.

**Table 4.3
 Diluted Samples**

Sample ID	Sample Delivery Group	Parameter	Dilution Factor	Results (ppb)
038SB00101	L5510(PEST)	4,4'-DDT	27,000	1,000,000
038SB00101	L5510(PEST)	4,4'-DDE	1,500	37,000
038SB00101	L5510(PEST)	4,4'-DDD	14,000	450,000
039SB00802	L5506(VOA)	Ethylbenzene	1,200	22,000
039SB00802	L5506(VOA)	Xylene	2,400	48,000
039SB00602	L5506(VOA)	Xylene	480	9,300

Note:

ppb = parts per billion

4.2.2 Inorganic Evaluation Criteria

The USEPA methods described in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846)*, and 40 CFR Part 264, Appendix IX define QC 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 Program National Functional Guidelines for Inorganic Data Review*, February 1994 (Inorganic Functional Guidelines). The guidelines were used throughout the data evaluation process to address data usability.

Data evaluation for samples collected at NAVBASE for inorganic analyses included:

- Holding times
- Instrument calibration
- MS results

- Laboratory duplicates
- Blank analysis
- Inductively Coupled Argon Plasma (ICAP) interference check samples
- ICAP serial dilutions
- LCS results
- Atomic Absorption (AA) duplicate injections and postdigestion spike recoveries
- Field duplicate precision

According to the Inorganic 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:

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 five times the blank concentration.

J **Estimated Value** – One or more QC parameters were outside control limits or the element was detected at a concentration less than the practical quantitation limit.

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 instrument performance 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 presence 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 data's usability depends on the reviewer's judgment and the blank's origin. According to the Inorganic Functional Guidelines, a sample result should not be considered positive unless the sample concentration exceeds five times the amount in any blank (the AL). Because blank samples may not be prepared using the same weight or volume of a

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 nondetect *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 Inductively Coupled Argon Plasma Interference Check Samples

The ICAP interference check sample is used to confirm the laboratory instrument's interelement and background correction factors. Interference samples should be analyzed at the beginning and end of each sample analysis or at least twice per 8-hour working shift. The %Rs for the interference check sample should fall between 80% and 120%.

4.2.2.5 Laboratory Control Samples

An LCS is 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 reproducibility. 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 ICAP Serial Dilutions

ICAP serial dilutions assess whether matrix interference is present. 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 and the diluted sample should agree within 10%.

4.2.2.9 AA Duplicate Injections and Postdigestion Spike Recoveries

During AA analysis, duplicate injections and postdigestion spikes are used to assess precision and accuracy of the laboratory analysis. The %RSD of duplicate injections must agree within 20%. Percent recovery of the post-digestion spike sample should fall between 85% and 115%.

4.3 Zone A Data Validation Reports

A complete copy of the Zone A Data Validation Reports is included as Appendix E for review. These reports are the outcome of the evaluations described above and are specific to the analytical data collected during the Zone A RFI.

5.0 METHODOLOGY FOR DETERMINING NATURE AND EXTENT OF CONTAMINATION

This section describes the approach and technical methods employed to determine types (nature) and areal extent of all chemicals present in site samples (CPSS) of soil and groundwater at Zone A SWMUs and AOCs, and to compare concentrations of inorganics in site samples to naturally occurring background concentrations. Nature and extent were evaluated to determine the overall distribution of constituents detected on micro (site-specific), and macro (zone-wide) scales. In addition, these data will be used to assess basewide conditions and the relationship of contaminants between zones across NAVBASE.

Types of chemicals detected at Zone A include: VOCs, SVOCs, pesticides, PCBs, dioxins, and inorganics. Detected concentrations were compared to corresponding RBCs in the USEPA Region III *Risk-Based Concentration Table* (October 1997) to: (1) evaluate the significance of the detections; (2) determine the need for additional sampling (if any) to define the extent of contamination; and (3) develop investigative endpoints. Detected inorganic concentrations were also compared to corresponding background (reference) concentrations. The comparisons 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.

Site-specific nature and extent evaluations for AOCs and SWMUs in Zone A are detailed in Section 10 of this report.

5.1 Organic Compound Analytical Results Evaluation

Concentrations of organic compounds detected in Zone A soil and groundwater were compared to RBCs. Information was also compiled on each compound's frequency of detection and its average and range of detected concentrations (see Section 10).

Dioxin data reflect summations of the tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) equivalency quotient (TEQ) values 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), the 1989 update (USEPA, 1989d), 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 microgram per kilogram ($\mu\text{g}/\text{kg}$) for a worker/industrial scenario, based on a slope factor approach currently endorsed by USEPA (Section 7.3.4). The rationale for using the industrial scenario based TEQ is provided in the risk management discussion in Section 11.

In accordance with recent carcinogenic polynuclear aromatic hydrocarbons (cPAH) guidance (USEPA, Region IV, November 1995a), 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.

5.2 Inorganic Analytical Results Evaluation

Sample results for inorganics are often difficult to evaluate because inorganics are naturally occurring and ubiquitous in soil. Compounding this difficulty is the fact that much of the soil at NAVBASE is dredge-fill material that has been artificially placed onsite. The following describes the step-by-step procedures used to determine background for inorganics in soil and groundwater at Zone A and the statistical approach for comparing background data to site data.

Many chemicals, particularly carcinogenic metals such as arsenic and beryllium, are typically detected at concentrations much higher 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 chemicals. The problem is how to determine these

reference (or background) concentrations, and how much higher than background a parameter must be at a site before it is of concern. In the past, USEPA Region IV guidance recommended using twice the mean of the background sample concentrations as an upper bound for each inorganic and considered any site-related sample higher than this bound to be contaminated. Although this method is appropriate with small datasets, it would be less appropriate to use with the relatively large grid-based datasets developed for soil at Zone A (13 soil borings). The larger soil datasets allowed the use of more sophisticated statistical tests.

EnSafe used a dual testing procedure to compare AOC/SWMU inorganic constituent concentrations to those of the grid-based dataset. Parametric or nonparametric upper tolerance limits (UTLs) were calculated and used as reference concentrations in combination with Wilcoxon rank sum tests to make the comparisons for soil. Due to the small size of the shallow and deep groundwater background datasets (three well pairs), twice the mean concentrations of most groundwater constituents in first-round samples served as their background reference levels. Following evaluation of analytical results from four sampling rounds, several groundwater reference values were recalculated using nonparametric UTLs. Background values were calculated according to established procedures for NAVBASE, in consultation with the project team technical subcommittee at meetings on April 7 and April 25, 1997.

5.2.1 Background Datasets

The background dataset for Zone A soil collected from the upper interval consisted of 13 grid-based samples (GDASB00101 to GDASB00301; GDASB00501 to GDASB01401) for all analytes except arsenic, which had a dataset of 16 samples due an anomalously high concentration in sample GDASB006 (see Section 10.8.1 for further details). The lower interval soil dataset consisted of 12 grid-based samples (GDASB00102 to GDASB00302; GDASB00502 to GDASB00902; and GDASB01102 to GDASB01402). The background dataset for shallow

groundwater was derived from three well locations (NBCAGDA001 to NBCAGDA003) as was the dataset for deep groundwater (NBCAGDA01D to NBCAGDA03D).

Descriptive statistics were compiled for the original soil 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 more closely approximate normal distributions. Descriptive statistics of the transformed data were compared to those of the originals. Seven of the ten upper-interval soil datasets that were analyzed parametrically required transformation before analysis, while seven of nine lower-interval soil datasets required transformation. Those datasets that could not be transformed to approximate normal distributions were analyzed nonparametrically.

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).

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 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 ends 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), in which all values greater than four standard deviations above the mean are discarded, as well as Rosner's test, Dixon's test, the Shapiro-Wilk test, and others (Gibbons, 1994).

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 to background.

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 the datasets. In practice, this meant using one-half of the *U* values reported by the analytical laboratory and confirmed by the validator. Analytical results qualified *R* or *UR* were considered unusable and were not included in the datasets.

5.2.3 Developing Datasets for Sites

Results of laboratory analyses of samples from the AOCs and SWMUs were assembled into datasets for each chemical of interest from upper and lower interval soils and from shallow and deep groundwater, for comparison to 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). Assuming 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. The other possible error, the false-negative rate, β , can be seen as the probability of concluding from a test that no difference exists when in reality such a difference does exist: the site will be considered clean when it is contaminated. The *power* of the test ($1-\beta$), which is the complement of the false-negative rate, is a measure of the strength of the conclusion that a difference does exist; it can be thought of as the probability of correctly identifying a contaminated site (Table 5.1). Calculating β and power is more difficult than specifying α ; they depend upon the magnitude of the actual concentration differences, the size of the sample, and the form of the probability distribution for the measurement process.

Table 5.1
Probability of Possible Conclusions of a Hypothesis Test

Test Results	— 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 sample size. A test that rarely rejects the hypothesis of "no contamination" will be more prone to miss an actual difference. A test that frequently concludes contamination is present, on the other hand, will be more likely to make the mistake of concluding that a difference arising by chance is a real difference. The total amount of error can be minimized in two ways: by increasing the sample size or by using a test that is "most powerful." The choice of the form of the hypothesis test is crucial to minimizing the total error.

USEPA Region IV often suggests a "two times the mean" test: If the maximum detected concentration of a chemical at a site exceeds twice the mean background concentration, 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 concentrations are never *level*; that is, the nature of the background data greatly affects the result of applying the "two times the mean" 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 exceeds 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 the mean" 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 use the available data most effectively.

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 ten 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 original or transformed values or by using standard methods of estimating quartiles (e.g., Gilbert, 1987). It can also be done nonparametrically by comparing to a percentile of the background sample 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 tolerance intervals 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 of the interval, with 95% confidence. Once the interval is constructed, each site sample is compared to the UTL, or reference concentration (USEPA, 1992b). 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:

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

For original (untransformed) data values, the expression reduces to:

$$X + k (s)$$

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 (the coverage). For a given set of α and P_0 , k depends on the sample size, n. For $n = 13$ (the background sample size for upper interval soil in Zone A), $k = 2.670$ when $\alpha = 0.05$ and $P_0 = 0.05$ (confidence = 95%, coverage = 95%). Based on these numbers, the UTL for original (untransformed) background concentration values of a given element is therefore:

$$\text{UTL} = \text{mean} + 2.670 (\text{standard deviation})$$

According to a USEPA statistical training course manual (USEPA, 1992c), “Tolerance intervals 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 8 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, to be used for background comparisons. Shallow and deep groundwater background datasets for most Zone A inorganics contain only three samples apiece. Reference concentrations for these chemicals in groundwater were computed as twice the mean of the three sample concentrations.

Where a significant proportion (>50%) of the samples were nondetect (ND), or where transformed values could not be made to approximate a normal distribution, means and standard deviations could not be computed accurately, and it was necessary to employ nonparametric tolerance intervals. In these circumstances, the UTLs 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 the largest observed background value as the standard of comparison (USEPA, 1992b). As with the parametric calculations, the method was applied after removal of outliers from the datasets.

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

- Where NDs $\leq 50\%$, use parametric UTL (where justified by data distribution).
- Where $50\% < \text{NDs} < 90\%$, use nonparametric UTL: highest value in dataset.
- Where NDs $\geq 90\%$, no valid background value can be determined.

The power of a tolerance-limit test 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 sample values. 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 site's 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 background samples, as a group, for contamination to be identified onsite.

The most commonly prescribed method for comparing two populations is the Student's *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. Not all of the background datasets could be transformed to approximate normality. Although values in most of the relatively large background datasets were approximately normally distributed after being transformed (by LN or square root), if necessary, there was no reason to expect that values in the smaller site datasets would be. In addition, the presence of estimated values for nondetects would have called 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). The method for handling nondetect and qualified values is important because it affects their ranks. Detected but not quantified values (*J*s) should receive higher ranks than nondetects (*U*s). 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 such differences.

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). 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 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 samples, the sample size at each site, and the sample size of the background.

5.2.7 Summary of Statistical Techniques Used

Techniques that allow the use of statistical inference were chosen. Methods used are capable of detecting situations where: (a) individual site values are much higher than background, or (b) site values are generally higher than background. For situation (a), soil background data values were transformed where appropriate to approximate normal distributions, then site values were compared to a parametric UTL consisting of mean plus *k* standard deviations of the background data values, where *k* depends on sample size. Where the percentage of background nondetects was high or an approximately normal distribution could not be achieved, nonparametric UTLs were used; above 90% nondetects in background, no reliable tolerance limits can be determined. For most groundwater constituents, twice the mean concentration of the first-round background samples served as the background reference value. With the concurrence of the project team

technical subcommittee, nonparametric UTLs replaced the original background values for several inorganics following analysis of four rounds of sampling results.

To account for situation (b) above, the Wilcoxon rank sum test was applied for both soil and groundwater, where appropriate, to compare each group of site values to its corresponding background group. Where the Wilcoxon test could not be run due to an insufficient number (<4) of site and/or background samples, only the tolerance-limit test or the “twice the mean” test was performed.

5.2.8 Combined Results of the UTL (Reference Concentration) and the Wilcoxon Rank Sum Tests

Methods described in Section 5.2.5 identify individual site samples with concentrations significantly higher than background, while the method in Section 5.2.6 identifies entire sites. If the results from either test were positive (i.e., significantly higher than background), sample values were compared to the corresponding USEPA RBCs and, where appropriate, carried forward into detailed human health risk assessment. Where background comparisons could not be carried out for a chemical due to lack of detections in background samples, site concentrations were screened against risk-based concentrations only.

5.2.9 Conclusion

The overall approach documented here is conservative for a number of reasons: (1) the number of background samples for soil is above the minimum recommended in various guidance documents (e.g., USEPA RAGS, 1989a), producing greater confidence in the ability to characterize background and to distinguish background concentrations from those at sites; (2) following procedures described in Section 5.2.1, high values were removed from the background datasets whether or not they were true outliers in the conventional sense, thereby lowering the total background concentrations to which the site values were compared; and (3) the

use of two complementary tests increased the likelihood that any contamination would be identified and addressed further, since a positive result from either test triggered a detailed human health risk assessment whenever site concentrations exceeded corresponding USEPA RBC values.

5.2.10 Background Reference Values

Tables 5.2 and 5.3 summarize the steps taken in calculating UTL or reference concentrations for Zone A surface soil and subsurface soil, respectively. UTLs were calculated for 13 inorganic chemicals in surface soil and 12 inorganics in subsurface soil. Table 5.4 presents reference concentrations for shallow and deep groundwater, most of which were derived using USEPA's "twice the mean" guideline applied to analytical results from first-round groundwater samples from grid wells. Background values for two shallow groundwater constituents (arsenic and manganese) and four deep groundwater constituents (arsenic, barium, chromium, and manganese) were later recalculated as nonparametric UTLs using four rounds of sampling results. In all of the background calculations, nondetect (ND) values were treated as discussed above in Section 5.2.2.

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Table 5.2
Charleston Zone A Surface Soils (upper interval)
Characteristics of Background Datasets

Chemical	n	Mean (mg/kg)	Data Transformation	Type of UTL	UTL (mg/kg)	RBC (mg/kg)
Aluminum	13	7,370	none	parametric	12,800	7,800
Antimony	13		(no detections)			3.1
Arsenic	12	4.37	sqrt	parametric	9.44	0.43
Barium	13	22.7	sqrt	parametric	53.0	550
Beryllium	13		(no valid UTL; NDs > 90%)			0.15
Cadmium	13		(no valid UTL; NDs > 90%)			3.9
Chromium	13	15.7	ln	parametric	50.4	39
Cobalt	13	1.41	none	nonparametric	4.4	470
Copper	13	18.3	ln	parametric	165	27,000
Lead	13	36.3	sqrt	parametric	140	400 ^a
Manganese	13	35.6	sqrt	parametric	98.1	180
Mercury	13	0.11	none	nonparametric	0.30	2.3
Nickel	13	7.26	sqrt	parametric	13.6	160
Selenium	13	0.54	none	nonparametric	1.2	39
Silver	13		(no detections)			39
Thallium	13		(no detections)			0.63
Tin	13		(no detections)			4,700
Vanadium	13	15.9	none	parametric	29.2	55
Zinc	13	76.2	none	parametric	208	2,300
Cyanide	13		(no detections)			160

Notes:

- n = number of samples
- mg/kg = milligrams per kilogram
- ln = natural logarithm
- sqrt = square root
- NDs = nondetects
- a = Preliminary remediation goal based upon OSWER Directive #9355.4-12 (1994)

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Table 5.3
 Charleston Zone A Subsurface Soils (lower interval)
 Characteristics of Background Datasets

Chemical	n	Mean (mg/kg)	Data Transformation	Type of UTL	UTL (mg/kg)	SSL (mg/kg)
Aluminum	12	9,133	ln	parametric	28,240	560,000 ^c
Antimony	12		(no detections)			2.5
Arsenic	12	3.90	none	parametric	9.84	15
Barium	12	16.5	sqrt	parametric	40.0	800
Beryllium	12		(no detections)			32
Cadmium	12		(no detections)			4
Chromium	12	25.2	none	nonparametric	63.4	19
Cobalt	12	0.99	none	nonparametric	1.7	990 ^c
Copper	12	4.12	ln	parametric	33.7	5,600 ^c
Lead	11	6.90	sqrt	parametric	22.0	400 ^a
Manganese	11	20.5	ln	parametric	85.5	350 ^c
Mercury	12		(no detections)			1
Nickel	12	9.16	none	nonparametric	35.0	65
Selenium	11	0.95	none	parametric	1.74	2.5
Silver	12		(no valid UTL; NDs > 90%)			17
Thallium	12		(no detections)			0.35
Tin	12		(no valid UTL; NDs > 90%)			5,500 ^a
Vanadium	12	23.0	sqrt	parametric	77.3	3000
Zinc	12	25.5	ln	parametric	165	6000
Cyanide	12		(no detections)			

Notes:

- c = calculated SSL value (see Section 6.2.1)
- n = number of samples
- mg/kg = milligrams per kilogram
- ln = natural logarithm
- sqrt = square root
- NDs = nondetects
- NL = not listed
- a = Preliminary remediation goal based upon OSWER Directive #9355.4-12 (1994)

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Table 5.4
Charleston Zone A Groundwater
Characteristics of Background Datasets

Chemical	First-round Shallow GW Detections	Shallow GW Mean (µg/L)	Shallow GW Background Reference Value (µg/L)	First- round Deep GW Detections	Deep GW Mean (µg/L)	Deep GW Background Reference Value (µg/L)	MCL (µg/L)
Aluminum	3	1,605	3,210	2	122.4	245	NL
Antimony	0	ND	ND	0	ND	ND	6
Arsenic	1	26.8	7.4*	1	5.33	11.1*	50
Barium	3	52.2	104	3	93.8	179*	2,000
Beryllium	0	ND	ND	0	ND	ND	4
Cadmium	0	ND	ND	0	ND	ND	5
Chromium	2	4.4	8.7	1	3.8	7.3*	100
Cobalt	0	ND	ND	1	6.0	12.1	NL
Copper	3	7.87	15.7	1	2.90	5.8	1,300 ^a
Lead	1	2.35	4.70	0	ND	ND	15 ^a
Manganese	3	189.3	377*	3	1,393	2,690*	NL
Mercury	0	ND	ND	0	ND	ND	2
Nickel	0	ND	ND	1	10.6	21.1	100
Selenium	0	ND	ND	0	ND	ND	50
Silver	0	ND	ND	0	ND	ND	NL
Thallium	0	ND	ND	1	82.5	2.0**	2
Vanadium	1	2.70	5.40	2	5.43	10.9	NL
Zinc	3	41.6	83.2	3	33.1	66.2	NL
Cyanide	0	ND	ND	1	0.026	0.05	200

Notes:

- µg/L = micrograms per liter
- ND = not detected in samples
- NL = not listed
- * = revised value based on results from four sampling rounds
- ** = provisional value pending results of basewide thallium study
- a = Treatment technique action level

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6.0 FATE AND TRANSPORT

Fate and transport assessment evaluates the ability of chemical constituents to become mobile or change in the environment, based on their chemical and physical properties and the processes that govern their interaction with environmental media. Macroscopic physical characteristics such as climate, hydrology, topography, and geology determine weathering and erosional transport processes. Microscopic characteristics of site soil, sediment, and water, as well as the chemical and physical properties of the constituents, govern the processes of infiltration, advection, diffusion, dispersion, erosion, and volatilization that move constituents within or between media. A discussion of fate and transport will help to identify potential receptors that may be impacted by constituent movement in the environment.

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

- Constituents leaching from soil to groundwater
- Constituents migrating from shallow groundwater into surface water bodies
- VOCs released from surface soil into air
- Surface soil erosion and runoff of constituents into adjacent zones of sediment deposition

Definitions:

Infiltration is the movement of water into and through the soil under the influence of gravity and capillary attraction.

Advection is the process by which dissolved substances migrate with moving groundwater. Hydraulic conductivity, effective porosity, and hydraulic gradient are some of the aquifer characteristics that determine a chemical's rate of movement by advection. This process is generally the most important transport mechanism for compounds associated with groundwater.

Diffusion is the random process by which solutes are transported from regions of high concentration to regions of low concentration as a result of the concentration gradient. In very fine sediments with very low hydraulic conductivities, diffusive transport may be the dominant mode of migration.

Dispersion is the hydrodynamic process by which solutes are mixed with uncontaminated water, diluted, and transported preferentially due to heterogeneous properties of the aquifer. Longitudinal dispersion can increase contaminant concentration ahead of the advective front.

Erosion is the process by which particles are suspended and subsequently moved by the physical action of water and/or wind. Compounds adsorbed to particulate material are thereby moved along with it.

Volatilization is the process whereby contaminants dissolved in water or present as nonaqueous phase liquids evaporate into soil gas in the vadose zone and/or into the atmosphere. Volatilization of solutes is controlled by their vapor pressures and Henry's law constants.

6.1 Properties Affecting Fate and Transport

Numerous chemical and physical properties of both the constituent and the surrounding media are used to evaluate fate and transport mechanisms.

6.1.1 Contaminant Properties Affecting Fate and Transport

Chemical and physical properties of constituents used to evaluate fate and transport include vapor pressure, density, solubility, half-life, Henry's law constant, organic carbon/water partitioning coefficient, and molecular weight. Table 6.1 below provides an overview of chemical properties and expected behavior in environmental media based on these properties.

Table 6.1
Constituent Characteristics Based On
Chemical and Physical Properties

Chemical Property	Critical Value	High (>)	Low (<)
Vapor Pressure	10 ⁻³ mm Hg	volatile	nonvolatile
Density ^a	1 g/cm ³	sinks/falls	floats/rises
Solubility ^a	0 to 100 mg/L	leaches from soil, mobile in water, does not readily volatilize from water	sorbs to soil, immobile in water, volatilizes from water
Henry's Law Constant	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	biologically dependent	does not degrade readily	degrades readily
Organic Carbon/Water Partitioning Coefficient ^a (K _{oc})	10 to 10000 L _{water} /kg _{oc}	tends to sorb to organic material in soil; immobile in the soil matrix	tends not to sorb to organic material in soil; mobile in the soil matrix
Molecular Weight	400 g/mole	difficult to predict chemical's behavior with respect to the properties listed above.	exhibits predictable behavior with respect to the properties listed above.

Notes:

- ^a Critical values were based on literature review and professional judgment.
- mm Hg Millimeters of mercury
- atm-m³/mole Atmosphere cubic meters per mole
- L_{water}/kg_{oc} Kilograms of organic carbon per liter of water

For each constituent detected in Zone A samples (soil, sediment, and groundwater), Table 6.2 lists chemical and physical properties needed to compute soil screening levels for protection of groundwater. Section 10 discusses SWMU- or AOC-specific fate and transport, migration pathways, and potential receptors.

Compounds with similar chemical and physical properties display similar fate and transport behavior, making it possible to group contaminants into the following categories based on those

Table 6.2
Soil to Groundwater and Soil to Air Soil Screening Levels
NAVBASE-Charleston, Zone A
Charleston, South Carolina

Site Specific Parameters:									
Fraction Organic Carbon (--) :	0.002	Organic Carbon-		Acceptable		Target		Soil to	Soil to
Dilution Attenuation Factor (--) :	10	Henry's	Water	Tap	Ground-	Leachate	Groundwater	Air	
Dry Soil Bulk Density (kg/L) :	1.5	Law	Part.	Water	water	Conc.	SSL	SSL	
Water-filled Soil Porosity (--) :	0.3	Constant	Coeff.	RBC	MCL/ MCLG	Conc.			
Air-filled Soil Porosity (--) :	0.13	[H']	[Koc]	(mg/L)	(mg/L)	(mg/L)	(mg/kg)	(mg/kg)	
Soil Porosity (--) :	0.43	(--)	(L/kg)	(mg/L)	(mg/L)	(mg/L)	(mg/kg)	(mg/kg)	
Volatile Organic Compounds									
Acetone	1.59E-03	5.75E-01	3.7	NL	3.7	37	7.4	100000	
Benzene	2.28E-01	5.89E+01	0.00036	0.005	0.005	0.05	0.017	0.8	
Bromodichloromethane	6.56E-02	5.50E+01	0.00017	0.1	0.1	1	0.32	3000	
Bromomethane	2.50E-01	1.10E+01	0.0087	NL	0.0087	0.087	0.021	2	
2-Butanone (MEK)	2.30E-03	1.90E+00	1.9	NL	1.9	19	3.9	NDA	
Carbon disulfide	1.24E+00	4.57E+01	1	NL	1	10	4.0	720	
Chlorobenzene	1.52E-01	2.19E+02	0.039	NL	0.039	0.39	0.25	130	
Chloroform	1.50E-01	3.98E+01	0.00015	0.1	0.1	1	0.29	0.3	
Chloromethane	3.60E-01	6.50E+00	0.0014	NL	0.0014	0.014	0.0034	0.063	
1,1-Dichloroethane	2.30E-01	3.16E+01	0.81	NL	0.81	8.1	2.3	1300	
1,2-Dichloroethane (EDC)	4.01E-02	1.74E+01	0.00012	0.005	0.005	0.05	0.012	0.4	
1,1-Dichloroethene	1.07E+00	5.89E+01	4.4E-05	0.007	0.007	0.07	0.029	0.07	
cis-1,2-Dichloroethene	1.67E-01	3.55E+01	0.061	0.07	0.07	0.7	0.20	1200	
trans-1,2-Dichloroethene	3.85E-01	5.25E+01	0.12	0.1	0.1	1	0.34	3100	
Ethylbenzene	3.23E-01	3.63E+02	1.3	0.7	0.7	7	6.7	400	
2-Hexanone	NDA	2.40E+01	1.5	NL	1.5	15	3.7	NDA	
4-Methyl-2-pentanone (MIBK)	5.70E-03	1.50E+01	2.9	NL	2.9	29	6.7	NDA	
Methylene chloride	8.98E-02	1.17E+01	0.0041	NL	0.0041	0.041	0.0095	13	
1,1,2,2-Tetrachloroethane	1.41E-02	9.33E+01	5.2E-05	NL	5.2E-05	0.00052	0.00020	0.6	
Tetrachloroethene	7.54E-01	1.55E+02	0.0011	0.005	0.005	0.05	0.029	11	
Toluene	2.72E-01	1.82E+02	0.75	1	1	10	5.9	650	
1,1,1-Trichloroethane	7.05E-01	1.10E+02	0.54	0.2	0.2	2	0.96	1200	
Trichloroethene	4.22E-01	1.66E+02	0.0016	0.005	0.005	0.05	0.028	5	
Trichlorofluoromethane	4.00E+00	1.20E+02	1.3	NL	1.3	13	10	790	
Vinyl chloride (chloroethene)	1.11E+00	1.86E+01	1.9E-05	0.002	0.002	0.02	0.0067	0.03	
Xylene (total)	2.48E-01	2.40E+02	12	10	10	100	70	320	
o-Xylene	2.13E-01	3.63E+02	12	10	10	100	94	410	
m-Xylene	3.01E-01	4.07E+02	12	10	10	100	104	420	
Semivolatile Organic Compounds									
Acenaphthene	6.36E-03	7.08E+03	2.2	NL	2.2	22	316	NDA	
Acenaphthylene	4.50E-03	3.10E+03	1.5	NL	1.5	15	96	NDA	
Anthracene	2.67E-03	2.95E+04	11	NL	11	110	6512	NDA	
Benzo(a)anthracene	1.37E-04	3.98E+05	9.2E-05	NL	9.2E-05	0.00092	0.73	NDA	
Benzo(a)pyrene	4.63E-05	1.02E+06	9.2E-06	0.0002	0.0002	0.002	4.1	NDA	
Benzo(b)fluoranthene	4.55E-03	1.23E+06	9.2E-05	NL	9.2E-05	0.00092	2.3	NDA	
Benzo(k)fluoranthene	3.40E-05	1.23E+06	0.00092	NL	0.00092	0.0092	23	NDA	
Benzo(g,h,i)perylene	5.74E-06	3.90E+06	1.5	NL	1.5	15	117003	NDA	
Butylbenzylphthalate	5.17E-05	5.75E+04	7.3	NL	7.3	73	8410	930	
Carbazole	6.26E-07	3.39E+03	0.0034	NL	0.0034	0.034	0.24	NDA	
4-Chloro-3-methylphenol	1.60E-05	1.10E+03	0.18	NL	0.18	1.8	4.3	NDA	
2-Chlorophenol	1.60E-02	3.88E+02	0.18	NL	0.18	1.8	1.8	53000	
Chrysene	3.88E-03	3.98E+05	0.0092	NL	0.0092	0.092	73	NDA	
Dibenzo(a,h)anthracene	6.03E-07	3.80E+06	9.2E-06	NL	9.2E-06	9.2E-05	0.70	NDA	
Dibenzofuran	5.30E-04	1.40E+04	0.15	NL	0.15	1.5	42	120	
Di-n-butylphthalate	3.85E-08	3.39E+04	3.7	NL	3.7	37	2516	2300	
1,2-Dichlorobenzene	7.79E-02	6.17E+02	0.064	0.6	0.6	6	8.6	560	
1,3-Dichlorobenzene	1.30E-01	7.00E+02	0.54	NL	0.54	5.4	8.7	NDA	
1,4-Dichlorobenzene	9.96E-02	6.17E+02	0.00044	0.075	0.075	0.75	1.1	1000000	
Di-n-octylphthalate	2.74E-03	8.32E+07	0.73	NL	0.73	7.3	1214721	10000	
bis(2-Ethylhexyl)phthalate (BEHP)	4.18E-06	1.51E+07	0.0048	0.006	0.006	0.06	1812	31000	
Fluoranthene	6.60E-04	1.07E+05	1.5	NL	1.5	15	3213	NDA	

Table 6.2
Soil to Groundwater and Soil to Air Soil Screening Levels
NAVBASE-Charleston, Zone A
Charleston, South Carolina

Site Specific Parameters	Organic Carbon-		Tap Water RBC (mg/L)	MCL/ MCLG (mg/L)	Acceptable Ground-water Conc. (mg/L)	Target Leachate Conc. (mg/L)	Soil to Groundwater SSL (mg/kg)	Soil to Air SSL (mg/kg)
	Henry's Law Constant [H'] (--)	Water Part. Coeff. [Koc] (L/kg)						
Fraction Organic Carbon (--) :	0.002							
Dilution Attenuation Factor (--) :	10							
Dry Soil Bulk Density (kg/L) :	1.5							
Water-filled Soil Porosity (--) :	0.3							
Air-filled Soil Porosity (--) :	0.13							
Soil Porosity (--) :	0.43							
Fluorene	2.61E-03	1.38E+04	1.5	NL	1.5	15	417	NDA
Indeno(1,2,3-cd)pyrene	6.56E-05	3.47E+06	9.2E-05	NL	9.2E-05	0.00092	6.4	NDA
2-Methylnaphthalene	2.10E-02	7.50E+03	1.5	NL	1.5	15	228	NDA
3-Methylphenol (m-cresol)	3.50E-05	8.50E+01	1.8	NL	1.8	18	6.7	NDA
4-Methylphenol (p-cresol)	3.20E-05	8.50E+01	0.18	NL	0.18	1.8	0.67	NDA
Naphthalene	1.98E-02	2.00E+03	1.5	NL	1.5	15	63	NDA
N-Nitrosodiphenylamine	2.05E-04	1.29E+03	0.014	NL	0.014	0.14	0.39	NDA
Phenanthrene	9.40E-04	3.00E+04	1.5	NL	1.5	15	903	NDA
Phenol	1.63E-05	2.88E+01	22	NL	22	220	57	NDA
Pyrene	4.51E-04	1.05E+05	1.1	NL	1.1	11	2312	NDA
1,2,4-Trichlorobenzene	5.82E-02	1.78E+03	0.19	0.07	0.07	0.7	2.6	3200
Dioxin Compounds								
2,3,7,8-TCDD Equivalents (TEQs)	3.20E-03	2.70E+06	4.5E-10	3E-08	3E-08	3E-07	0.0016	NDA
Pesticide/PCB Compounds								
Aldrin	6.97E-03	2.45E+06	4E-06	NL	4E-06	4E-05	0.20	3
Aroclor 1260	NDA	3.09E+05	3.4E-05	0.0005	NA	NA	1.0	1
alpha-BHC (alpha-HCH)	4.35E-04	1.23E+03	1.1E-05	NL	1.1E-05	0.00011	0.00029	0.8
beta-BHC (beta-HCH)	3.05E-05	1.26E+03	3.7E-05	NL	3.7E-05	0.00037	0.0010	1000000
delta-BHC (delta-HCH)	1.80E-05	2.30E+03	3.7E-05	NL	3.7E-05	0.00037	0.0018	NDA
gamma-BHC (Lindane)	5.74E-04	1.07E+03	5.2E-05	0.0002	0.0002	0.002	0.0047	NDA
alpha-Chlordane	1.99E-03	1.20E+05	0.00019	0.002	0.002	0.02	4.8	20
gamma-Chlordane	1.99E-03	1.20E+05	0.00019	0.002	0.002	0.02	4.8	20
4,4'-DDD	1.64E-04	1.00E+06	0.00028	NL	0.00028	0.0028	5.6	NDA
4,4'-DDE	8.61E-04	4.47E+06	0.0002	NL	0.0002	0.002	18	NDA
4,4'-DDT	3.32E-04	2.63E+06	0.0002	NL	0.0002	0.002	11	1000000
Dieldrin	6.19E-04	2.14E+04	4.2E-06	NL	4.2E-06	4.2E-05	0.0018	1
Endosulfan II	4.59E-04	2.14E+03	0.22	NL	0.22	2.2	9.9	NDA
Endosulfan sulfate	4.59E-04	2.14E+03	0.22	NL	0.22	2.2	9.9	NDA
Endrin	3.08E-04	1.23E+04	0.011	0.002	0.002	0.02	0.50	NDA
Endrin aldehyde	3.08E-04	1.23E+04	0.011	0.002	0.002	0.02	0.50	NDA
Endrin ketone	3.08E-04	1.23E+04	0.011	0.002	0.002	0.02	0.50	NDA
Heptachlor	6.07E+01	1.41E+06	2.3E-06	0.0004	0.0004	0.004	11	0.1
Heptachlor epoxide	3.90E-04	8.32E+04	1.2E-06	0.0002	0.0002	0.002	0.33	5
Inorganics								
		<i>Kd [6.8 pH]</i> (L/kg)						
Aluminum	NA	1.50E+03	37	NL	37	370	555074	NDA
Antimony	NA	4.50E+01	0.015	0.006	0.006	0.06	2.7	NDA
Arsenic	NA	2.90E+01	4.5E-05	0.05	0.05	0.5	15	750
Barium	NA	4.10E+01	2.6	2	2	20	824	690000
Beryllium	NA	7.90E+02	1.6E-05	0.004	0.004	0.04	32	1300
Cadmium	NA	7.50E+01	0.018	0.005	0.005	0.05	3.8	1800
Chromium (III)	NA	1.80E+06	37	0.1	0.1	1	1800000	NDA
Chromium (VI)	NA	1.90E+01	0.18	0.1	0.1	1	19	270
Cobalt	NA	4.50E+01	2.2	NL	2.2	22	994	NDA
Copper	NA	4.30E+02	1.5	1.3	1.3	13	5593	NDA
Cyanide	NA	1.00E+01	0.73	0.2	0.2	2	20	NDA
Lead	NA	NA	0.015	NL	0.015	0.15	400	400
Manganese	NA	6.50E+01	0.84	NL	0.84	8.4	548	NDA
Mercury	4.67E-01	5.20E+01	0.011	0.002	0.002	0.02	1.0	10
Nickel	NA	6.50E+01	0.73	0.1	0.1	1	65	13000

Table 6.2
Soil to Groundwater and Soil to Air Soil Screening Levels
NAVBASE-Charleston, Zone A
Charleston, South Carolina

Site Specific Parameters:									
Fraction Organic Carbon (--) :	0.002	Organic Carbon-	Henry's Law Constant [H'] (--)	Water Part. Coeff. [Koc] (L/kg)	Tap Water RBC (mg/L)	Acceptable Ground- water MCL/ MCLG (mg/L)	Target Leachate Conc. (mg/L)	Soil to Groundwater SSL (mg/kg)	Soil to Air SSL (mg/kg)
Dilution Attenuation Factor (--) :	10								
Dry Soil Bulk Density (kg/L) :	1.5								
Water-filled Soil Porosity (--) :	0.3								
Air-filled Soil Porosity (--) :	0.13								
Soil Porosity (--) :	0.43								
		<i>Kd [6.8 pH] (L/kg)</i>							
Selenium	NA	5.00E+00	0.18	0.05	0.05	0.5	2.6	NDA	
Silver	NA	8.30E+00	0.18	NL	0.18	1.8	15	NDA	
Thallium	NA	7.10E+01	0.0029	0.0005	0.0005	0.005	0.36	NDA	
Tin	NA	2.50E+01	22	NL	22	220	5544	NDA	
Vanadium	NA	1.00E+03	0.26	NL	0.26	2.6	2601	NDA	
Zinc	NA	6.20E+01	11	NL	11	110	6842	NDA	

Notes:

Henry's Law Constant (H') and Organic Carbon-Water Partitioning Coefficient (Koc) - From USEPA Soil Screening Guidance: User's Guide, Attachment C, April 1996 (first preference), or Superfund Chemical Data Matrix (SCDM), June 1996
Tap Water RBC - From USEPA Region III Risk-Based Concentration Table, October 1997
MCL/MCLG - From USEPA Drinking Water Regulations and Health Advisories, October 1996
Acceptable Groundwater Concentration - MCL/MCLG if available, otherwise tap water RBC
Target Leachate Concentration - Acceptable groundwater concentration multiplied by dilution attenuation factor
Soil to Groundwater SSL - Calculated using Equation 10 from USEPA Soil Screening Guidance: User's Guide, April 1996
Soil to Air SSL - From USEPA Soil Screening Guidance: Technical Background Document, Appendix A, May 1996 (first preference), or USEPA Region III Risk-Based Concentration Table, June 1996

NA - Not applicable
NDA - No data available
NL - Not listed
L/kg - Liters per kilogram
mg/L - Milligrams per liter
mg/kg - Milligrams per kilogram

properties: VOCs, SVOCs, pesticides/PCBs, chlorinated herbicides, chlorinated dibenzodioxins/dibenzofurans, and inorganics.

VOCs

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

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

VOCs have low molecular weights, moderate Henry's law constants, varying organic carbon/water partitioning coefficients, and high solubilities and vapor pressures. Densities may be less than or greater than that of water. Overall, VOCs are expected to be highly mobile in the environment and therefore quick to migrate from soil and groundwater.

SVOCs

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

- SVOCs tend to adsorb to soil particles.
- SVOCs tend to be immobile in the environment.
- SVOC movement often occurs by colloidal suspension.
- SVOCs exhibit greater mobility when coupled with "carrier" compounds.

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 exceptions to 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 sorb 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 sorb to soil particles, particularly clays.
- Inorganics are not degradable.
- Inorganics tend to have moderate to low mobility; however, in environments where pH is less than 5 (i.e., acidic conditions), inorganics can become mobile.

Properties of the surrounding environmental media tend to dictate the fate and transport mechanisms of inorganic elements. Generally, 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 total organic carbon (TOC), normalized partitioning coefficient, cation exchange capacity (CEC), redox conditions, pH, soil type, and retardation rate. The following briefly discusses these properties.

Total Organic Carbon

TOC indicates the soil's sorptive capabilities. The higher the TOC, the higher the potential for a given chemical to sorb to soil particles, especially for organic compounds. TOC may also be expressed in unitless form as f_{oc} , or fraction organic carbon of the soil (e.g., grams of solid organic carbon per gram of dry soil).

Normalized Partitioning Coefficient (K_d)

K_d is used to predict the capacity for a constituent to partition between soil and water; it is a function of both the constituent and the soil. To estimate K_d , the constituent's organic carbon/water partitioning coefficient (K_{oc}) is adjusted by the soil's TOC: $K_d = K_{oc} f_{oc}$. Soil/constituent combinations with higher K_d s have a higher potential for sorption.

Cation Exchange Capacity

CEC reflects the soil's capacity to adsorb ions, neutralizing ionic deficiencies on the surfaces of its particles. Generally, trivalent ions are preferentially adsorbed to soil over divalent ions, and divalent ions are preferentially adsorbed over monovalent ions. The amount of cation exchange also depends on soil pH. Soils with high CEC values have the potential to adsorb inorganic ions and organic compounds with dipole moments.

Redox Conditions

Redox is the process which includes oxidation (the loss of electrons), and reduction (the gain of electrons). Changes in oxidation state generate products that are different from the reactants in their solubilities, toxicities, reactivities, and mobilities. Extreme redox conditions tend to mobilize chemicals, especially transition metals.

pH

The pH value is a negative inverse logarithmic measure of hydrogen ion concentration in the soil or groundwater, indicating the acidity or alkalinity of the medium. Chemicals react differently 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 affect chemical fate and transport. Soil characteristics influence or determine hydraulic conductivity, effective porosity, and hydraulic gradient, which in turn dictate groundwater flow.

Retardation Factor (R)

The retardation factor is a measure of the ability of an aquifer matrix to inhibit the movement of a chemical by preferentially binding contaminants with high organic carbon/water partitioning coefficients. Retardation factors are calculated as follows:

$$R = 1 + \frac{K_d \rho_b}{n}$$

Where:

- R = Retardation Factor
- K_d = Normalized Partitioning Coefficient (L/kg)
- ρ_b = Soil Dry Bulk Density (kg/L)
- n = Soil Total Porosity

Table 6.3 summarizes the soil and aquifer parameters used to evaluate fate and transport for Zone A. The geometric mean pH of 10 Zone A soil samples collected at SWMU 43 is 7.8. Detected pH values for SWMU 43 soil range from 7.2 to 8.2. The geometric mean pH of six aquifer samples collected at SWMU 39 is 7.6, with a range from 6.2 to 8.7. Aquifer samples at SWMU 39 were collected from depths of 8 feet to 48 feet bgs. Nonacidic soil and aquifer conditions indicate limited mobility for inorganics by the processes of advection, diffusion, and dispersion.

Table 6.3
Soil and Aquifer Parameters Used to Evaluate Fate and Transport

Parameter	Number of Samples	Zone A Minimum Value	Zone A Maximum Value	Zone A Geometric Mean Value ^e	Units
CEC ^a	6	ND	200	8.9	meq/100g
TOC ^a	6	ND	60,000	63	mg/kg
pH ^b	16	6.2	8.7	7.7	(—)
Total Porosity ^c	7	0.35	0.57	0.40	(—)
Dry Bulk Density ^c	7	1.15	1.77	1.57	(kg/L)
Hydraulic Conductivity ^d					
Shallow Wells	13	0.065	12.9	0.95 ^f	ft/d
Intermediate Wells	5	0.15	18.1	2.6 ^g	ft/d
Deep Wells	7	0.37	24	3.2 ^f	ft/d

Notes:

- ^a CEC and TOC values for six aquifer samples at SWMU 39 only
- ^b pH values for ten soil samples at SWMU 43 and six aquifer samples at SWMU 39
- ^c Total porosity and dry bulk density values based on Shelby tube aquifer samples
- ^d Hydraulic conductivity values based on slug test results
- ^e Mean values calculated using one-half the sample quantitation limits of nondetect samples
- ^f Spatially weighted geometric mean hydraulic conductivity values, as detailed in text
- ^g Intermediate-depth hydraulic conductivity values for five wells at SWMU 39 only

The average total porosity of the shallow aquifer in Zone A is 40%, as determined through Shelby tube analysis of seven samples, with a range of values from 35% to 57%. Six of the seven

samples were collected from intervals between 10 feet and 13.5 feet bgs, while one was collected from 32 feet to 34 feet bgs. Results of an eighth Shelby tube sample analysis were not included in the compilation because the lithology was described as “organic material.” The computed porosity of this eighth sample is 80%. Dry bulk density of the same seven aquifer samples ranges from 1.15 kg/L to 1.77 kg/L, with a geometric mean of 1.57 kg/L.

Horizontal hydraulic conductivity of the shallow portion of the surficial aquifer, based on slug tests in 13 shallow wells, ranges from 0.065 feet/day to 12.9 feet/day, with a spatially weighted geometric mean of 0.95 feet/day. Because 10 of the 13 shallow wells with slug-test results were concentrated in the northern portion of Zone A, they were grouped into four clusters. The geometric mean hydraulic conductivity of each cluster was treated as a single value to determine the zonewide mean hydraulic conductivity, which thereby became the geometric mean of seven values (four “cluster means” and three individual values from wells elsewhere in the zone). From west to east, the four clusters of shallow wells are (1) NBCA039009 and NBCA039010; (2) NBCA039001, NBCA039002, NBCA039004, and NBCA039012; (3) NBCA039006 and NBCA039007; and (4) NBCA002002 and NBCA002005.

Slug test results for deep wells were more spatially skewed than for shallow wells, and were therefore treated somewhat differently to determine a zonewide mean hydraulic conductivity. Six of the seven deep wells with slug tests were located in the northwest corner of the zone, at SWMUs 38 and 39. The calculated geometric mean hydraulic conductivity of these six wells (3.75 feet/day) was double-weighted (i.e., treated as the results from two wells) and combined with results from the remaining deep well, NBCAGDA003, to obtain the spatially weighted geometric mean hydraulic conductivity.

Table 6.4 lists the approximate time of travel for advective groundwater flow from various SWMUs to water bodies (Cooper River or Noisette Creek) or to the NAVBASE property line,

depending on direction of flow, local groundwater gradient, and local hydraulic conductivity. A river gauging station at the Army Depot in North Charleston at mile 10.5 of the Cooper River, upstream from Zone A, reported a mean river stage of 1.06 feet for the year 10/92 to 9/93. Downstream from Zone A at the gauging station at Charleston Harbor (mile 0.6), mean river stage is roughly zero. Calculation of travel times was based on an assumption of 0.5 feet local elevation for water in the Cooper River. Water elevation in Noisette Creek was estimated from Figures 2.8 and 2.9.

Table 6.4
Travel Time Analysis
Advective Transport Only

AOC/SWMU	Hydraulic Conductivity (feet/day) ^a	Horizontal Gradient (-)	Effective Porosity (-) ^b	Horizontal Velocity (feet/year)	Horizontal Distance (feet) ^c	Travel Time (years)
SWMU 2 (Well 5 → Cooper River)	0.78	0.0038	0.20	5.4	440	81
SWMU 38 (to Cooper River)	0.79	0.0054	0.20	7.8	960	120
SWMU 39 (Well 1 → Cooper River)	0.79	0.0047	0.20	6.8	1570	230
SWMU 39 (to western zone boundary)	4.6	0.0056	0.20	47	450	10
SWMU 42 (to western zone boundary)	1.2	0.0016	0.20	3.5	150	43

Notes:

- ^a = Based on slug test data from nearby and zonewide monitoring wells
- ^b = Estimated, based on textural classes of shallow aquifer samples (USEPA 1989)
- ^c = Based on the potentiometric path of groundwater flow

6.2 Fate and Transport Approach for Zone A

Each site-specific fate and transport discussion in Section 10 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 A. Each SWMU and AOC has been evaluated for 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.

Evaluation of an individual constituent's ability to migrate considers four cross-media transfer mechanisms: (1) soil to groundwater, (2) groundwater to surface water, (3) surface soil to air, and (4) surface soil to sediment. Cases can be made for each potential transfer mechanism based on empirical data available for each environmental medium sampled. For example, if a constituent is found in soil as well as in groundwater, it is reasonable to conclude that the soil constituent may be leaching to the groundwater. In support of such conclusions, Zone A fate and transport were evaluated using constituent-specific chemical and physical properties, assumed soil and aquifer properties, USEPA risk-based screening concentrations and maximum contaminant levels, and grid-based background reference concentrations (Table 6.2).

The following sections describe the methods used to evaluate the potential migration of constituents identified at each SWMU/AOC. Where a specific migration pathway could not be identified for a site, no screening or formal assessment was performed for that pathway. Fate and transport were not evaluated for essential nutrients (calcium, iron, magnesium, potassium, and sodium), or for chlorides or sulfates, which are abundant in shallow coastal/estuarine environments. Section 10 contains discussions of site-specific fate and transport, migration pathways, and potential receptors.

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 surficial aquifer. Due to the nature and age of most SWMU/AOC operations, it might be assumed that any compounds with the potential to migrate from soil into the surficial aquifer would have done so already. This assumption would also be appropriate in light of the thin, permeable soil layer above the water table at Zone A. However, all soil constituents were evaluated for their potential threat to groundwater regardless of whether the constituent was detected in groundwater. The screening process may be summarized as follows:

Quantitative — Maximum soil constituent concentrations for each SWMU/AOC (or group thereof) were compared to leachability-based generic soil-to-groundwater screening levels (SSLs) as presented in the USEPA *Soil Screening Guidance: Technical Background Document*, May 1996 (primary source) or USEPA Region III RBC table, June 1996. SSLs were modified from those in the *Technical Background Document*, used directly from the RBC table, or calculated independently, as described below, assuming a dilution attenuation factor (DAF) of 10.

Soil background reference values for inorganics in Zone A were determined after consultation with the project team technical subcommittee. At the request of SCDHEC, however, background reference values were not considered during comparisons of maximum soil concentrations with SSLs. The theoretical effect of this exclusion during the screening process was to identify all possible threats to groundwater, irrespective of their sources as naturally occurring or anthropogenic soil constituents. Since chromium is the only inorganic chemical in Zone A soil samples with a background reference value greater than its SSL (conservatively assuming that all detected chromium is hexavalent), the practical effect of the exclusion was limited.

Maximum groundwater constituent concentrations for each SWMU/AOC (or group thereof) were compared to the greater of:

- Tap water risk-based screening concentrations as presented in the USEPA Region III RBC table, October 1997, assuming a target hazard quotient (THQ) of 1.0.
- Groundwater background reference values for inorganics in Zone A, determined in consultation with the project team technical subcommittee; selected as described below.

Quantitative screening defines the list of chemicals to be considered for detailed fate and transport assessment. It reveals constituents in soil having the potential to impact the surficial aquifer,

identifying areas where relatively recent releases or immobile constituents may not yet have impacted samples from existing monitoring wells. A conservative screening approach was employed using generic SSLs to provide the most comprehensive list of constituents with the potential to impact groundwater. It was assumed that if soil concentrations do not exceed conservative leachability-based screening levels or background, no significant migration potential exists. Likewise, if current groundwater concentrations do not exceed risk-based screening values or background, it was concluded that current soil/groundwater equilibria sufficiently protect human health relative to potential groundwater ingestion exposure pathways.

The soil-to-groundwater migration pathway was assessed using generic SSLs that assume a DAF of 10, rather than site-specific SSLs. DAFs higher than 10 would be justified for Zone A SWMUs and AOCs, based on site-specific values of hydraulic conductivity, hydraulic gradient, aquifer thickness, and estimated infiltration rate (to estimate dilution), as well as soil type and organic content (to estimate attenuation). Higher DAF values translate into higher SSLs. Section 6.3 compares assumptions underlying the fate and transport screening process with site-specific and zonewide conditions, including factors affecting dilution and attenuation of contaminants. As a conservative screening tool, generic SSLs are used to compile a list of potential fate and transport concerns; detailed fate and transport assessments then evaluate the identified concerns to facilitate risk management decisions.

Table 6.2 contains physical site characteristics along with chemical and physical properties and regulatory standards for each constituent detected in Zone A soil, sediment, and groundwater samples, enabling calculation of soil screening levels for protection of groundwater. Where generic SSLs for organics were not listed in the *Technical Background Document* or the Region III RBC table, they were calculated using the chemical property values shown in Table 6.2. Values of Henry's law constant, K_{oc} , and K_d not available in the *Technical Background Document* or the USEPA *Soil Screening Guidance: User's Guide*, April 1996, were obtained from the Superfund

Chemical Data Matrix (SCDM), June 1996, which is the source of the values presented in the two *Soil Screening Guidance* documents. Values of K_d not available in the USEPA documents were taken from the TERRA model (Oak Ridge National Laboratory, 1984), which is considered a standard reference source. Where calculated SSLs in Table 6.2 differed from EPA's generic values, the EPA values prevailed. Differences between the generic listed SSLs and EnSafe's calculated SSLs were generally due to EPA's use of nonstandard target leachate concentrations as starting points for their calculations: rather than starting with their own listed RBCs or MCLs, EPA often rounds them off to one significant figure. EPA's starting-point values are listed in Attachment D, "Regulatory and Human Health Benchmarks for SSL Development," of the *User's Guide*.

The greater of the background reference values for shallow and deep groundwater was used as the screening alternative to tap water RBCs. The lithology of the surficial aquifer in Zone A is complex, with thick sandy units but no apparent widespread aquitards. Vertical hydraulic gradients measured at pairs of wells with different depths are almost all positive (Section 2.2.6), indicating general downward movement of groundwater. Over distances involved in migration from SWMUs/AOCs to surface water or NAVBASE property boundaries, aquifer units at all depths down to the confining unit (Ashley Formation or Qco) are assumed to be interconnected, so that the higher background value is always relevant. Arsenic and manganese are the only inorganics with groundwater background values higher than their corresponding tap water RBCs.

Detailed Assessment — Upon completion of the quantitative screening process, site constituent concentrations exceeding the screening values were examined to delineate the magnitude, number, and areal extent of soil impacts potentially affecting groundwater. Maximum constituent concentrations in surface soil were compared to those in subsurface samples to estimate the extent of downward migration. The number and spatial distribution of exceedances were noted. Relative

concentrations in soil and groundwater were compared. If relevant, corresponding exceedances in nearby SWMUs/AOCs were examined as possible sources or as indicators of lateral migration.

Detailed assessments helped determine the significance of soil impacts relative to the surficial 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 and to decide which 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

Groundwater in the upper part of the surficial aquifer in Zone A moves generally eastward toward the Cooper River, southward toward Noisette Creek, and south-southwestward toward the marsh north of Noisette Creek and west of the NAVBASE property line (Figures 2.8 and 2.9); in the lower part of the aquifer, groundwater apparently moves generally eastward (Figures 2.10 and 2.11). The principal focus of this evaluation was determining whether constituents identified in groundwater have the potential to extend their impacts to different locations within the surficial aquifer or to surface water in the Cooper River, Noisette Creek, or the marsh. Other than at five sample locations in the marsh beyond the zone property boundary (039W000101 through 039W000501), surface water was not sampled as part of the Zone A RFI. Therefore, potential impacts on surface water were evaluated by comparing groundwater constituent concentrations to surface water screening standards, as described below. The screening process may be summarized as follows:

Quantitative — Chemicals present in groundwater and/or surface water were compared to appropriate screening values. Relative to human health evaluation, maximum shallow and deep groundwater results for each SWMU/AOC (or group thereof) were compared to the greater of:

- Tap water risk-based screening levels as presented in USEPA Region III RBC tables, October 1997, assuming a target hazard quotient (THQ) of 1.0
- Groundwater background reference values for inorganics in Zone A, determined in consultation with the project team technical subcommittee; selected as described above in Section 6.2.1

To evaluate potential impact on ecological receptors, maximum shallow and deep groundwater analytical results for each SWMU/AOC (or group thereof) were also compared to USEPA saltwater surface water chronic screening values (also known as ambient water quality criteria, or AWQCs) for hazardous waste sites, from *Supplemental Guidance to RAGS: Region 4 Bulletins, Ecological Risk Assessment*, November 1995. Since the only surface water samples collected as part of the Zone A RFI were the five SWMU 39 samples from outside the zone boundary, and since these surface water samples were analyzed only for VOCs, no background values for surface water inorganics were determined for use as alternatives to surface water screening standards.

The quantitative assessment identifies chemicals detected in groundwater with the potential to disperse within the aquifer, increasing the areal extent of groundwater concentrations that exceed human health-based standards, or impacting surface water via groundwater migration and discharge. If groundwater concentrations do not exceed tap water risk-based screening levels or background concentrations, no significant threat relative to migration potential exists. If reported concentrations in groundwater do not exceed saltwater surface water chronic screening levels, minimal threat exists relative to ecological impacts from groundwater discharge to surface water.

This screening assessment purposely does not consider effects of dilution and attenuation on transport between the affected well and the surface water discharge point, or the dilution capacity of the receiving water body. Omitting these factors from the quantitative screening ensures that a conservative list of potential groundwater to surface water concerns is developed.

Detailed Assessment — Upon completion of the quantitative screening process, detailed assessments were performed to delineate the magnitude and areal extent of groundwater impacts that may adversely affect human or ecological receptors. Maximum constituent concentrations in shallow groundwater were compared to those in deep groundwater to estimate the extent of downward migration. The number and spatial distribution of exceedances were noted. Where relevant, corresponding exceedances in nearby SWMUs/AOCs were examined as possible sources or as indicators of lateral migration.

The detailed assessments helped to determine the significance of groundwater impacts and potential impacts. In addition, inferences were drawn about the potential for significant impacts on surface water. The Zone J RFI results will be used to confirm or refute preliminary conclusions. Detailed assessments were also used to determine which areas of groundwater contamination may require supplemental investigation and/or modeling applications during the CMS as part of the remedial alternatives development process.

6.2.3 Surface Soil to Sediment Cross-Media Transport

To evaluate surface soil to sediment erosional migration, a phased screening approach identified chemicals with 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) for surface soil and sediment were compared to determine which chemicals were present in both media.

Sediments are formed largely by surface soil erosion, with accumulation in depositional areas. Normally, site topography and ground cover are used to identify areas with erosional potential and the corresponding expected areas of deposition. Because erosional/depositional processes within Zone A are limited at most SWMUs/AOCs due to the presence of buildings, paved surfaces, and engineered drainage, evidence of constituent migration from surface soil to sediment is rare. Several Zone A sediment samples were collected from catch basins. Nevertheless, all sediment results were compared to data for proximate surface soil representing possible points of origin for sediment contaminants.

Semiquantitative — The maximum concentration in surface soil was compared to the maximum concentration in sediment for constituents present in both media. The purpose of the semiquantitative assessment was to provide additional evidence in support of this possible migration pathway.

Evaluation of fate and transport for sediments in Zone A was limited to sediments as contaminant receptors. Fate and transport for constituents originating in Zone A catch-basin sediments will be provided in the RFI report for Zone L; fate and transport for constituents originating in fluvial sediments will be provided in the RFI report for Zone J.

6.2.4 Soil to Air Cross-Media Transport

To evaluate the potential for soil to air migration of contaminants, a screening approach focused on chemicals possessing the greatest potential to volatilize or become airborne in particulate form in sufficient quantities to create a human health threat in ambient air. The screening process may be summarized as follows:

Quantitative — The maximum concentrations of all chemicals detected in surface soil at each SWMU/AOC were compared to soil to air screening concentrations as presented in the USEPA

Soil Screening Guidance: Technical Background Document, May 1996 (primary source) or USEPA Region III RBC table, June 1996 (secondary source). Concentrations of organic compounds were compared to generic values representing the inhalation of volatiles pathway; concentrations of inorganics were compared to values representing the fugitive dust pathway, except for mercury, whose concentrations were compared to the inhalation of volatiles pathway.

The quantitative assessment defines the list of chemicals under consideration for formal fate and transport evaluation. If soil concentrations do not exceed soil-to-air volatilization or fugitive particulate screening concentrations, minimal migration potential exists, and current soil conditions are considered protective of human health relative to potential inhalation exposure pathways.

Detailed Assessment — Following the quantitative screening process, detailed assessments were performed to delineate the magnitude and areal extent of surface soil impacts potentially affecting ambient air. The number and spatial distribution of exceedances were noted, as were site-specific conditions possibly affecting release of contaminants into the air.

The outcome of the detailed assessments was used to determine the significance of soil impacts relative to ambient air. In some instances, isolated areas of soil contamination above soil-to-air screening levels may have the potential for localized ambient air impacts, but not be of such magnitude to pose a long-term or widespread threat through inhalation pathways. The detailed assessment identified these cases and determined which areas of soil contamination may require supplemental investigation and/or modeling applications during the CMS as part of the remedial alternatives development process.

6.3 Fate and Transport Screening Assumptions Versus Site Conditions

The fate and transport screening procedure was designed as a conservative method to identify and evaluate soil and groundwater constituents with the potential to impact groundwater and surface

water quality in the Cooper River, Noisette Creek, or the marsh west of the Zone A property line. The screening tables identify the constituents, while the detailed assessments evaluate their significance. The procedure depends heavily on EPA's soil screening methodology, and makes many simplifying assumptions that come directly from the 1996 *Soil Screening Guidance*. This section compares some of the assumptions of the screening procedure with actual conditions encountered at SWMUs and AOCs in Zone A in an attempt to demonstrate the conservative nature of the method. The screening assumptions are shown in italics, followed by commentary.

1. The contaminant source is infinite (i.e., steady-state concentrations are maintained during the exposure period). With the possible exception of SWMU 39, which is downgradient from an offsite petroleum tank farm and has reported TPH detections in soil and groundwater samples, the original sources of soil and/or groundwater contamination have been eliminated; there is no ongoing contamination. As constituent molecules migrate through the system or degrade, they are generally not replaced from the original sources.

2. Each soil contaminant is uniformly distributed from the surface to the top of the aquifer, at a concentration equal to the maximum value reported from any of the samples. Site conditions vary greatly, as seen in sample analytical results. Most often, screening exceedances are reported from a relatively small percentage of samples, as presented in the detailed assessments.

3. There is no contaminant attenuation (i.e., adsorption, biodegradation, chemical degradation) as leachate moves downward through soil. In reality, dissolved organic compounds and metallic ions originating in the upper soil horizons are not particularly mobile, due to sorption. Because of their origins in back-barrier, lagoonal, and other low-energy environments (Section 2.1.4), many NAVBASE soils and lithologic units exhibit clay content varying from moderate to very high. The geometric mean clay proportion of Shelby tube samples from eight Zone A wells, ranging in depth from 6 to 52 feet (Table 2.2), was 7.9% (arithmetic mean = 10.6%). The

geometric mean CEC of six Zone A aquifer samples, all from SWMU 39, was 8.9 meq/100g (arithmetic mean = 40.7 meq/100g). For comparison, CEC for pure montmorillonite clay (smectite) ranges from 80 to 150 meq/100g. Other clays such as illite (10-40 meq/100g) and kaolinite (3-15 meq/100g) have lower values (Boulding, 1995). The moderate clay content and corresponding CEC values of Zone A soil and aquifer units should result in varying but substantial attenuation of migrating site constituents, especially inorganics.

The geometric mean TOC of the same six aquifer samples was 63 mg/kg ($f_{oc} = 0.00006$), while the arithmetic mean was 10,550 mg/kg ($f_{oc} = 0.0106$). Measured TOC values ranged from nondetected to 60,000 mg/kg. Because the highest concentrations of organic material in soils are normally in the upper layers, expected TOC values for surface soil samples would be higher; the average depth of the measured TOC samples was 25.5 feet bgs. The default soil value of f_{oc} used by EPA to calculate generic SSLs is 0.002, indicating that Zone A soils probably have, on average, more organic carbon available to bind contaminants to soil particles than soils assumed in the generic model's partitioning equation for migration to groundwater.

EPA's generic SSLs are based on reference values of K_{oc} for ionizing organics and K_d for inorganics. The listed reference values assume a soil pH of 6.8. For Zone A, the geometric mean pH for 16 soil and aquifer samples was considerably higher at 7.72; 14 of the 16 measured pH values exceeded 6.8. Values of K_d for most metals are higher with higher soil pHs and lower with lower pHs. The effect of pH variations on the value of K_{oc} for ionizing organics is reversed, but is weaker than for inorganics.

4. *The generic SSLs used in the screening tables are based on a dilution attenuation factor (DAF) of 10.* Since EPA's methodology unrealistically assumes zero attenuation for migration of leachate through the vadose zone and groundwater through the aquifer, the default DAF of 20 recommended in the 1996 *Soil Screening Guidance* is actually a dilution factor only. Using

equations presented in the *User's Guide*, a site-specific dilution factor of 9.9 was calculated for leachate and shallow groundwater at SWMU 39. The calculation assumes a rainfall infiltration rate of 0.45 inches per year, which is one and one-half times the rate assigned by the ongoing USGS groundwater modeling study to the semi-industrial areas of the base (Zones A, H, and I). In the DAF equation, a higher infiltration rate is conservative because it increases the delivery of contaminant to the aquifer, where it is diluted by groundwater flowing past the site. Considering the moderately high clay content (Table 2.2), CEC, and TOC (assumed for surface soil) of Zone A soil and aquifer sediments, a default DAF of 10 is suitably conservative for initial screening purposes.

5. *There is no contaminant attenuation as groundwater moves through the aquifer.* The lithology and the CEC and TOC values of soil samples in the vadose zone and aquifer samples in the saturated zone indicate otherwise, as discussed above in item 3:

- Moderately high amounts of clay present, especially locally
- Geometric mean CEC of six aquifer samples similar to those of some clay minerals
- Arithmetic mean TOC of six aquifer samples five times higher than EPA default values

6. *The contaminant concentration in the theoretical groundwater plume associated with each site is equal to (a) the concentration of leachate produced by the maximum detected soil concentration and diluted 10:1 by groundwater, or (b) maximum groundwater concentration.* This assumption should be compared to analytical results from soil and groundwater samples collected at each SWMU/AOC and from groundwater samples collected downgradient from each site. High constituent concentrations in Zone A soil or groundwater samples were generally reported from a few isolated locations rather than across entire sites. The number and spatial distribution of screening exceedances is discussed in the detailed assessment for each site.

7. *An appropriate human health screen for groundwater is EPA's Region III tap water RBCs using a total hazard quotient of 1.0. Since the focus of the fate and transport analysis was on individual chemical concentrations and behavior rather than risk, a THQ of 1.0 was considered appropriate. The many built-in conservatisms discussed above should more than make up for any possible compounding effects of multiple contaminants in environmental media.*

8. *An appropriate ecological screen for surface water in the Cooper River, Noisette Creek, and the adjoining marsh is USEPA's saltwater surface water chronic screening values for hazardous waste sites (Supplemental Guidance to RAGS, Region 4 Bulletins: Ecological Risk Assessment, November 1995). Noisette Creek and the portion of the Cooper River opposite NAVBASE are both tidally influenced streams containing brackish water. The screening values in the USEPA publication noted above include the "Criteria to Protect Aquatic Life" incorporated by reference into SCDHEC's Water Classifications and Standards (Regulation 61-68), plus additional values.*

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7.0 HUMAN HEALTH RISK ASSESSMENT

7.1 Introduction

A human health risk assessment (HHRA) analyzes the potential for adverse effects on actual or hypothetical human receptors who could be exposed to hazardous substances released from a site, assuming that no remedial actions are taken to reduce any onsite environmental contamination. The methods used to analyze these effects are discussed in the following text.

Section 7.2 describes the objectives of this assessment and Section 7.3 describes the methods for site-specific implementation of these objectives. The site-specific assessments are detailed in Section 10. Overall, the human health risk assessment was conducted in accordance with the risk assessment and human health evaluation guidance listed below:

- *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).
- *Dermal Exposure Assessment: Principles and Applications – Interim Report*, ORD, EPA/600/8.91/011B, January 1992.
- Supplemental Guidance to RAGS: Region IV Bulletin, *Human Health Risk Assessment – Interim*, (USEPA Region IV, 1995a).

- 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).
- Supplemental Guidance to RAGS: Region IV Bulletin, *Provisional Guidance of Quantitative Risk Assessment of PAHs*, (USEPA Region IV, 1993), (PAH Guidance).
- *Exposure Factors Handbook*, (USEPA, 1989d).
- USEPA Region III *Risk-Based Concentration Table, October 1997*, (USEPA Region III, October 1997), (RBC Screening Tables).
- *Technical Memorandum Guidance on Estimating Exposure to VOCs During Showering*, (USEPA, 1991c).

These references are detailed in Section 12.

7.2 Objectives

Chemical contamination at the site must be characterized adequately before a risk assessment can be used to determine whether detected concentrations are potentially toxic or may increase the risk of cancer incidents, and before remedial decisions can be based on the assessment. To characterize the study area, the amount, type, and location of contaminant sources are studied. Variables include 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 objectives of the HHRA 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 A under current and future conditions;
- Evaluate the uncertainties related to exposure predictions, toxicological data, and resultant carcinogenic risk and noncarcinogenic hazard predictions; and
- Establish remedial goal options (RGOs) for chemicals of concern (COCs) in each environmental medium, based on risk/hazard, to facilitate risk management decisions.

The focus of each 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, intermediate, and deep intervals of the surficial aquifer. Analytical results from surface soils, shallow groundwater,

intermediate 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 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, visualization of potential exposure pathways, calculation of exposure point concentrations (EPCs), and quantification of 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.
- *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.

- *Uncertainty*: Discussion and evaluation of the areas of recognized uncertainty in human health risk assessments in addition to medium- and exposure pathway-specific influences.
- *Risk/Hazard Summary*: Presentation and discussion of the results of exposure (risk and hazard) quantification for potential receptors and their exposure pathways, identified under current and future conditions.
- *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 Hazard Quotient (HQ) goals of 0.1, 1, and 3 for noncarcinogenic COCs.

This general process was followed in preparing the HHRA for each Zone A SWMU and AOC at NAVBASE.

7.3 Human Health Risk Assessment Methods

When performing an HHRA, environmental media data are analyzed to determine potential site-related chemicals and exposures for each medium as outlined in RAGS Part A. The general process outlined below was used to evaluate human health risks for Zone A.

7.3.1 Data Sources

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

7.3.2 Data Validation

Data validation is an independent, systematic process of evaluating data after they are collected and comparing them to established criteria to confirm that they are of the technical quality necessary to support RFI decisions. Parameters specific to the data are reviewed to determine whether they meet the stipulated DQOs. The data 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 standards.

Data collected for the Zone A RFI were validated in accordance with the USEPA CLP Functional Guidelines as discussed in Section 4 of this report. Complete data validation reports for the Zone A dataset are included in Appendix E. Data from several past Zone A investigations have been considered for use in the HHRA. Data validation cannot be documented for any data collected prior to the 1995 RFI sampling event. The implications of historical data use will be addressed where applicable in the uncertainty section of SWMU/AOC-specific HHRA.

7.3.3 Management of Site-Related Data

All environmental sampling data were evaluated to determine suitability for use in the quantitative HHRA. Data obtained by the following methods were not appropriate for the quantitative HHRA:

- Analytical methods not specific for a particular chemical, such as TOC or total organic halogen.
- Field screening instruments, including total organic vapor monitoring units and organic vapor analyzers.
- Soil and groundwater samples collected during the Geoprobe investigation.

Because duplicate samples were collected for QA/QC, some sample locations had more than one analytical result. One objective of data management was to provide one result per sample location per analyte. Therefore, 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 HHRAs addressed limitations of analytical results by including estimated concentrations for nondetected parameters. A nondetect indicates that the analyte was not detected above the quantitation limit of the sample (*U*-qualified results), which is determined by the analytical method, the instrument used, and possible matrix interferences. However, an analyte could be nondetected and still 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 potentially present below the sample quantitation limit, and was inserted into the adjusted data set used to calculate exposure point concentration (see Section 7.3.6 for discussion of the exposure point concentration).

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 for Zone A 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 and to identify COPCs at potential receptor locations. The statistical methods used in data evaluation are discussed below. The rationale for this methodology and statistical implementation techniques 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, 1992c)

Microsoft FoxPro, Corel Quattro Pro, and SPlus 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 95% upper confidence limit (UCL) for the mean of log transformed concentration values (UCLs were calculated for COPCs only).

7.3.4 Selection of Chemicals of Potential Concern

The objective of this step was to screen available information on the Chemicals Present in Site Samples (CPSS) detected at each SWMU or AOC to develop a list or group of COPCs. COPCs are 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 a COPC to be considered a COC, and warrant 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 a hazard index

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

(HI) greater than 1 for any of the exposure scenarios evaluated in the risk assessment. Second, 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 onsite contamination. This was accomplished by noting the chemicals detected in environmental media. These chemicals represent the CPSS for each SWMU or AOC. The nature and general extent of CPSS at each site are discussed in detail in Section 10 of the RFI. To reduce the list and focus the risk assessment on COPCs, site-related data were compared to risk-based screening concentrations and background concentrations.

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

The maximum CPSS concentrations detected in samples were compared to risk-based screening values obtained from *Determination of COCs by Risk-Based Screening, USEPA Region III*, October 22, 1997. According to this guidance, USEPA used a target HQ of 1 and a risk goal of 10^{-6} to calculate screening concentrations for noncarcinogens and carcinogens, respectively. Noncarcinogenic chemical values were adjusted to equate with an HQ of 0.1.

Groundwater 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 current OSWER directives considering protection of a hypothetical child resident; the lead groundwater screening value used was the USEPA Office of Water treatment technique AL of 15 $\mu\text{g/L}$.

A soil screening value of 1 $\mu\text{g/kg}$ (as 2,3,7,8-TCDD equivalents – total TEQs) was applied to chlorinated dibenzodioxins and dibenzofurans, based on a worker/industrial scenario and a target risk of $1\text{E-}04$. USEPA Region IV has determined this value to be an appropriate cleanup level,

although normally a residential scenario and a target risk of 1E-06 serve as the basis for screening values. For dioxin, USEPA Region IV considers this target risk more appropriate because of the high level of uncertainty associated with dioxin exposure. In a pending South Carolina Record of Decision for the Kopper's site, a similar worker/industrial-based cleanup level of 2.5 µg/kg was presented. For groundwater, the TEQ value computed for each sample was compared to the 2,3,7,8-TCDD tap water screening level of 4.5E-07 µg/L.

In accordance with recent cPAH guidance (USEPA Region IV, 1993), 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.

Groundwater RBC screening relevance is discussed in Sections 7.3.6 and 7.3.8. Because groundwater beneath most of Zone A contains chlorides and/or TDS above South Carolina potable source criteria, water from these aquifers is not appropriate for domestic use. Consequently, screening compound concentrations detected in groundwater against tap water RBCs provides a highly conservative assessment of the significance of groundwater impacts.

For CPSSs present in all depths of soil and groundwater, an additional risk-based screening was conducted as part of the fate and transport assessment. Fate and transport methods are explained in Section 6; site-specific discussions are in Section 10.

Comparison of Site-Related Data to Background Concentrations

Soil and groundwater background concentrations were determined on a zone-wide basis in Zone A, using results from the grid-based soil and groundwater background sampling locations. Surface soil, subsurface soil, shallow groundwater, and deep groundwater were all addressed separately as discussed in Section 5. The statistical methods and rationale used to determine background concentrations and compare site data to background are detailed in Section 5 of this report. This technical approach was developed in conjunction with the NAVBASE Charleston project team and has been approved for use in Zone A by USEPA Region IV and SCDHEC. After risk- and hazard-based screening values were compared, CPSSs were retained for further consideration as COPCs in the HHRA on a SWMU- or AOC-specific basis if their maximum detected concentrations exceeded corresponding background concentrations, or if overall site concentrations were significantly greater than corresponding overall background concentrations as determined by Wilcoxon rank sum test procedures. 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 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 values.

The background concentration is a fixed value determined to represent the upper bound of naturally occurring levels for a chemical in a specific matrix. Comparisons using background 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, excluding definable hot spots. Statistical methods, UTL calculations, Wilcoxon rank sum test outputs, and background sample information are discussed in Section 5. If the maximum concentration of a CPSS was determined to be less than either background (via background concentration comparison *and* population test) or the risk-based screening value, the CPSS was not considered further in risk assessments unless deemed appropriate, based on chemical-specific characteristics (e.g., degradation product with greater toxicity).

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

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

Summary of COPCs

Screening evaluation results are presented on a medium-specific basis in each HHRA in Section 10. In summary, the risk information usually obtained from the Integrated Risk Information System (IRIS) or Health Effects Assessment Summary Tables (HEAST) is necessary to calculate risk and hazard estimates and risk-based screening values. This information is based on toxicological and epidemiological data which are critiqued and approved by the scientific and regulatory community (i.e., listed in IRIS and/or HEAST). Risk information was not available

for some CPSSs; therefore, it was not possible to calculate risk and/or hazard for those chemicals. For each environmental medium sampled at a SWMU or AOC, the data were screened using risk-based and background values. Screening process results are presented in CPSS tables in each site-specific HHRA. Those chemicals determined to be COPCs through the screening process are designated with an asterisk. Total isomer concentrations reported for chlorinated dibenzodioxins and dibenzofurans (e.g., Total HxCDD) were not specifically used in formal assessment per USEPA protocol. No risk-based screening values are available for the generic group TPH. As a result, TPH assessment was consistent with the NAVBASE soil action level of 100 mg/kg. If no groundwater impacts were identified, the current soil concentrations were considered sufficiently protective of the underlying aquifer.

7.3.5 Calculation of Risk and Hazard

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, then comparing these values 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 are retained as COCs. Section 7.3.7 discusses cancer risk thresholds and noncancer toxicity.

7.3.6 Exposure Assessment

This step is designed to determine the magnitude of contact a potential receptor may have with site-related COCs. Exposure assessment involves four stages:

- Characterizing the site's physical setting and land use

- Identifying COPC release and migration pathway(s)
- Identifying potential receptors, under various land use or site condition scenarios, and the pathways through which they might be exposed
- Quantifying the intake rates, or contact rates, of COPCs

Exposure Setting and Land Use

During this part of the HHRA process, the basic layout of the SWMU or AOC as well as the suspected source(s) of contamination are described. Where multiple SWMUs and AOCs were combined for the RFI, the rationale is discussed. In addition, the site's projected future use is discussed, if known. Prior Zone A land uses included station supply, industrial supply, and administration. Current base reuse plans call for Zone A to be developed into a marine terminal, which would likely require maintaining or renovating most of the warehouse buildings currently in the area.

At some SWMUs or AOCs, site features such as asphalt surfaces, buildings, and fences would prevent or minimize exposure to impacted media if they are maintained under base reuse plans. Each site-specific HHRA evaluated the potential influence of site features on exposure. Where current site features affect how an individual might be exposed, detailed analyses were performed to calculate alternative EPCs and to derive factors to account for the fraction ingested/contacted (FI/FC) from the contaminant source. The assessments performed in consideration of existing features are presented as an additional exposure scenario in the quantification of exposure and risk characterization sections of the site-specific HHRAs.

Potentially Exposed Populations

In each site-specific HHRA, this section describes who may be exposed to contaminants in environmental media. For the Zone A HHRAs, the potentially exposed populations addressed were current and future site workers, as well as hypothetical future site residents. Because current site workers at most Zone A sites would be expected to have limited contact with contaminated media, worker-related exposure was addressed exclusively for maximally exposed future site workers. The future site worker scenario assumes that groundwater exposures will include both ingestion and inhalation via showering. While providing a reasonably conservative assessment of future site worker risk/hazard, this approach 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 uses cannot be definitively stated.

Exposure Pathways

This section of each HHRA summarizes how potential receptors (site workers, residents, etc.) could 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 exposure pathways evaluated.

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 95% UCL for the mean of concentrations to quantify exposure. Applying the UCL is generally inappropriate with fewer than 10 samples. Instead of the UCL, the maximum concentration detected was used for each dataset with fewer than 10 samples. In general, outliers were 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:

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

where:

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

USEPA Region IV guidance prefers an alternative to the 95% UCL for exposures involving groundwater. EPCs for groundwater were calculated as the arithmetic mean concentration of a COPC in the most concentrated area of the plume. As the definition of a plume for any given COPC becomes more uncertain, and to account for the data variability associated with multiple quarters of groundwater data, a UCL may be calculated for comparison to the arithmetic mean of

the COPC in the most concentrated area of the plume. For some COPCs at certain sites it was more appropriate to use the UCL or the maximum detected concentration as the groundwater EPC.

The calculated values for the 95% UCL (or arithmetic mean in the most concentrated area of the plume) are presented in tables that statistically summarize COPCs identified in each environmental medium. For soil, 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, and the maximum of detected concentrations. For groundwater, included for each COPC are the number of detects, the number of samples analyzed, and any statistical parameters used to determine the EPC.

Modified or alternative EPCs were calculated for some SWMUs or 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 current features be maintained under 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 FI/FC from the contaminated source. This approach was used where impacts were found to be extremely limited in areal extent (hot spots). In these cases, the basis for the decision is discussed in the site-specific HHRA.

As previously discussed in the data management subsection (Section 7.3.3) of this report, analytical results are presented as "nondetects" when chemical concentrations in samples do not exceed 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

statistical procedures mentioned above to a dataset with reported nondetects for organics, the smaller of two values was chosen as the applicable default proxy concentration: either one-half of the nondetect value for the sample or one-half of the lowest *J*-qualified value at the site. For inorganic chemicals, one-half of the nondetect value was assumed to be the applicable proxy 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.

Quantification of Exposure

This section describes the models, equations, and input parameter values used to quantify doses or intakes of COPCs for 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, ensure that the estimated intakes represent the reasonable maximum exposure (RME) when applied to the EPC. 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 Zone A SWMU and AOC. Because Zone A is part of BRAC III, future site use cannot be assumed with any certainty. Therefore, the conservative assumptions were used to account for any reasonable future use. Zone A media analytical results and exposure methods have been designed so that exposure estimates can be refined as base reuse plans materialize. Age-adjusted ingestion factors were derived for the potential future residential receptors (resident adult and 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
Averaging Time, Noncancer	8,760 ^e	2,190 ^e	9125 ^e	days
Averaging Time, Cancer	25,550 ^f	25,550 ^f	25,550 ^f	days

Notes:

- a = USEPA (1989a) *Risk Assessment Guidance for Superfund Vol. 1, Human Health Evaluation Manual (Part A)*.
- b = USEPA (1991b) *Risk Assessment Guidance for Superfund Vol. 1: 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. 1 – 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.

Surface Soil Pathway Exposure

Ingestion of COPCs in Surface Soil

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

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

where:

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

Dermal Contact with COPCs in Surface Soil

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

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

where:

- CDI_{sd} = dermal dose (mg/kg-day)
- C_s = concentration of contaminant in soil (mg/kg)
- CA = contact area (cm²)
- EF = exposure frequency (days/year)
- ED = exposure duration (years)
- F = conversion factor (10⁻⁶ kg/mg)
- FC = fraction contacted from contaminated source (unitless)
- ABS = absorption factor (unitless value, specific to organic versus inorganic compounds)
- AF = adherence factor (mg/cm²)
- BW = body weight (kg)
- AT = averaging time (days)

Groundwater Pathway Exposure

Ingestion and Inhalation of COPCs in Groundwater

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

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

where:

CDI _w	=	ingested/inhaled dose (mg/kg-day)
C _w	=	concentration of contaminant in water (mg/L)
IR	=	ingestion rate (L/day)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
BW	=	body weight (kg)
AT	=	averaging time (days)

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 HHRA 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]).

7.3.7 Toxicity Assessment

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 also can 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

Figure 7.1

Formulae for Calculating CDI for Soil

SOIL INGESTION PATHWAY

Residential Scenario:

Noncarcinogens-Residential Scenario:

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

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

Carcinogens (based on a lifetime weighted average):

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

SOIL DERMAL CONTACT PATHWAY

Residential Scenario:

Noncarcinogens-Residential Scenario:

$$CDI_{NC-A} = \frac{C_S * CA_{soil/adult} * EF_{res} * F * FC * AF * ABS * ED_{adult}}{AT_{NC-A} * BW_{adult}}$$

$$CDI_{NC-A} = \frac{C_S * CA_{soil/adult} * EF_{res} * F * FC * AF * ABS * ED_{adult}}{AT_{NC-A} * BW_{adult}}$$

Carcinogens (based on a lifetime weighted average):

$$CDI_C = \frac{C_S}{AT_C} \left[\frac{CA_{soil/child} * EF_{res} * F * FC * AF * ABS * ED_{child}}{BW_{child}} + \frac{CA_{soil/adult} * EF_{res} * F * FC * AF * ABS * ED_{adult}}{BW_{adult}} \right]$$

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)
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 (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)
$CA_{soil/child}$	child soil dermal contact area (cm ²)
$CA_{soil/adult}$	adult soil dermal contact area (cm ²)
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:

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

Noncarcinogens-Adult-Residential Scenario:

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

Carcinogens (based on a lifetime weighted average):

$$CDI_C = \frac{C_W}{AT_C} \left[\frac{IR_{water/child} * EF_{res} * F * FI * ED_{child}}{BW_{child}} + \frac{IR_{water/adult} * EF_{res} * F * FI * ED_{adult}}{BW_{adult}} \right]$$

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 (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.

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

For noncarcinogens, other toxic effects are generally considered possible if the HQ (or HI, the sum of HQs for a pathway) 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 HHRA's 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 was 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 HHRA's. The HHRA 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).

Toxicity Profiles for COPCs

In accordance with RAGS, the HHRA's include brief toxicological profiles for all COPCs. Most information for the profiles was gleaned from IRIS and HEAST, and the 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 exposure and toxicity assessments 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 nonprobabilistic 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 HHRA characterizes the potential health risks associated with intake of chemicals originating from each 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. This supplemental information is presented to more clearly depict 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, exposure-related inhalation 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 HHRA 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):

$$\text{ILCR} = (\text{CDI})(\text{SF})$$

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:

$$\text{Risk}_p = \text{ILCR}(\text{chem}_1) + \text{ILCR}(\text{chem}_2) + \dots \text{ILCR}(\text{chem}_i)$$

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

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 = chronic daily intake of chemical (mg/kg-day)
- RfD = reference dose (mg/kg-day)

Chemical noncarcinogenic effects are evaluated chronically, 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, potential adverse health effects may be a concern.

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 tables for each medium following the general discussions of risk and hazard quantification methods. For most SWMUs and AOCs, the following subsections are included.

Surface Soil Pathways

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

Groundwater Pathways

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

Other Applicable Pathways

This section appears in HHRAs 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.

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 tables 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 A HHRAs, 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 HQ exceeds 0.1. For carcinogens, this approach is relatively conservative, because a cumulative risk of 10^{-4} (and individual ILCR of 10^{-6}) is generally recognized by USEPA Region IV as the 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 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 of this report, the cumulative risk threshold used to identify COCs in the following HHRA is 10^6 , which is more conservative by two orders of magnitude.

Risk/Hazard Maps

In addition to the standard tabular presentation of risk/hazard, point maps summarizing risk and hazard were plotted where appropriate for applicable environmental media. As an extension of conventional risk/hazard interpretations, excess cancer risk and/or hazard were calculated for each sample location by summing the contributions of each COPC detected in the corresponding sample. Each mapped sample location was then color-coded to signify a cumulative range of risk or hazard.

Maps were prepared only where they were considered a useful aid in data interpretation and/or CMS decision making, and only for SWMUs/AOCs, media, and pathways for which sufficient data were available to produce relevant displays. Narratives are provided where graphical presentations were inappropriate. If COCs were not identified in the HHRA for a specific site, or if an adequate narrative explanation could be provided, risk point maps were not developed for that site.

ArcInfo², a standard graphical data presentation and geographic information system package, was used to plot the risk/hazard projections on SWMU/AOC base maps. Section 7.3.9 discusses the uncertainties involved in the mapping process. The point maps illustrate risks or hazards associated with COPCs in the subject medium. The risk or hazard for individual locations was

² Reference to specific software products are not to be construed as an endorsement by the U. S. Navy or E/A&H.

based exclusively on chemicals detected. Tables summarize the data used to generate graphical presentations. Summarizing the data on maps allows the reviewer to determine the nature of the contaminants identified and helps in screening remedial alternatives during the CMS.

7.3.9 Risk Uncertainty

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

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 CDI estimates. 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, individual chemical risk is added to determine the incremental excess cancer risk for each exposure pathway. If calculations of 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 prediction of 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 discussions. 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 HHRA 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 on which they are based; 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 HHRA 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, risks and hazards calculated using RME exposure assumptions are generally over rather than underestimates. The following paragraphs discuss sources of uncertainty and variability pertinent to each exposure pathway evaluated.

Quality of Data

Data collected during the Zone A investigation are presented in Section 10 of this RFI, which includes results from AOC and SWMU sites. The purpose of the data evaluation is to verify that the QC requirements of the dataset have been met and to characterize questionable data. The analytical methods and DQO laboratory deliverables are summarized in Section 4, Data Validation.

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.

Identification of COPCs

Rather than addressing risk/hazard for all chemicals detected, screening values were used to focus the HHRA 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, comparisons were made using the most conservative set of screening values (residential land use) provided by USEPA for each exposure medium. Many CPSS 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 with low range risk/hazard goals alleviates much uncertainty. A large number of constituents (more than 10) 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 risk-based concentrations calculated by USEPA. If these pathways were the primary concern (as opposed to ingestion), the screening method could eliminate contaminants that should otherwise be considered COPCs. Any constituents omitted based on comparison to residential RBCs that have the potential to significantly contribute to risk via other exposure pathways were added back to the list of COPCs. Additionally, Zone A soil data are

compared to cross-media transport soil screening values in the fate and transport discussion of this report to identify other potential indirect exposure pathways.

Comparison to Reference Concentrations (Background)

Because the HHRA's purpose is to estimate the excess cancer risk or health hazard posed by COPCs, individual sample data values of inorganic chemicals were compared to background reference concentrations in the Zone A RFI, after comparing the data to risk-based 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 concentrations differed significantly between onsite and background locations, as detailed in Section 7.3.4. The dual approach to background screening reduces the probability that a COPC would be improperly dismissed from formal assessment.

Additional uncertainty is introduced by comparing site data to nonspecific screening reference data. Although the background concentrations are specific to Zone A, they are not specific to individual SWMUs or AOCs. The use of zone-specific background reference standards, however, decreases the uncertainty that would result from using a single set of standards across the entire base.

Elimination of Essential Nutrients

In accordance with RAGS, the following nutrients were eliminated from Zone A HHRAs: calcium, sodium, potassium, magnesium, and iron. Toxicity from overexposure to these nutrients 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 HI calculations in the HHRA could be positively influenced by the nutrient concentrations detected onsite. Therefore, the HIs are possibly underestimates.

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 (e.g., 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 also very 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 affected media for 8 hours per day, 250 days per year, as assumed in the exposure assessment. Mowing grass 52 days per year would result in approximately one-fifth the projected risk/hazard for site workers.

Residential use of Zone A sites is not likely, 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 — soil could be covered with roads, paved driveways, landscaping soil, and/or houses, or parts of the property 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 HHRA would generally overestimate the risk and hazard posed to current site workers and future site residents.

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

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

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 guidance document *Supplemental Guidance to RAGS: Calculating the Concentration Term* (May 1992) outlines a statistical estimation of EPC. These calculated concentrations are 95% UCLs for 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 includes 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, local linearity was assumed to facilitate interpolation of the statistic for each COPC addressed in the HHRAs.

Linear interpolation provides a good estimate of H; however, both 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 them if they were not transformed. The effect of multiplying a number in log form is exponential and H is applied as a multiplier in this case. 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 EPCs. 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 deviations as concentration variability or range widens. A higher standard deviation results in a high H-statistic, typically leading to a UCL greater than the maximum concentration detected onsite. If that is the case, then using the UCL or maximum concentration detected as the EPC (or possibly including

the COPC in question as a COC) 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. Use of the maximum concentrations (or the UCL) is questionable for these contaminants, and the calculated risk and hazard could be skewed upward 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.

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 HHRA. 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 relative to human health concerns. In the presence of such uncertainty, the USEPA and the risk assessor are obligated to make conservative assumptions to minimize the chance that the actual health risk is greater than that determined by 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 A HHRA.

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

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 HHRA.

Quantification of Risk/Hazard

This section of each HHRA is reserved for a 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.

Mapping Risk/Hazard

Risk and hazard maps developed to present site-specific HHRA results are in Section 10. For selected sites, point maps were constructed to show the cumulative risk/hazard computed at specific points, based on the location-specific data for the medium of interest. Location-specific totals were summed and plotted to illustrate ranges of total risk and/or total hazard at sites where data supported such a representation.

Risk and hazard point mapping is useful in risk assessment for determining whether hot spots (or isolated areas of gross contamination) are present in an otherwise unimpacted area. This information is important because heterogeneous 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. Point maps allow for visual analysis of risk and hazard distributions and make it easier to estimate the extent of hot spots relative to the overall site area. These maps also support preliminary scoping of remedial requirements and assessment of potential cleanup alternatives in the CMS.

7.3.10 Risk Summary

In each site-specific HHRA, 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 HQ is considered to significantly contribute to the pathway ILCR or HI. Based on this method, COCs were identified which required calculating

RGOs; they are listed in the risk characterization section of the HHRA for each site. RGOs were calculated for all COCs 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 for the site resident and the adult site worker. Calculations of hazard-based RGOs, based on either the hypothetical child resident or the adult site worker, were noted in the corresponding tables.

8.0 ECOLOGICAL RISK ASSESSMENT

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

8.1 Zone Rationale

Basewide, eight Ecological Study Areas (ESAs) were designated to assist in appropriately qualifying geographic boundaries with contiguous habitats or similar ecosystem distributions (Figure 8-1). Within these ESAs, Areas of Ecological Concern (AECs) were further specified to focus the investigation relative to potential SWMU or AOC contribution, and thus the receptor exposure. Using an ecological survey form, all ESA and AEC habitat and resident biota were evaluated to obtain preliminary ecological information essential to zone-specific ERAs. The completed forms are presented in Appendices A and B of the Zone J RFI Work Plan; those pertinent to Zone A are summarized below. The survey methodology is used in conjunction with the Zone A RFI report and is also described in the Zone J RFI Work Plan (final submitted November 20, 1996).

Basewide, zone configurations were based on SWMU or AOC locations and therefore do not necessarily parallel ESA boundaries. Within the designated Zone A boundaries are two ESAs (all of ESA I and a portion of ESA II) and one AEC (Figure 8-2). A large portion of Zone A was not relevant to this ERA based on the lack of habitat and receptors. These areas were the

industrialized sections associated with the DRMO and surrounding buildings. Due to the lack of habitat and receptors in these areas, they will not be discussed relative to ecological risk. As receptors of surface water runoff, the adjacent Noisette Creek and Cooper River are associated with Zone A. If contaminants could migrate to these aquatic areas, risks to applicable receptors will be evaluated during the Zone J investigation.

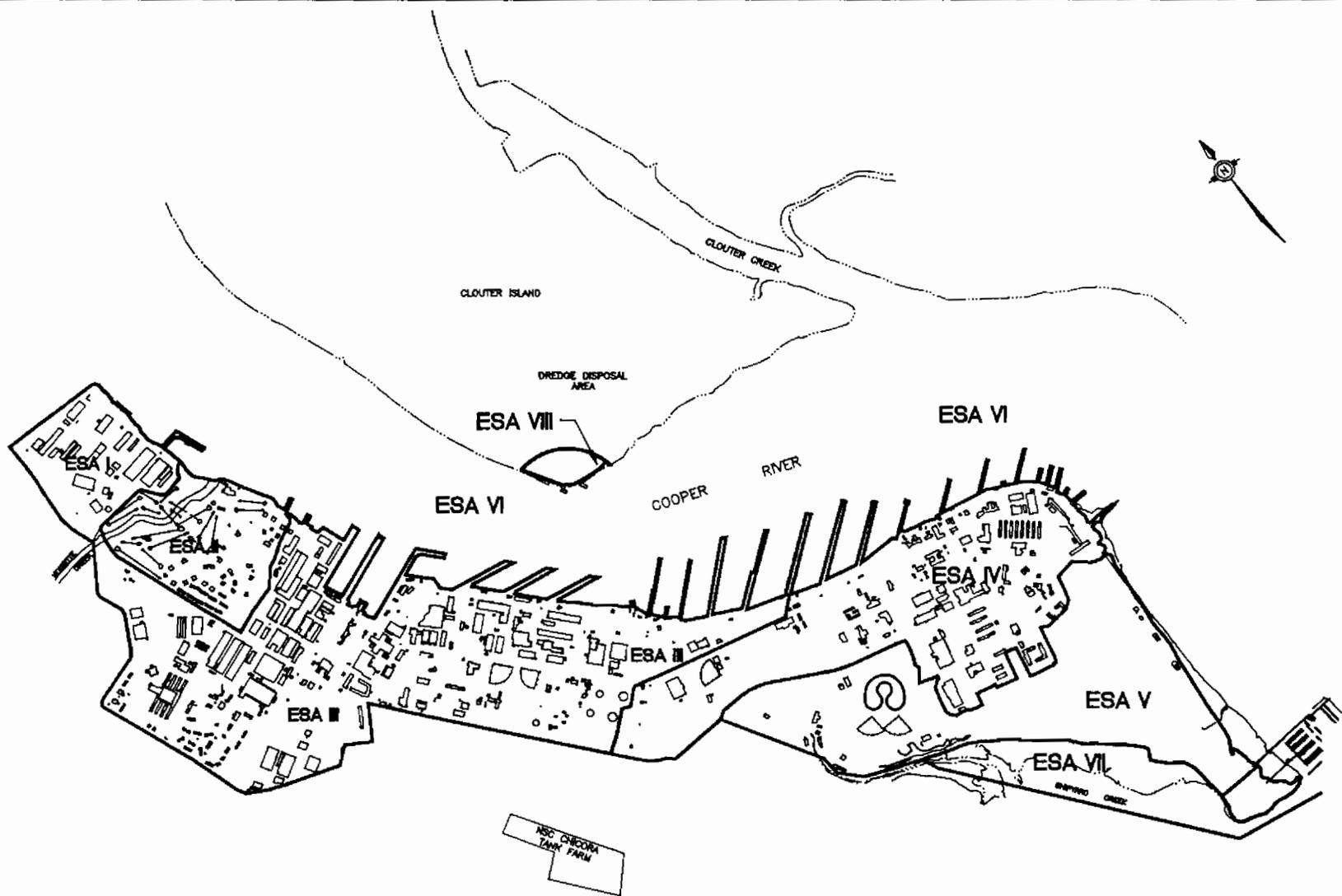
Only one distinct ecological area (Subzone A-1) was defined within Zone A, and potential risk to this subzone from surrounding AOCs and SWMUs was assessed. These AOCs/SWMUs are listed below:

- SWMU 1 DRMO Storage
- SWMU 2 Lead Contamination Area
- SWMU 38 Miscellaneous Storage, North of Building 1605
- SWMU 39 Former POL Drum Storage Area, Building 1604

8.2 Environmental Setting

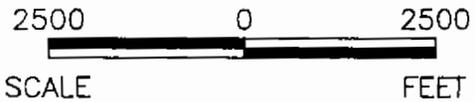
8.2.1 Problem Formulation

The habitat and biota survey of Zone A identified only one ecologically significant area, Subzone A-1, a small overgrown area in the eastern portion of an approximately 2-acre mowed grass field. Due to the vegetation and apparent site hydrology, the 1988 National Wetlands Inventory classified this area as a palustrine scrub-shrub, seasonally flooded/saturated wetland. During the initial site visit in April 1995, the central portion of this area was flooded with several inches of water. However, upon subsequent sampling events (October 1995 and March 1996), this "wetland" area and associated substrate was dry, preventing collection of the proposed surface water samples. Apparently, the water source for this region was a leaking underground water line. Once this line was repaired, the wetland vegetation began to wilt.



LEGEND

— — ESA BOUNDARY



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



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

FIGURE 8-1
ECOLOGICAL STUDY AREA
LOCATION MAP

DWG DATE: 08/14/96 | DWG NAME: 29CHASAM

Subzone vegetation was thickest in the center and consisted of common elderberry (*Sambucus canadensis*), black willow (*Salix nigra*) and several small ornamental trees planted on the western perimeter. Terrestrial faunal species associated with this habitat include passerine birds (mourning dove, American Robin, starling, and red-wing blackbird), Eastern cottontail rabbit (*Sylvilagus floridanus*) along with other small rodents (mice and voles), amphibians, and reptiles.

8.2.2 Threatened and Endangered Species

Within this small subzone in Zone A, several federally and state-designated species of concern may be present. Table 8.1 lists those species which have been identified at or near NAVBASE. Risks to these species from observed contamination will be addressed as appropriate.

8.3 Conceptual Model

Figure 8-3 presents a conceptual model of the potential contaminant pathways from source to ecological receptors for Subzone A-1. For the assessment of this predominantly dry habitat, only exposure routes directly related to soil pathways are evaluated. Although samples collected in the center of the subzone were initially designated as sediments, the dry conditions observed throughout most of the year are not expected to support aquatic biota. Therefore, for this risk assessment, the three sediment samples collected across the subzone were considered as soil samples. Direct impacts to plants are also 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.

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 Section 8 — Ecological Risk Assessment
 Revision: 0

Table 8.1
 Federally 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	C2	SC
Eastern Tiger Salamander	<i>Ambystoma tigrinum</i>	FR	—	SC
Broad-Striped Dwarf Siren	<i>Pseudobranchius striatus</i>	PR	—	SC
Crawfish Frog	<i>Rana areolata</i>	PR	—	SC
Loggerhead Turtle	<i>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

Table 8.1
Federally 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				
Canby's Dropwort	<i>Oxpolis canbyi</i>	UR	E	E
Pondberry	<i>Lindera melissifolia</i>	UR	E	E
Incised Groovebur	<i>Agrimonia incisa</i>	UR	C2	NC
Sea-Beach Pigweed	<i>Amaranthus pumilus</i>	UR	SR	NC
Cypress Knee Sedge	<i>Carex decomposita</i>	UR	SR	—
Chaff-Seed	<i>Schwalbea americana</i>	UR	SR	NC
Whisk Fern	<i>Psilotum 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's Flytrap	<i>Dionaea muscipula</i>	UR	—	RC
Sweet Pinesap	<i>Monotropsis odorata</i>	UR	—	RC
Climbing Fetter-Bush	<i>Pieris phillyreifolia</i>	UR	—	SL
Sea Purslane	<i>Trianthema portulacasfrum</i>	CR	—	SC

Notes:

- = Wading bird colony has been a confirmed resident at the base, but was not present during field studies in April 1994
- CR = Confirmed 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 regional concern
- NC = Of national concern
- C2 = 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

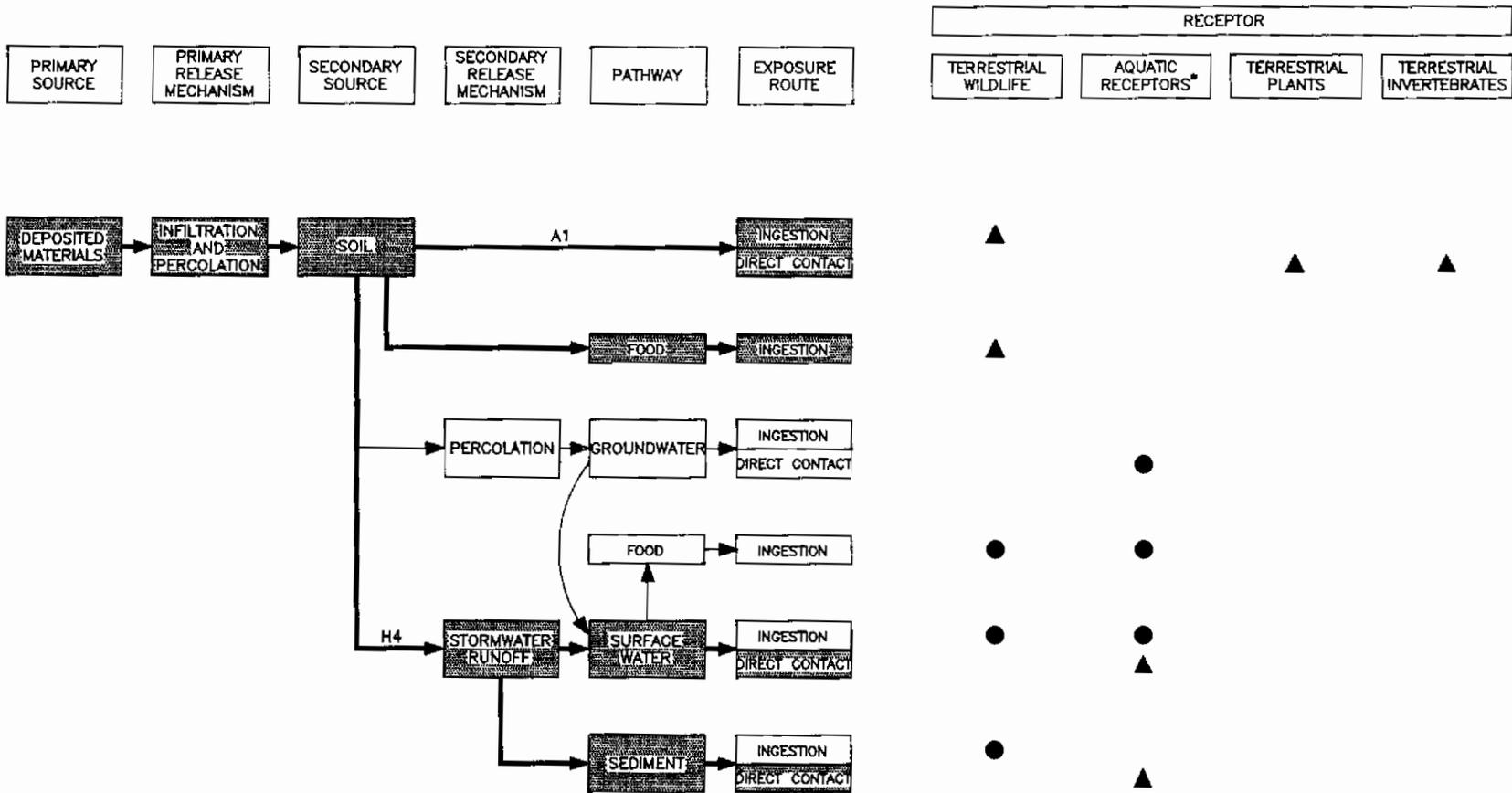
Source: Final Environmental Impact Statement for Disposal and Reuse of the Charleston Naval Base, North Charleston, South Carolina (Ecology and Environment, 1995)

8.4 Selection of Ecological Chemicals of Potential Concern

Past activities at Zone A SWMUs and AOCs that may have impacted the surrounding ecosystem are discussed on a site-specific basis in Section 10. COCs resulting from these activities have been identified and quantified according to USEPA methods and protocols for analyses of soil, sediments, and groundwater.

For ecological risk, only the results from surficial soil (0 to 1 foot bgs interval) are addressed. It is presumed, even considering root development in the lower strata, that most biological effects will be limited to the upper zone. Based on the transient or mobile nature of biological components within the subzone, parameter concentrations detected at one location in a subzone will be used to assess the entire subzone. Therefore, maximum concentrations for contaminants detected at all sample locations within the subzone are used in this assessment. Although groundwater has been monitored, water table depth (averaging approximately 5 feet bgs) in Zone A upland portions precludes assessing ecological impacts from this medium immediately within the zone perimeter. Based on the extended dry periods in the subzone, it is also not considered significantly affected by groundwater discharge. See Section 6 for more information on groundwater-to-surface water cross-media transport.

Inorganic parameters are identified as Ecological Chemicals of Potential Concern (ECPCs) if detected in site surface soil equal to or more than twice the maximum concentration detected in reference sample concentrations (upper tolerance level of background), or if that parameter was not detected in reference samples. Any organic constituent detected in greater than 5% of the samples is considered an ECPC. Any constituent detected in less than 5% of the samples is not considered an ECPC. With only six soil samples collected at Subzone A-1, the 5% rule makes all detected organics ECPCs. Calcium, magnesium, potassium, and sodium were not assessed because they are naturally occurring nutrients. Tables 8.2 and 8.3 present ECPCs identified for Subzone A-1.



*AQUATIC RECEPTORS - INVERTEBRATES, PLANTS, ALGAE, AMPHIBIANS, AND FISH
 NOTE: SHADED BOXES, BOLD ARROWS, AND TRIANGLES INDICATE SELECTED PATHWAY.



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FIGURE 8-3
 CONTAMINANT PATHWAY MODEL FOR
 ECOLOGICAL RECEPTORS

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8.5 Stressor Characteristics

This section summarizes the findings observed in various studies of certain inorganic and organic stressors and their ecological effects (toxicity, biomagnification, mobility, adsorption rates, etc.) which may apply to Zone A ecological receptors. This general information can be used to compare Subzone A-1 contaminant concentrations to those known to affect biota. More direct comparisons using specific stressor studies, receptors, and the maximum concentrations detected in Subzone A-1 are made in Section 8.8.

Inorganics

In general, heavy metals adversely affect survival, growth, reproduction, development, and metabolism of terrestrial invertebrate species, but effects are substantially modified by physical, chemical, and biological variables. Pascoe et al. (1994) observed that, in general, bioavailability of metals and arsenic in soil to small mammals was limited. The study also suggests that metal and arsenic intake for higher trophic species may be similarly limited and that most heavy metals do not biomagnify. In contact tests with terrestrial earthworms, the order of toxicity for heavy metals from most toxic to least toxic was copper > zinc > nickel = cadmium > lead.

Arsenic — Arsenic occurs naturally and, with respect to cycling in the environment, is constantly changing. Many inorganic arsenicals are known teratogens and are more toxic than organic arsenicals (Eisler, 1988a). Soil biota appear able to tolerate and metabolize relatively high concentrations (microbiota to 1,600 mg/kg) of arsenic (Wang et al., 1984). Furthermore, arsenic in soil does not appear to magnify along the food chain.

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Table 8.2
Inorganic Constituents in Subzone A-1 Surface Soil

Inorganic Elements (N=6)	Number of Detections	Range of Concentrations	Mean Concentrations	Upper Tolerance Limit of Background ^a	ECPC
Aluminum	6	3,000 - 40,100	16,310	12,800	Yes
Antimony	3	1.8 - 11.5	6.6	Not Valid ^b	Yes
Arsenic	6	2.4 - 21.5	14.1	9.4	Yes
Barium	6	14 - 260	93.3	53	Yes
Beryllium	4	0.08 - 2.1	0.29	Not Valid ^b	Yes
Cadmium	6	0.12 - 7.2	4.3	Not Valid ^b	Yes
Chromium	6	6.7 - 112	46.3	50.4	Yes
Cobalt	6	0.24 - 14	6.4	4.4	Yes
Copper	6	6.4 - 174	106	165	Yes
Iron	6	5,630 - 34,200	16,320	Not Valid ^b	Yes
Lead	6	7.5 - 1,500	829	140	Yes
Manganese	6	6.5 - 172	75.6	98.1	Yes
Mercury	2	0.13 - 0.23	0.18	0.3	No
Nickel	6	1.0 - 61.7	33.6	13.6	Yes
Selenium	1	0.91	NA	1.2	No
Thallium	1	1.2	NA	Not Valid ^b	Yes
Tin	5	3.5 - 45.5	19.5	Not Valid ^b	Yes
Vanadium	6	11.4 - 114	49.1	29.2	Yes
Zinc	6	5.5 - 982	525	208	Yes

Notes:

All units are in milligrams per kilogram

N = Number of samples collected.

ECPC = Ecological Chemical of Potential Concern

a = Determination based on Zone A grid-based samples. See Section 5 for background determination.

b = Number of nondetections prevented determination of upper tolerance limit.

Table 8.3
Organic Constituents in Subzone A-1 Surface Soil

Compound Name	Detected Concentration ($\mu\text{g}/\text{kg}$)
Volatile Organic Compounds (N = 1)	
Acetone	29
2-Butanone (MEK)	6
Semivolatile Organic Compounds (N = 1)	
Benzo(b)fluoranthene	120
Benzo(k)fluoranthene	74
Benzo(g,h,i)perylene	73
Benzo(a)pyrene	78
Chrysene	130
2-Methylnaphthalene	140
Fluoranthene	170
Phenanthrene	150
Pyrene	120
Pesticides/Polychlorinated Biphenyls (N = 1)	
4,4'-DDE	140
4,4'-DDD	8.5
4,4'-DDT	26
Endrin	12
Aroclor-1260	500

Notes:

All detected organics were considered ECPCs.

N = Number of Samples

$\mu\text{g}/\text{kg}$ = micrograms per kilogram

Cadmium — Cadmium is a relatively rare heavy metal. It is a known teratogen and carcinogen and probably a mutagen, and has been implicated as the cause of severe deleterious effects on fish and wildlife (Eisler, 1985). Birds and mammals are comparatively resistant to cadmium's biocidal properties. Freshwater organisms appear to be the most susceptible group to cadmium toxicity and their sensitivity is modified significantly by water hardness. Adsorption and desorption are likely to be major factors in controlling cadmium concentrations in natural waters. Adsorption and desorption rates of cadmium are rapid on mud solids and particles of clay, silica, humic material, and other naturally occurring solids.

Copper — Copper is an essential micronutrient and therefore is readily accumulated by aquatic organisms. It is a broad-spectrum biocide which may be associated with both acute and chronic toxicity.

Lead — In soil, lead concentrates in organic-rich surface horizons (NRCC, 1973). Estimated residence time of lead in soil is about 20 years (Nriagu, 1978). In sediments, lead is primarily associated 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.

No information was available on the toxicological effects associated with other inorganic Subzone A-1 ECPCs for soil.

Organics

PAHs — PAHs vary by molecular weight. With increasing molecular weight, aqueous solubility decreases and the 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 degrade through photooxidation, chemical oxidation, and biological transformation by bacteria and animals (Neff, 1979).

Most environmental concern has focused on PAHs that range in molecular weight from 128.16 (naphthalene) to 300.36 (coronene). Generally, lower-molecular-weight PAH compounds containing two or three aromatic rings exhibit significant acute toxicity but are not carcinogenic. Higher-molecular-weight PAH compounds (four to seven rings) are significantly less toxic, but are demonstrably carcinogenic, mutagenic, or teratogenic to aquatic species. PAHs show little tendency to biomagnify in food chains because most are rapidly metabolized (Eisler, 1987a). Very little information is available on food chain adverse effects as a result of soil PAH contamination.

Pesticides — Organochlorine pesticides have been used extensively in the United States since the 1940s. They appear to be ubiquitous in the environment, being found in soil, surface water, sediment, and biological tissues. 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 — PCBs are distributed worldwide with measurable concentrations recorded in fishery and wildlife resources from numerous locations (Eisler, 1986). They are known to bioaccumulate and 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 food chain transfer to lower-level vertebrate species may occur.

Contaminant Fate and Transport

Surface soil across the site 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. The fate of these contaminants then will be expected to remain in the soil to undergo degradation and/or migrate downward.

In addition, contaminants sorbed to surface soil could conceivably be transported via air or surface water runoff, although these pathways are unlikely major routes. Contaminants are not expected to spread far via surface runoff due to the highly permeable nature of the substrate. Storm drains, sewers, and ditches near several Zone A AOC/SWMUs are indicated in the Subzone A-1 area. Therefore, potential risk from surface water migration to Subzone A-1 and/or the Cooper River exists. The physical adsorption of contaminants to soil particles and available organic material may limit 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.

8.6 Exposure Pathways and Assessment

Exposure pathways for three receptor types were considered for the Subzone A-1 ERA; infaunal invertebrates (earthworms, crickets, and mites), terrestrial wildlife (birds and small mammals), and vegetation.

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 used as a migratory corridor or if animals burrow into it. The contact time, and thus 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 in Subzone A-1 is the maintenance of well-balanced terrestrial wildlife populations and communities. Results of laboratory toxicity studies in literature, relating the oral contaminant dose with adverse response to growth, reproduction, or survival, were used as a measure of the assessment endpoint selected. Two representative wildlife species evaluated through this comparison include: the Eastern cottontail rabbit (*Sylvilagus floridanus*) and American robin (*Turdus migratorius*). These species (or an equivalent) are likely to occur in the designated ecological Subzone A-1.

To assess biotransfer of contaminants along food chains, the total potential dietary exposure (PDE) has been modeled for representative wildlife species within Subzone A-1. Calculation of PDEs is based on predicted concentrations of the ECPC 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 8.4). The concentrations of ECPCs in food items are

Table 8.4
Wildlife Contaminant Exposure Model for Surface Soil
Zone A

$$\begin{aligned} \text{Food Contaminant Concentration (mg/kg)} &= \text{BAF} \times \text{Soil Contaminant Concentration (mg/kg)} \\ \text{Soil Exposure, SE (mg/kg)} &= (\% \text{ of diet as soil}) \times \text{Soil Contaminant Concentration} \\ \text{PDE (mg contaminant/kg BW/day)} &= \frac{[P_1 \times T_1 + P_2 \times T_2 + \dots + P_n \times T_n + \text{SE}] \times \text{IR}_{\text{diet}} \times \text{SFF}}{\text{BW}} \end{aligned}$$

where:

- BAF = Bioaccumulation factors from Table 8.6
- PDE = Potential Dietary Exposure
- BW = receptor body weight (kg)
- P_n = percent of diet composed of food item N
- T_n = tissue concentration in food item N (mg/kg), (Food Contaminant Concentration)
- IR_{diet} = food ingestion rate of receptor (kg of food per day)
- SFF = site foraging factor (cannot exceed 1)

estimated based on literature-reported bioaccumulation factors (BAFs), which are a ratio of the ECPC concentration in dietary items to the concentration in soil. The BAFs reported for avian and mammalian species are reported ratios of ECPCs in animal tissue to ECPC concentrations in their diets.

The site foraging factor (SFF) allows for consideration of feeding frequency in the site area by estimating the acreage of the site relative to the receptors' feeding range, and by considering the fraction of the year the receptor would be exposed to site contaminants.

Vegetation

Woody and herbaceous vegetation in Subzone A-1 could likely incorporate certain detected constituents (metals) through processes such as uptake/accumulation, translocation, adhesion, or biotransformation. Terrestrial herbivores, in turn, could ingest plant-borne constituents.

8.7 Ecological Effects Assessment

Using the above exposure pathways for the selected receptor groups, the following assessment methods were used to evaluate identified ECPC effects on receptors.

Infaunal Invertebrates

Predicted potential adverse ecological effects to soil invertebrates from identified ECPCs are based on effects information in available literature. Because soil screening values 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 correlates the dose of each 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 dies) for the most closely related test species. 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 is an acceptable level of risk to individuals within terrestrial wildlife populations across Zone A.

A sublethal TRV is also identified, representing a threshold for sublethal effects (those effects that impair or prevent reproduction, growth, or survival). 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.

8.8 Risk Characterization

This section presents specific stressor information as it pertains to each of the receptor groups. At the end of each receptor-specific discussion is an assessment of risk to that receptor type from either the maximum detected ECPC concentrations as compared to the literature-based effect levels (infaunal invertebrates and vegetation), or hazard indices derived from computation (terrestrial wildlife).

Little information exists on the toxic effects of VOCs on terrestrial biota. Primarily, the only information available are effects studies of inhalation of specific compounds by laboratory animals, which are then related to human health. Impact from the limited occurrence and relatively low concentrations of volatile compounds observed in soil is difficult to assess, but it is predicted that VOCs will have little to no effect on terrestrial species at Subzone A-1.

8.8.1 Infaunal Invertebrates

Most toxicological information reviewed for the infaunal invertebrates deals with earthworms and other infaunal species. It is important to note that Zone A soil is predominantly sand and may not support these specific-type organisms. Although infaunal species in the sandy environment may

not be the same as those identified in the literature, the ecological niche which they occupy should be similar; therefore, comparison to toxicological concentrations should apply.

Metals — Most studies on metals toxicity to terrestrial receptors have been directed at infaunal ecosystems or avian biology (Table 8.5). 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 µg/cm² 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 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 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 its concentration on soil biota.

Ma (1984) investigated sublethal effects of copper in soil on 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.

Table 8.5
Summary of 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	1843 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
		Phenol	401 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)	<i>Eisenia foetida</i>	Cadmium	250 mg/kg	Growth difference to control
		Nickel	440 mg/kg	Growth difference to control
		Copper	1,320 mg/kg	Growth difference to control
		Zinc	2,800 mg/kg	Growth difference to control
		Lead	21,600 mg/kg	Growth difference to control
Strait (1984)	Mite <i>Platynothrus peltifer</i>	Copper	200 mg/kg	Population decrease

Table 8.5
Summary of Chemical Effects Studies on Terrestrial Infaunal Invertebrates

Study	Organisms	Measured Parameter	Effects Level	Measured Response
van Straalen et al. (1989)	Mites	Cadmium	> 128 mg/kg	Mortality
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 [®] Bioassay (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>	PCB	1,200 mg/kg	LC ₅₀
Reinecke & Nash (1984)	Earthworm <i>Allotobophora 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

Table 8.5
Summary of Chemical Effects Studies on Terrestrial Infaunal Invertebrates

Study	Organisms	Measured Parameter	Effects Level	Measured Response
Beyer et al. (1985)	<i>Eisenia foetida</i>	Methyl mercury	25 mg/kg 5 mg/kg	100% mortality 21% mortality
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>	PCB	240 mg/kg	LC ₅₀
Nielson (1951)	earthworms	Copper	150 mg/kg 260 mg/kg	Population reduced by 1/2 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-week LC ₅₀

- Notes:*
- ^a = Growth effects levels are the average of at least five of six compounds: metal acetate, metal carbonate, metal chloride, metal nitrate, metal oxide, and metal sulfate.
 - ^b = Carabidae, entobeyidae, formicidae, gryllidae and staphylinidae
 - ^c = Average soil concentration levels [maximum values]
 - mg/kg = milligrams/ kilogram
 - µg/kg = micrograms/ kilogram

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.

SVOCs — Although some 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, and phenol) were somewhat toxic to earthworms, with PAHs being relatively less toxic than other semivolatile compounds studied. Artificial tests of soil produced lethal concentration (LC_{50}) values for fluorene and phenol near 200 mg/kg and 400 mg/kg, respectively. Callahan et al. (1994) found similar results in their study on toxicity of 62 chemicals to several earthworm species. Fluorene is acutely toxic at certain concentrations but it is not a carcinogen. It is important to note that field variability and soil chemical matrices can greatly influence toxicological effects of PAH compounds.

Pesticides — Most toxicological studies of terrestrial infaunal organisms have measured 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 were 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 impact to robins. Callahan et al. (1991)

also found that chlordane, as with 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.

PCBs — Risk factors associated with PCBs are similar to those for pesticides. After acute mortality, food chain biomagnification and transfer are the most important issues to be considered when assessing long-term risk. Paine et al. (1993) suggested a benchmark value between 100 and 300 mg/kg PCB for mortality in terrestrial insects. Also, Rhett et al. (1988) observed LC₅₀ values at 240 mg/kg for earthworms treated with PCBs. 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.

Risk to Infaunal Invertebrates from ECPCs at Subzone A-1

Inorganics — Maximum concentrations for some inorganic constituents in the six soil samples from Subzone A-1 pose only a slight risk to infaunal species during the dry seasons. Although lead is a primary COC in Zone A, the maximum soil concentration for lead (1,500 mg/kg) at Subzone A-1 was below the lowest cited effects level for earthworms (6,000 mg/kg) found by Neuhauser et al. (1986). The maximum copper concentration of 174 mg/kg, however, is above the effects level for earthworms as observed in several studies — Ma (1982), 150 mg/kg; and Nielsen (1951), 150 mg/kg — but the mean copper value (106.3 mg/kg) for the subzone is below cited effects levels. The maximum zinc concentration (982 mg/kg) was also above or near the levels found to impact earthworms in two separate studies: Neuhauser et al. (1986), 662 mg/kg, and Malecki et al. (1982), 2,800 mg/kg. As with copper, the subzone mean value for zinc (525 mg/kg) was below cited effects levels. Effects on earthworms from inorganic mercury have also been documented at concentrations as low as 0.79 mg/kg, which is above the maximum

mercury concentration (0.23 mg/kg) detected at A-1. Therefore, risk to infauna from mercury contamination is not anticipated.

Organics — Based on the results of the single sample analyzed for organic parameters, no risk to infaunal communities is predicted from observed PAH concentrations. Concentrations of individual PAH compounds (maximum to 170 $\mu\text{g}/\text{kg}$) are not above the minimum effects levels observed by Neuhauser et al. (1986) in earthworms ($\text{LC}_{50} = 173,000 \mu\text{g}/\text{kg}$ for fluorene), and do not indicate toxicity to infauna. Although PAH transfer to other biological organisms is possible, high PAH concentrations in soil can also lead to increased populations of microorganisms capable of degrading the compounds (Edwards, 1983). Risks related to biotransfer of contaminants through infaunal species to terrestrial vertebrate species will be addressed later.

Risk from the observed 4,4'-DDE concentrations (140 $\mu\text{g}/\text{kg}$) is considered negligible since this concentration is below those cited in the literature (200+ $\mu\text{g}/\text{kg}$ for DDE) where no effect was observed on earthworms. Potential transfer of pesticides through infaunal organisms to upper-level species is expected to be minimal. Again, this pathway will be evaluated relative to upper-level vertebrate species in subsequent sections.

The PCB concentration found in A-1 soil (500 $\mu\text{g}/\text{kg}$) is well below the lowest PCB concentrations cited in the literature where acute effects on soil invertebrates were observed ($\text{LC}_{50} = 240,000 \mu\text{g}/\text{kg}$; Rhett et al., 1988). No effect on infauna is predicted from PCBs in soil.

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 estimated dietary exposure concentration (PDE) by the toxicological benchmark (TRV). HIs are determined for each representative wildlife species by summing the calculable 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 on growth, reproduction, or survival and no risk to wildlife populations is assumed. When the HQ or HI is greater than 1, the ecological significance is discussed and risk is assumed. When HIs are greater than 1, the HQs comprising the HI are evaluated.

For representative terrestrial wildlife species, PDEs were calculated using available bioaccumulation data (Table 8.6) for ECPCs presented in Tables 8.2 and 8.3. PDEs could not be calculated for those compounds without an associated BAF. Exposure parameters and assumptions for representative species at Subzone A-1 (Table 8.7) were used to calculate food contaminant concentrations. PDE values were obtained using the model for prediction of contaminant exposure presented in Table 8.4. When the maximum concentration of an ECPC produced HQs greater than 1, the soil concentration necessary to produce risk quotients (HQs) equal to or below 1 can be determined through back-calculation. This concentration is referred to as the Significant Risk Level (SRL). For representative species in Subzone A-1, all lethal and sublethal HQs were below 1, so SRLs were not calculated. HQs for both lethal and sublethal ECPC effects at Subzone A-1 were determined and are presented in Tables 8.8 and 8.9.

Risk to Terrestrial Wildlife from ECPCs at Subzone A-1

There are no potential lethal effects ($HI > 1$) from maximum soil concentrations in Subzone A-1 based on the HI values calculated for the Eastern cottontail rabbit and American robin (Table 8.8). All HQs and the HI value for lethal effects were less than 1. For the robin, lead had the highest HQ (0.011) based on the concentration of 1,500 mg/kg. For the rabbit, the highest HQ was for manganese (0.0089) which had a maximum concentration of 172 mg/kg. No potential lethal or adverse effects on passerine bird or mammal species are predicted as a result of exposure to ECPCs in surface soil.

Table 8.6
 Bioaccumulation Data¹
 Baseline Risk Assessment
 Zone A

Bioaccumulation or Biotransfer Factor (unitless)

Analyte	Log K_{ow}	Plant	Terrestrial Invertebrate	Mammal	Bird
Semivolatiles					
Acenaphthene	NA	NA	NA	NA	NA
Acenaphthylene	NA	NA	NA	NA	NA
Anthracene	4.4 [c]	NA	0.005 [d]	6.30E-04 [a]	1 [ab]
Benzoic acid	NA	NA	NA	NA	NA
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]
Di-n-octylphthalate	NA	NA	NA	NA	NA

Table 8.6
 Bioaccumulation Data¹
 Baseline Risk Assessment
 Zone A

Bioaccumulation or Biotransfer Factor (unitless)

Analyte	Log K_{ow}	Plant	Terrestrial Invertebrate	Mammal	Bird
Semivolatiles					
Fluorene	NA	NA	NA	NA	NA
Indeno(1,2,3-cd)pyrene	7.7 [c]	0.0014 [e]	0.042 [d]	1.26E+00 [a]	1 [ab]
2-Methylnaphthalene	NA	NA	NA	NA	NA
4-Methylphenol	NA	NA	NA	NA	NA
Naphthalene	NA	NA	NA	NA	NA
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]
Pesticides/Herbicides/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 [l]
4,4'-DDT	4.48 [f]	0.027 [ac]	0.98 [v]	2.91E+00 [ak]	2.91 [l]

Table 8.6
 Bioaccumulation Data¹
 Baseline Risk Assessment
 Zone A

Bioaccumulation or Biotransfer Factor (unitless)

Analyte	Log K _{ow}	Plant	Terrestrial Invertebrate	Mammal	Bird
Pesticides/Herbicides/PCBs/Dioxins					
Dieldrin	4.95 [f]	0.049 [e]	1.2 [m]	7.10E-01 [ak]	0.71 [n]
Endosulfan II	NA	NA	NA	NA	NA
Endrin	NA	NA	NA	NA	NA
Endrin aldehyde	NA	NA	NA	NA	NA
Heptachlor	NA	NA	NA	NA	NA
Heptachlor epoxide	NA	NA	NA	NA	NA
2,3,5-TP (Silvex)	NA	NA	NA	NA	NA
2,3,4-T	NA	NA	NA	NA	NA
2,4-D	NA	NA	NA	NA	NA
Parathion	NA	NA	NA	NA	NA
2,3,7,8 TCDD	6.80 [am]	0.005 [e]	5.0 [b]	8.40E-01 [an]	1 [ab]
Inorganics					
Aluminum	NA	NA	NA	NA	NA
Antimony	NA	NA	NA	NA	NA
Arsenic	NA	0.3 [p]	0.77 [ae]	3.60E-01 [ag]	0.45 [ah]

Table 8.6
Bioaccumulation Data¹
Baseline Risk Assessment
Zone A

Bioaccumulation or Biotransfer Factor (unitless)

Analyte	Log K _{ow}	Plant	Terrestrial Invertebrate	Mammal	Bird
Inorganics					
Barium	NA	0.56 [ag]	0.77 [ae]	3.40E-01 [af]	0.45 [ah]
Beryllium	NA	NA	NA	NA	NA
Cadmium	NA	33 [q]	1.4 [k]	2.06E+00 [r]	0.38 [s]
Chromium	NA	NA	NA	NA	NA
Cobalt	NA	NA	NA	NA	NA
Copper	NA	0.78 [t]	0.16 [i]	6.00E-01 [q]	0.45 [ah]
Iron	NA	NA	NA	NA	NA
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]
Nickel	NA	NA	NA	NA	NA
Selenium	NA	0.009 [y]	0.77 [ae]	3.40E-01 [af]	0.51 [z]
Silver	NA	NA	NA	NA	NA
Tin	NA	NA	NA	NA	NA

Table 8.6
Bioaccumulation Data¹
Baseline Risk Assessment
Zone A

Bioaccumulation or Biotransfer Factor (unitless)

Analyte	Log K_{ow}	Plant	Terrestrial Invertebrate	Mammal	Bird
Inorganics					
Vanadium	NA	NA	NA	NA	NA
Zinc	NA	0.61 [t]	1.77 [j]	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 nonlactating 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 (1980). Mean of values. Converted to wet weight assuming 90% bodyweight as water.
 - [e] = Calculated using the following equation in Travis and Arms (1988) for analytes with $\log K_{ow,s} > 5$: $\log (\text{Plant Uptake Factor}) = 1.588 - 0.578 \log K_{ow}$.
 - [f] = From USEPA (1986).
 - [g] = Value from Verschueren (1983).
 - [h] = Value from Howard (1990).
 - [i] = BAF 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 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).

Notes (continued):

- [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).
- [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, 1985a). 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 (1985b) 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 Lafshaw, 1978).
- [aa] = USEPA, 1985b.
- [ab] = Assumption.
- [ac] = Assumed value based on average of BAFs calculated for other pesticides and PCBs.
- [ad] = Assumed value based 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).
- NA = Not available.
- ¹ = Table adapted from BRA, NAS Cecil Field, Jacksonville, Florida.

Table 8.7
Exposure Parameters and Assumptions for Representative Wildlife Species

Prey in Diet (%)

Representative Wildlife Species	Trophic Status	Prey in Diet (%)					Incidental Soil Ingestion (%)	Home Range (acres)	ED	Site Foraging Frequency (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	9.61E-01	0.01	0.077
Eastern Cottontail ^b	Small Herbivorous Mammal	0	97	0	0	0	3	9.3	1	1.08E-01	0.08	1.2

SITE AREA: 1 acre

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, 1942; and Weatherhead & 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.
- 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 8.8
Hazard Quotients for Potential Lethal Effects on Wildlife Species Associated with
Maximum Exposure Concentrations of ECPCs in Soil

Analyte	Max Conc (mg/kg)	PDE	American Robin			Eastern Cottontail		
			TRV	HQ	PDE	TRV	HQ	
Benzo(b)fluoranthene	0.120	1.90E-03	NA	NC	3.26E-05	NA	NC	
Benzo(k)fluoranthene	0.074	1.12E-03	NA	NC	1.90E-06	NA	NC	
Benzo(g,h,i)perylene	0.073	1.09E-03	NA	NC	1.73E-05	NA	NC	
Benzo(a)pyrene	0.078	1.26E-03	NA	NC	2.34E-05	1.0E+01	2.3E-06	
Chrysene	0.130	2.06E-03	NA	NC	4.53E-05	NA	NC	
Fluoranthene	0.170	2.30E-03	NA	NC	7.95E-05	NA	NC	
2-methylnaphthalene	0.140	NA	NA	NC	NA	NA	NC	
Phenanthrene	0.150	NA	NA	NC	NA	1.4E+02	NC	
Pyrene	0.120	1.77E-03	NA	NC	6.28E-05	5.4E+02	1.2E-07	
Aroclor-1260	0.500	6.85E-02	NA	NC	1.53E-04	1.0E+02	1.5E-06	
4,4'-DDE	0.140	4.98E-05	NA	NC	1.60E-02	1.6E+02	1.0E-04	
4,4'-DDD	0.085	NA	NA	NC	NA	NA	NC	
4,4'-DDT	0.026	1.05E-05	8.0E+02	1.9E-08	2.97E-03	5.0E+01	5.9E-05	
Endrin	0.012	NA	NA	NC	NA	5.3E-01	NC	
Aluminum	40,100	NA	NA	NC	NA	1.0E+02	NC	
Antimony	11.5	NA	NA	NC	NA	NA	NC	
Arsenic	21.5	2.04E+00	NA	NC	4.97E-02	1.5E+02	3.3E-04	
Barium	260	2.53E+01	NA	NC	1.07E+00	NA	NC	
Beryllium	2.1	NA	NA	NC	NA	2.0E+00	NC	

Table 8.8
Hazard Quotients for Potential Lethal Effects on Wildlife Species Associated with
Maximum Exposure Concentrations of ECPCs in Soil

Analyte	Max Conc (mg/kg)	American Robin			Eastern Cottontail		
		PDE	TRV	HQ	PDE	TRV	HQ
Cadmium	7.2	3.21E+00	NA	NC	1.66E+00	5.0E+04	3.3E-05
Chromium	112	NA	NA	NC	NA	NA	NC
Cobalt	14	NA	NA	NC	NA	NA	NC
Copper	174	6.24E+00	NA	NC	9.85E-01	2.4E+02	4.1E-04
Iron	34,200	NA	NA	NC	NA	2.4E+02	NC
Lead	1,500	5.29E+01	4.9E+03	1.1E-02	3.24E-01	NA	NC
Manganese	172	1.67E+01	NA	NC	7.10E-01	8.0E+01	8.9E-03
Mercury	0.23	1.21E-02	2.5E+00	4.8E-03	9.49E-04	1.8E+01	5.3E-05
Nickel	61.7	NA	NA	NC	NA	1.3E+01	NC
Selenium	0.91	8.40E-02	NA	NC	2.54E-04	1.3E+03	1.9E-07
Tin	45.5	NA	NA	NC	NA	NA	NC
Vanadium	114	NA	1.9E+01	NC	NA	NA	NC
Zinc	982	1.98E+02	NA	NC	4.40E+00	5.0E+02	8.8E-03
HI =				1.6E-02			1.9E-02

Notes:
Max Conc = Maximum Concentration of Analyte
NA = Data not available
NC = Not able to calculate value
PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.4
TRV = Toxicity Reference Value (mg/kg/BW/day) - 1/5 of the lowest reported LD₅₀ value from Appendix F for closest related species
HQ = Hazard Quotient - PDE divided by the TRV
HI = Hazard Index (HQ₁ + HQ₂ + ...HQ_n)

Table 8.9
Hazard Quotients for Potential Sublethal Effects on Wildlife Species Associated with
Maximum Exposure Concentrations of ECPCs in Soil

Analyte	Max Conc (mg/kg)	American Robin			Eastern Cottontail		
		PDE	TRV	HQ	PDE	TRV	HQ
Benzo(b)fluoranthene	0.120	1.90E-03	NA	NC	3.26E-05	NA	NC
Benzo(k)fluoranthene	0.074	1.12E-03	NA	NC	1.90E-06	NA	NC
Benzo(g,h,i)perylene	0.073	1.09E-03	NA	NC	1.73E-05	NA	NC
Benzo(a)pyrene	0.078	1.26E-03	NA	NC	2.34E-05	4.0E+01	5.85E-07
Chrysene	0.130	2.06E-03	NA	NC	4.53E-05	NA	NC
Fluoranthene	0.170	2.30E-03	NA	NC	7.95E-05	4.0E+02	2.0E-07
2-methylnaphthalene	0.140	NA	NA	NC	NA	NA	NC
Phenanthrene	0.150	NA	NA	NC	NA	NA	NC
Pyrene	0.120	1.77E-03	NA	NC	6.28E-05	NA	NC
Aroclor-1260	0.500	6.85E-02	NA	NC	1.53E-04	6.4E+00	2.4E-05
4,4'-DDE	0.140	4.98E-05	5.8E-01	8.9E-05	1.60E-02	1.6E+02	1.0E-04
4,4'-DDD	0.085	NA	NA	NC	NA	NA	NC
4,4'-DDT	0.026	1.05E-05	1.4E-01	7.5E-05	2.97E-03	1.5E+02	2.0E-05
Endrin	0.012	NA	NA	NC	NA	5.3E-01	NC
Aluminum	40.100	NA	NA	NC	NA	NA	NC
Antimony	11.5	NA	NA	NC	NA	NA	NC
Arsenic	21.5	2.04E+00	NA	NC	4.97E-02	5.8E-01	8.6E-02
Barium	260	2.53E+01	NA	NC	1.07E+00	NA	NC
Beryllium	2.1	NA	NA	NC	NA	NA	NC

Based on the model, potential sublethal effects from maximum soil contaminant concentrations in Subzone A-1 are present for the American robin (Table 8.9). HQs for the robin were all below 1 but cumulatively produced an HI of 1.6. While inorganic HQs were all below 1, they were the primary EPCs (cadmium, copper, and lead) accountable for the HI over 1 (Figures 8-4, 8-5 and 8-6). Mean inorganic concentrations will reduce risk to an acceptable level.

The model prediction of risks to carnivorous bird species appears to be accurate in relation to literature information. Soil invertebrates such as earthworms have been shown to uptake metals to levels equal to soil concentrations (Neuhäuser et al., 1985), and it has been shown that earthworms are an important food item for the American robin (McDonald, 1983). Based on the maximum values observed at A-1, birds preying on soil infaunal species are likely at risk. Again, in-situ bioaccumulation studies would help to reduce any uncertainty inherent in the model prediction.

8.8.3 Vegetation

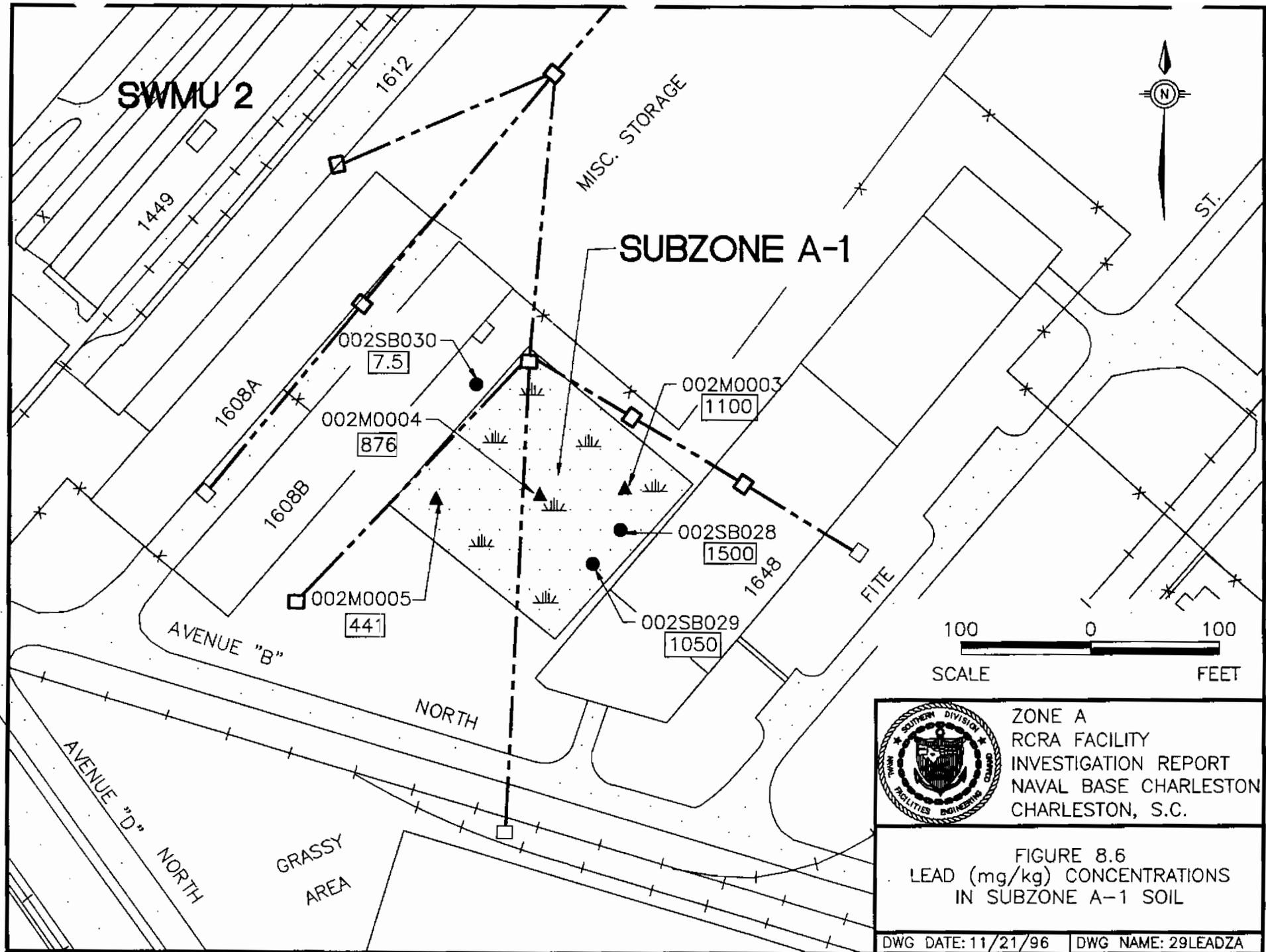
Limited information exists regarding the toxic effects of soil contamination on plants in natural environments. Most literature containing effects information deals with herbicide or fungicide application programs. Beyer et al. (1985) demonstrated that only a small portion of all metals measured in soil became incorporated into plant foliage. In the study, the suggested origin of plant metal residues was primarily aerial deposition. Table 8.10 presents phytotoxic effect concentrations of arsenic, lead, and zinc for several plant species. Effect concentrations vary depending on specific soil physiochemical conditions such as pH, organic content, and cation exchange capacity (CEC).

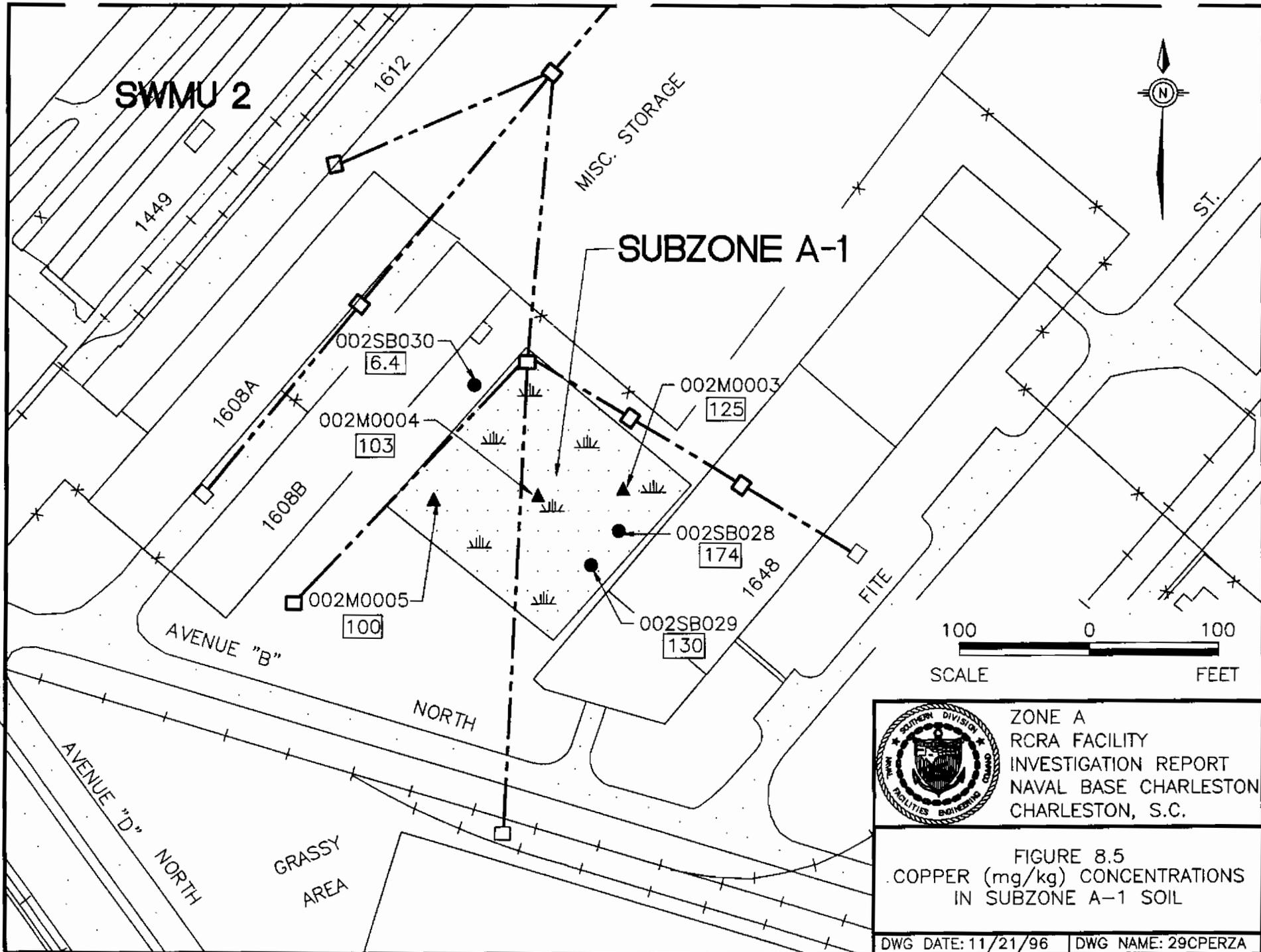
Arsenic availability to plants is typically highest in coarse-textured soil having little CEC, and lowest in clay containing organic material, iron, calcium, and phosphate (NRCC, 1978). Cadmium appears to be taken up by plants in soil that has abnormally high cadmium residues.

Table 8.9
Hazard Quotients for Potential Sublethal Effects on Wildlife Species Associated with
Maximum Exposure Concentrations of ECPCs in Soil

Analyte	Max Conc (mg/kg)	American Robin			Eastern Cottontail		
		PDE	TRV	HQ	PDE	TRV	HQ
Cadmium	7.2	3.21E+00	1.0E+01	3.2E-01	1.66E+00	2.2E+01	7.5E-02
Chromium	112	NA	2.5E+01	NC	NA	NA	NC
Cobalt	14	NA	NA	NC	NA	NA	NC
Copper	174	6.24E+00	1.1E+01	5.7E-01	9.85E-01	1.5E+02	6.6E-03
Iron	34,200	NA	NA	NC	NA	NA	NC
Lead	1,500	5.29E+01	1.3E+02	4.1E-01	3.24E-01	5.2E+02	6.2E-04
Manganese	172	1.67E+01	NA	NC	7.10E-01	9.3E+02	7.6E-04
Mercury	0.23	1.21E-02	6.4E-02	1.9E-01	9.49E-04	5.0E-01	1.9E-03
Nickel	61.7	NA	NA	NC	NA	1.6E+02	NC
Selenium	0.91	8.40E-02	1.8E+00	4.6E-02	2.54E-04	1.3E+02	2.0E-06
Tin	45.5	NA	NA	NC	NA	NA	NC
Vanadium	114	NA	NA	NC	NA	NA	NC
Zinc	982	1.98E+02	NA	NC	4.40E+00	1.6E+02	2.8E-02
HI =				1.6E+00			2.0E-01

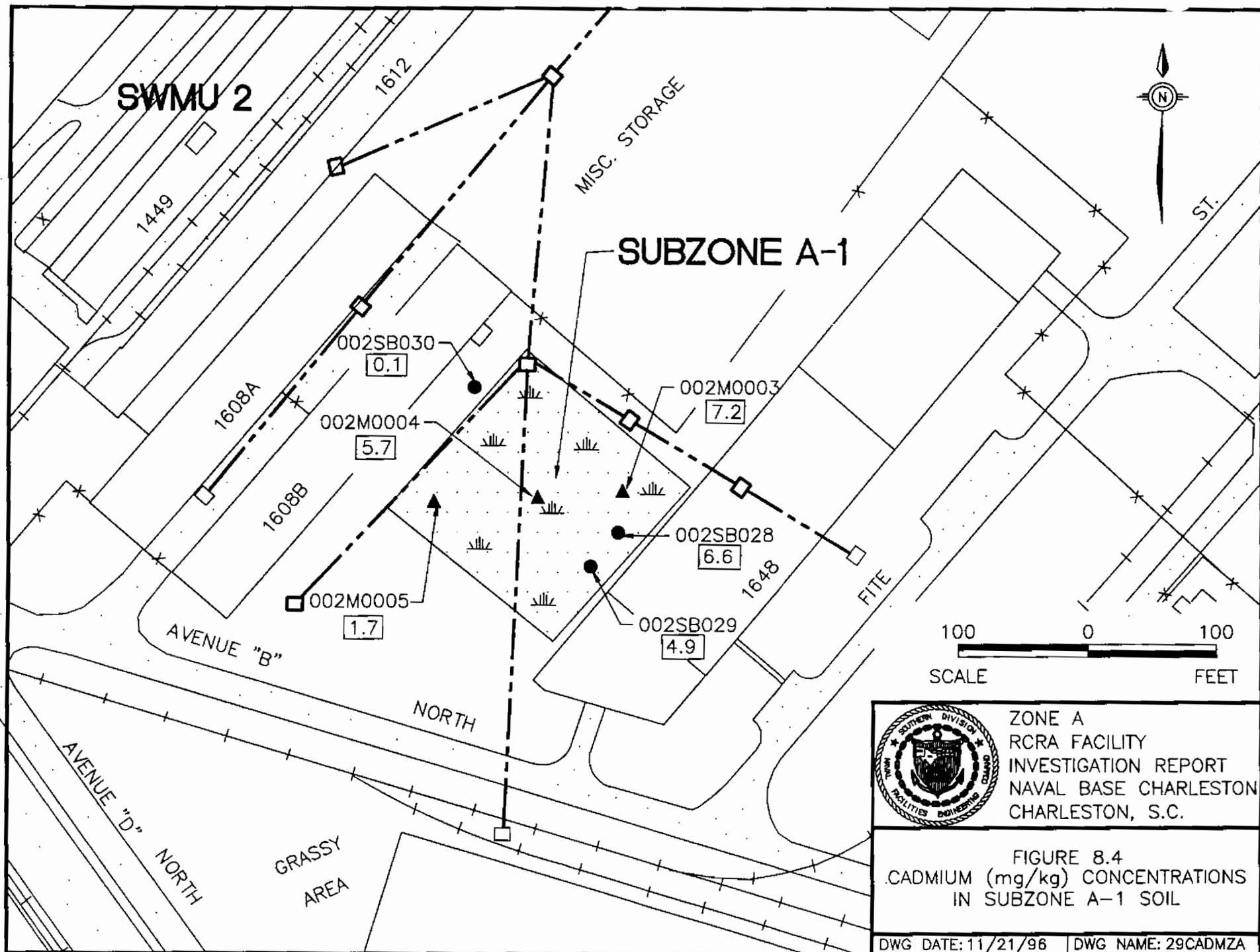
Notes:
 maxconc = Maximum Concentration of Analyte
 NA = Data not available
 NC = Not able to calculate value
 PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.4
 TRV = Toxicity Reference Value (mg/kg/BW/day) - lowest reported LOAEL value in Appendix F for closest related species
 HQ = Hazard Quotient - PDE divided by the TRV
 HI = Hazard Index (HQ₁ + HQ₂ + ...HQ_n)





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

FIGURE 8.5
COPPER (mg/kg) CONCENTRATIONS
IN SUBZONE A-1 SOIL



Towill et al.'s (1978) study showed no phytotoxic effects on plants from elevated chromium concentrations.

Like other metals, the bioavailability of lead in soil to plants is enhanced when soil pH, organic matter, iron oxides, and phosphorus content are reduced (NRCC, 1973). Studies have shown no convincing evidence that terrestrial vegetation is important in food-chain biomagnification of lead (USEPA, 1985a). Chang et al. (1983) observed that zinc uptake was lower in coarse loamy soil than in fine loamy soil. The phytotoxic nature of copper to crop production has been studied relative to application rates (Hirst et al., 1961). Little information exists on mercury effects to herbaceous or woody plants (Eisler, 1987b).

Studies by USEPA (1980), Lee and Grant (1981), Wang and Meresz (1982) and Edwards (1983) generally conclude six points for PAH's effects on plants.

- Plants can absorb PAHs from soil through roots and distribute them to other parts.
- Lower molecular-weight compounds are absorbed more readily than higher-molecular-weight compounds.
- Aboveground parts have higher residue concentrations, which are most likely attributable to airborne deposition.

- PAH-induced phytotoxic effects are rare.

- Higher plants can catabolize benzo(a)pyrene and possibly other PAH compounds.

- Plant uptake of PAHs is not likely a significant pathway to terrestrial vertebrate species.

Table 8.10
Comparison of Phytotoxic Responses to
ECPC Soil Concentrations

Study	Organisms	Measured Parameter	Maxconc at Subzone A-1 (mg/kg)	Effects Level	Measured Response
USEPA (1987)	<i>Acer rubrum</i> Red Maple	Zinc	982	100 mg/kg	Lethal to seedlings
USEPA (1987)	<i>Quercus rubra</i> Red Oak	Zinc	982	100 mg/kg	Lethal to seedlings
NRCC (1978)	Canadian crops	Arsenic	21.5	25-85 mg/kg	Depressed crop yield
	<i>Oryza sativum</i> Rice	Arsenic (disodium methylnaesonate)	21.5	50 mg/kg	75% decrease yield
Sadiq (1985)	Corn plant	Lead	1,500	800 mg/kg	No elevated concentration in plants
Krishnayya and Bedi (1986)	<i>Cassia</i> spp. Weeds	Lead	1,500	500 mg/kg	90% reduced pollen germination
Miller et al. (1985)	Radish (seed germination)	Copper	174	47 mg/kg	EC ₅₀
		Zinc	982	53 mg/kg	EC ₅₀
	Cucumber (seed germination)	Copper	174	55 mg/kg	EC ₅₀
		Zinc	982	61 mg/kg	EC ⁵⁰

Note:
 Maxconc = Maximum Concentration

For PCBs, Klekowski (1982) suggested there was no evidence of genetic damage to terrestrial plants at a PCB-contaminated site in Massachusetts.

Risk to Vegetation from ECPCs in Subzone A-1

Based on detected maximum concentrations of lead (1,500 mg/kg), copper (174 mg/kg), and zinc (982 mg/kg), and considering the physical nature of soil within Subzone A-1, a risk to young herbaceous species exists. From a spatial perspective, the mean concentration for the subzone is below these maximum levels. Again, effects from organic concentrations could not be assessed and man-induced modifications to the area made it difficult to determine observable effects on vegetation from soil contamination.

8.9 Uncertainties

General uncertainties associated with the ecological risk assessment for Zone A include:

- 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 for some ECPCs were unavailable.
- Synergistic or antagonistic effects cannot be quantified.
- For some ECPCs, only assumptions relative to similar compounds or classes of elements can be made.
- Use of related species for risk determination may over- or underestimate risk to selected representative wildlife species.
- Dermal or inhalation exposure pathways were not evaluated.
- Maximum exposure scenarios and concentrations may tend to overestimate risk potentials.
- On occasion, BAFs were assumed due to lack of information.
- Actual occurrence of selected wildlife species within the contaminated area is uncertain.
- Food ingestion rates in food chain analyses may be a source of uncertainty to exposure.

8.10 Ecological Risk Assessment Conclusions

Potential risks for ecological receptors were evaluated for ECPCs in surface soil at the ecological areas within Zone A. Risks associated with exposure to ECPCs in surface soil were evaluated for terrestrial wildlife based on a model that predicts the amount of contaminant exposure via the diet and incidental soil ingestion. Comparison of predicted doses for representative wildlife species, with doses representing thresholds for both lethal and sublethal effects, is the basis of the risk evaluation. Risks for soil invertebrates and plants were evaluated based on qualitative comparisons to literature effects levels for taxonomic groups similar to those potentially occurring at Zone A.

Risk Summary

A slight risk to soil infaunal organisms exists from maximum inorganic concentrations (copper, zinc) associated with SWMU 2 and low concentrations of PAH compounds detected in Subzone A-1. The risk from other organic ECPCs in A-1 appears to be minimal. Mean concentrations for copper and zinc are below effects levels cited in literature. For representative terrestrial wildlife species, both lethal and sublethal risk quotients are below 1. Potential sublethal effects from maximum inorganic concentrations (copper, lead, cadmium, and mercury) are present in Subzone A-1, based on the HI value calculated for the American robin. The HQs of individual inorganics detected in surface soil samples are below 1. Therefore, contaminants at A-1 are considered to pose negligible risk to the representative species. Based on comparisons to studies on the phytotoxic responses in plants from exposure to contaminants, maximum concentrations of soil ECPCs (copper, lead, and zinc) in Subzone A-1 may pose a risk to young herbaceous species. However, mean concentrations for these inorganic constituents do not indicate a risk.

Recommendation

Based on the assessment of risk to ecological receptors from soil/sediment exposure found within subzone A-1, no further work is recommended. Exposure scenarios are based on detected concentrations and current status of the area. Risk may be different if land use is modified.

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9.0 RECOMMENDATIONS FOR CORRECTIVE MEASURES

According to Permit Condition IV.E., Corrective Action Plan, SCDHEC will review the final RFI report and notify NAVBASE if further investigations, corrective actions, or a corrective action study or plan are needed to meet R.61-79.264.101 requirements for corrective actions for SWMUs. This section on recommendations and a subsequent section on conclusions are in response to SCDHEC's comment that the RFI report should address whether the extent of contamination has been defined and then propose recommended actions for the SWMUs and AOCs. The extent of contamination, as determined by the formal risk assessment process, is delineated in figures in Section 10, Site-Specific Evaluations; recommended actions for the SWMUS and AOCs are summarized in a table in Section 11, Conclusions.

The NAVBASE project team initially established action levels (ALs) to assess whether a hypothetical Corrective Measures Study would be conducted at 10^{-6} residential risk and/or 100 ppm TPH. In lieu of ALs, industrial cleanup levels could be used if NAVBASE could demonstrate that appropriate and effective institutional controls could be maintained at the site. In addition, any unacceptable ecological risk, as determined by the ERA and defined by the SCDHEC, could also be used to initiate and drive CMS efforts.

The following discussions, in conjunction with Sections 10 and 11, address each site relative to the established ALs, the need for additional investigation, corrective actions, or a corrective action study and/or treatability study. The potential remedies listed are based on current data and the remedies presented in the RFI work plan. The steps to be conducted during a typical CMS are also reviewed.

9.1 Introduction

Any NAVBASE CMS will be conducted according to standard methods presented in the USEPA guidance document *RCRA Corrective Action Plan* (USEPA, 1994g). The standard methodology

will be presented in the CMS Work Plan, and will facilitate collecting necessary data, identifying and evaluating potential alternatives, and presenting the final remedial alternative(s) by establishing a set procedure for evaluation and assessment.

The results of risk management decisions will determine which sites become candidates for the CMS process. Cleanup objectives, reuse scenarios, and risk management issues will be instrumental in defining the course of the CMS.

For sites that may require remedial action, it will be the SCDHEC's responsibility, in conjunction with public involvement and support, to select the final cleanup method from the options presented by the CMS. The outcome of a CMS can also result in a "single" or a "no action" alternative.

To establish this procedure, the CMS Work Plan will outline basic elements of the CMS Report. The overall structure of the plan is explained to illustrate the decision-making process.

CMS Report Outline

- A. Introduction/Purpose
- B. Description of Current Conditions
- C. Corrective Action Objectives
- D. Identification, Development, and Screening of Corrective Measure Alternatives
- E. Evaluation of a Final Corrective Measure Alternative
- F. Recommendation by a Permittee/Respondent for a Final Corrective Measure Alternative
- G. Public Involvement Plan

Each required element will be discussed in detail in the CMS Work Plan to:

- Identify minimum requirements for CMS Reports in each area
- Define the base "pool" of technologies which will be evaluated for each medium
- Define the evaluation process
- Identify selection criteria for the final corrective measure alternative

Issues to be discussed under each element are identified as follows:

- An activity-specific description of the overall purpose of the CMS for NAVBASE.

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. When possible, 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 risk assessments will be established and achieved for each site, zone, and activity.

Cleanup standards will be developed for each site, zone, or activity using the designated exposure scenario (residential, commercial, or industrial) for that area and relative to receptor type, human or ecological. BRAs, 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 to human and

ecological receptors will be evaluated according to media, primary contaminants contributing to risk, and the potential for groundwater contamination.

- Identification, screening, and development of corrective measures alternatives.

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 and areal extent of contamination, number and type of contaminants, remedial goals, future land use scenarios, and adjacent remedial activities.

Once technologies have been screened, they will be assembled into corrective action alternatives. These alternatives will be evaluated according to criteria discussed as follows.

- 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 as follows:

Primary

- *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 practicable, further releases that may pose a threat to human health and the environment.*
- *Comply with all applicable standards for management of wastes.*

Secondary

- *Long-term reliability and effectiveness.*
- *Reduction in the toxicity, mobility, or volume of wastes.*
- *Short-term effectiveness.*
- *Implementability.*
- *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.

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 processes for treating groundwater. However, ultraviolet (UV)/oxidation, an innovative technology, may require extensive treatability testing to determine oxidant dosages and retention times.

The basic structure and objectives of a treatability study will be discussed. Objectives may include: dosages, percent reduction in contaminant, 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.

- A description of how statement of basis/response to comments or permit modifications are to be processed.

Statement of basis and responses to comments will be handled through NAVBASE and Southern Division Naval Facilities Engineering Command (SOUTHDIV). The Comprehensive Long-Term Environmental Action Navy (CLEAN) Contractor, E/A&H, will assist the U.S. Navy in preparing statement of basis and responses to comments. Permit modifications will be managed through SOUTHDIV and NAVBASE's caretaker. According to the existing RCRA permit (May 4, 1990, Appendix C, Facility Submission Summary), a permit modification is required to prepare and conduct a Corrective Action Study/Plan.

- A description of overall project management including overall approach levels of authority (including organizational chart), lines of communication, project schedules, budget, and personnel.

The overall project management is the responsibility of SOUTHDIV for the 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 SOUTHDIV Commander.

The budget for conducting the 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 tasks. EnSafe will manage the CMS effort through the EnSafe Charleston, South Carolina, office.

- Qualifications of personnel to direct or perform the work will be described.

EnSafe will use trained, experienced, and qualified registered engineers and geologists of South Carolina where required.

9.2 Remedy Selection Approach

As agreed in the Final Comprehensive Project Management Plan, 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
- Presumptive remedies
- Petroleum, oils, and lubricants remedies for those type of contaminants

CAMUs and temporary units (TUs) will be used where necessary to facilitate storage and treatment during remediation activities.

9.3 Proposed Remedy

Before selecting and implementing corrective measures for releases, environmental and cost-effectiveness goals must be established. Typically, the environmental goal is to reduce exposure via the 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.

9.4 Development of Target Media Cleanup Goals

Cleanup goals will be developed by the SCDHEC for each site at NAVBASE where risk exceeds acceptable levels as specified in the Part B permit. Sites requiring further remediation (defined

as those sites exceeding unacceptable risk levels) will undergo a CMS. During the CMS, alternatives will be developed for future residential and/or future worker uses. 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.

The USEPA guidance document *RCRA Corrective Action Plan* (USEPA, 1994g) outlines issues to be considered in developing cleanup goals for groundwater, soil, surface water, sediment, and air. These recommendations are outlined as follows.

9.4.1 Groundwater Cleanup Goals

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:

- The MCL value for any constituents for which an MCL has been promulgated under the Safe Drinking Water Act,.
- Background concentration of the constituent in groundwater.
- An alternate standard (e.g., alternative concentration limit for a regulated unit) to be approved by the implementing agency.

Additional considerations 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.

9.4.2 Soil Cleanup Goals

The CMS will provide information to support the development of soil cleanup goals. The following information may be required:

- The volume and physical and chemical characteristics of the wastes in the unit

- The effectiveness and reliability of containing, confining, and collecting systems and structures in preventing contaminant migration

- The hydrologic characteristics of the unit and the surrounding area, including the topography of the surrounding land

- Regional precipitation patterns

- The current quality of surface soil, including other sources of contamination and their cumulative impacts on surface soil

- The potential for contaminant migration and impact to the underlying groundwater

- The patterns of land use in the region

- The potential for health risks caused by human exposure to waste constituents

- The potential for damage to wildlife, food chains, and vegetation caused by exposure to waste constituents

Damage potential to domestic animals and crops (not applicable at NAVBASE), and to physical structures caused by exposure to waste constituents was not assessed during this RFI and therefore, these three elements will not assist in determining soil cleanup goals. Additional information which may be considered includes background soil concentrations and regulatory guidance (e.g., Underground Storage Tank guidance documents), among others.

9.4.3 Surface Water and Sediment Cleanup Goals

The CMS will provide information to support the development of surface water and sediment cleanup goals. The following information may be required:

- The volume and physical and chemical characteristics of waste in the unit
- The effectiveness and reliability of containing, confining, and collecting systems and structures in preventing contaminant migration
- The hydrologic characteristics of the unit and the surrounding area, including the topography of surrounding land
- Regional precipitation patterns
- The quantity, quality, and direction of groundwater flow
- The proximity of the unit to surface water
- The current and potential uses of nearby surface water and any established water quality standards

- The existing quality of surface water, including other sources of contamination and their cumulative impacts on surface water

- The patterns of land use in the region

- The potential for health risks caused by human exposure to waste constituents

- The potential for damage to wildlife, food chains, and vegetation caused by exposure to waste constituents

Damage potential to domestic animals and crops (not applicable at NAVBASE), and to physical structures caused by exposure to waste constituents was not assessed during this RFI and therefore, these three elements will not assist in determining surface water and sediment cleanup goals. Additional data which may be considered include the presence of endangered, threatened, or ecologically sensitive species, and National Oceanic and Atmospheric Administration (NOAA) sediment screening values, among others.

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 current 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
- The potential for damage to wildlife, food chains, and vegetation caused by exposure to waste constituents

Damage potential to domestic animals and crops (not applicable at NAVBASE), and to physical structures caused by exposure to waste constituents was not assessed during this RFI and therefore, these three elements will not assist in determining air cleanup goals. Other factors which may be considered include National Ambient Air Quality Standards, and state and local air quality standards/regulations, among others.

9.5 Identification, Screening, and Development of Corrective Measure Technologies

The initial step in assembling corrective measures alternatives is to identify, screen, and develop corrective measure technologies which apply to the site. Technologies are typically screened using waste-, media-, and site-specific characteristics. This section addresses the range of technologies which 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 COCs has been identified in the RFI. The BRA identified 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
- PCBs
- Dioxins
- Inorganics (e.g., metals)
- TPH

These contaminant groupings and the sites at which COCs have been identified are listed in Table 9.1. This table lists *possible* remedial technologies for the sites and notes with an asterisk which sites contain petroleum hydrocarbon contamination. Similar technologies may be used at sites containing TPH-contaminated soil. These lists of *possible* remedial technologies do not consider potential single site multi-technology interference. Remedial technologies in this table are described in Section 9.5.2 of this document.

Table 9.2 lists nontreatment options for soil, groundwater/leachate, sediment, surface water, and air. These options include removal, containment, and disposal. Table 9.3 list types of compounds and the types of treatment for each media. These tables supply general waste management options for various situations.

Several sites contain a combination of contaminants (e.g., inorganics, PCBs, and semivolatile organic compounds in soil at SWMU 42/AOC 505). As a result, multiple technology types may be identified to remove these contaminants. However, some sites contain only one type of contaminant (e.g., nonchlorinated semivolatiles at AOC 506) so that a single treatment technology may prove sufficient if the site is recommended for a CMS.

Table 9.1
Sites Containing COCs, Types of COCs, and Possible Remedial Technologies

Site	Type of Compounds	Possible Remedial Technologies
SWMU 2 - Soil	Nonchlorinated Semivolatiles (PAHs; benzo(a)pyrene equivalents)	a) No Action/Intrinsic Remediation b) No Action/Intrinsic Remediation and Monitoring
	PCBs (Aroclor-1260)	c) Containment by Capping d) Excavation and Landfill, if RCRA-nonhazardous waste
SWMU 2 - Groundwater	Inorganics (aluminum, antimony, arsenic, beryllium, lead, and thallium)	e) In-Situ Treatment 1) Biodegradation 2) Soil Flushing 3) Solidification/Stabilization 4) Vitrification
		f) Ex-Situ Treatment 1) Biodegradation 2) Solidification/Stabilization 3) Vitrification 4) Dehalogenation 5) Soil Washing 6) Solvent Extraction 7) Incineration 8) LTTD/HTTD 9) Pyrolysis

Table 9.1
Sites Containing COCs, Types of COCs, and Possible Remedial Technologies

Site	Type of Compounds	Possible Remedial Technologies
*SWMU 38 - Soil	Pesticides (DDE, DDD, and DDT) PCBs (Aroclor-1260) Inorganics (arsenic, aluminum, and beryllium) TPH (GRO/DRO)	a) No Action/Intrinsic Remediation b) No Action/Intrinsic Remediation and Monitoring c) Containment by capping d) Excavation and Landfill, if RCRA-nonhazardous waste e) In-Situ Treatment 1) Enhanced Biodegradation 2) Solidification/Stabilization 3) Soil Flushing 4) Vitrification f) Ex-Situ Treatment 1) Enhanced Biodegradation 2) Incineration 3) LTTD/HTTD 4) Dehalogenation 5) Soil Washing 6) Solidification/Stabilization 7) Vitrification
SWMU 38 - Groundwater	Pesticides (DDD and DDT) Inorganics (arsenic and thallium)	a) No Action/Intrinsic Remediation b) No Action/Intrinsic Remediation and Monitoring c) In-Situ Treatment 1) Biodegradation Enhancement 2) Treatment/Slurry Walls 3) Steam Strip/Flush 4) Phyto-remediation d) Extract, Treat, Discharge to POTW 1) Biodegradation 2) Air/Steam Strip 3) Carbon Adsorption 4) UV Oxidation 5) Filtration 6) Ion Exchange 7) Precipitation

Table 9.1
Sites Containing COCs, Types of COCs, and Possible Remedial Technologies

Site	Type of Compounds	Possible Remedial Technologies
SWMU 39 - Soil	Nonchlorinated Semivolatiles (PAHs; benzo(a)pyrene equivalents)	a) No Action/Intrinsic Remediation b) No Action/Intrinsic Remediation and Monitoring
	Inorganics (Aluminum, arsenic, and beryllium)	c) Containment by Capping d) Excavation and Landfill, if RCRA-nonhazardous waste e) In-Situ Treatment 1) Biodegradation 2) Soil Flushing 3) Solidification/Stabilization 4) Vitrification f) Ex-Situ Treatment 1) Biodegradation 2) Solidification/Stabilization 3) Vitrification 4) Dehalogenation 5) Soil Washing 6) Solvent Extraction 7) Incineration 8) LTTD/HTTD i) Pyrolysis
SWMU 39 - Groundwater	Inorganics (arsenic, beryllium, manganese, and thallium)	a) No Action/Intrinsic Remediation b) No Action/Intrinsic Remediation and Monitoring
	VOCs and SVOCs (benzene, bis(2-ethylhexyl)phthalate, chloroform, 1,1-dichloroethene, 1,2-dichloroethane, 1,2-dichloroethene (total), cis-1,2-dichloroethene, 2-methylnaphthalene, naphthalene, 1,1,2,2-tetrachloroethene, tetrachloroethene, and vinyl chloride)	c) In-Situ Treatment 1) Biodegradation Enhancement 2) Treatment/Slurry Walls 3) Steam Strip/Flush 4) Phyto-remediation
	Dioxin equivalents	d) Extract, Treat, Discharge to POTW 1) Biodegradation 2) Air/Steam Strip 3) Carbon Adsorption 4) UV Oxidation 5) Filtration 6) Ion Exchange 7) Precipitation

Table 9.1
Sites Containing COCs, Types of COCs, and Possible Remedial Technologies

Site	Type of Compounds	Possible Remedial Technologies
SWMU 42/AOC 505 - Soil	Inorganics (arsenic and beryllium)	a) No Action/Intrinsic Remediation b) No Action/Intrinsic Remediation and Monitoring
	Nonchlorinated Semivolatiles (PAHs; benzo(a)pyrene equivalents)	c) Containment by Capping d) Excavation and Landfill, if RCRA-nonhazardous waste e) In-Situ Treatment <ol style="list-style-type: none"> 1) Biodegradation 2) Soil Flushing 3) Solidification/Stabilization 4) Vitrification f) Ex-Situ Treatment <ol style="list-style-type: none"> 1) Biodegradation 2) Solidification/Stabilization 3) Vitrification 4) Dehalogenation 5) Soil Washing 6) Solvent Extraction 7) Incineration 8) LTTD/HTD 9) Pyrolysis
SWMU 42/AOC 505 - Groundwater	Chlorinated Volatiles (tetrachloroethene, 1,1,2,2-tetrachloroethane, and 1,1-dichloroethene) Inorganics (aluminum, arsenic, chromium, manganese, silver, and vanadium)	a) No Action/Intrinsic Remediation b) No Action/Intrinsic Remediation and Monitoring c) In-Situ Treatment <ol style="list-style-type: none"> 1) Biodegradation Enhancement 2) Treatment/Slurry Walls 3) Stream Strip/Flush 4) Phyto-remediation d) Extract, Treat, Discharge to POTW <ol style="list-style-type: none"> 1) Biodegradation 2) Air/Steam Strip 3) Carbon Adsorption 4) UV Oxidation 5) Filtration 6) Ion Exchange 7) Precipitation

Table 9.1
Sites Containing COCs, Types of COCs, and Possible Remedial Technologies

Site	Type of Compounds	Possible Remedial Technologies
AOC 506 - Soil	Nonchlorinated Semivolatiles ^b (PAHs; benzo(a)pyrene equivalents)	a) No Action/Intrinsic Remediation b) No Action/Intrinsic Remediation and Monitoring c) Containment by Capping d) Excavation and Landfill, if RCRA-nonhazardous waste e) In-Situ Treatment 1) Biodegradation 2) Soil Flushing 3) Solidification/Stabilization 4) Vitrification f) Ex-Situ Treatment 1) Biodegradation 2) Solidification/Stabilization 3) Vitrification 4) Dehalogenation 5) Soil Washing 6) Solvent Extraction 7) Incineration 8) LTTD/HTTD 9) Pyrolysis

Notes:

- * = Site contains TPH
- b = Compounds were not identified as COCs in the HHRA because detections were in second interval soil samples only.
- POTW = Publicly Owned Treatment Works
- UV = Ultraviolet
- LTTD = Low Temperature Thermal Desorption
- HTTD = High Temperature Thermal Desorption

**Table 9.2
 Removal/Containment/Disposal Options**

Action	Soil	Groundwater/Leachate	Sediment	Surface Water	Air
Removal	<ul style="list-style-type: none"> • Excavation 	<ul style="list-style-type: none"> • Groundwater extraction • Leachate collection 	<ul style="list-style-type: none"> • Dredging 	<ul style="list-style-type: none"> • Diversion • Pumping 	NA
Containment	<ul style="list-style-type: none"> • Institutional controls • Capping • Storm water controls • Long-term monitoring • Intrinsic (natural) bioremediation/attenuation 	<ul style="list-style-type: none"> • Slurry wall • Gradient controls • Long-term monitoring • Intrinsic (natural) bioremediation/attenuation 	<ul style="list-style-type: none"> • Berms/diversion • Storm water controls 	<ul style="list-style-type: none"> • Diversion 	NA
Disposal	<ul style="list-style-type: none"> • Landfill 	<ul style="list-style-type: none"> • POTW • NPDES discharge • Land application 	<ul style="list-style-type: none"> • Landfill 	<ul style="list-style-type: none"> • POTW • NPDES • Injection 	Discharge via air permit

Notes:
 POTW = Publicly Owned Treatment Works
 NPDES = National Pollutant Discharge Elimination System
 NA = Not Applicable

Table 9.3
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 SVE 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
Pesticides	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	Same as soil	Oxidation
Inorganics	Solidification/stabilization Soil washing Vitrification	Chemical precipitation Adsorption Sedimentation Filtration	Same as soil	Filtration Scrubbers Adsorption

Notes:

SVE = Soil Vapor Extraction
 UV = Ultraviolet

The following example presents a common situation where more than one type of contaminant is identified at a site. The example site contains volatile and semivolatile organic compounds in soil which have been identified at concentrations slightly exceeding risk-based remediation goals. A containment alternative may include fencing to restrict unauthorized access, aerating the contaminated area, adding fertilizer and enriched soil, seeding to maintain a vegetative cover to control surface water runoff, and monitoring. This containment approach seeks to reduce health risks through land management and natural attenuation.

As discussed in previous sections, COCs and cleanup goals may vary between scenarios because each site may be evaluated under both residential and site-worker scenarios. Two lists of applicable technologies may be developed for each site, one for each scenario.

No COCs were identified by the risk assessments at SWMU 43 (Building 1628, Publications and Printing Plant) and AOC 506 (Building 1629, Flammable Storage Shelter). However, subsurface contamination warrants the corrective measures considerations included in Table 9.1.

Several treatment technologies such as incineration and LTDD/HTDD may produce an off-gas that could require additional treatment or control and could be subject to air permitting requirements.

9.5.2 Description of Prescreened Technologies

The following paragraphs describe the 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

Capping

A layer of clay, synthetic membrane, soil-vegetative cover, or asphalt is applied to prevent human exposure to contaminants. Capping also helps to prevent rainwater infiltration and water percolation, which may transport contaminants (via leaching) from the soil to the groundwater. This solution may be the most economical and most protective of human health for certain sites. Several Zone A SWMUs and AOCs are in areas surrounded by pavement and/or crushed gravel parking lots.

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 introduced to the soil. In many cases, nutrients can be supplemented to enhance this process. Nitrate and phosphate are often the limiting nutrients in the soil at a site. However, an insufficient electron acceptor 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 nonchlorinated SVOCs are good candidates for this technology.

Solidification/Stabilization

This technology consists of mixing reagents with soil to prevent contaminants such as metals from leaching into the groundwater below. This technology immobilizes contaminants, preventing migration. However, this technology does not remove or reduce the contaminant.

Ex-Situ Treatment of Soil

All ex-situ soil treatments require excavation to another location or bringing the material to the surface. Typically, heavy equipment is used to move the soil. If contaminated soil is limited in volume and considered RCRA-nonhazardous waste, it may be feasible to dispose of it in a permitted landfill. If sites have a limited area of contaminated soil, it may be feasible to remove the soil with heavy equipment and treat it ex-situ. For RCRA-nonhazardous waste, the presently closed landfill (SWMU 9, Zone H) at the southern end of NAVBASE could be a disposal option.

Soil Washing

Soil washing physically separates soil particles by size, then treats the smaller grains with solutions that desorb the contaminants. The resulting solution containing contaminants requires treatment by another technology. In general, small soil particles such as clay and silt have a higher total organic carbon content which tends to adsorb hydrophobic compounds such as chlorinated contaminants. This technology essentially compacts contaminated soil, then washes it with a solvent to remove the contaminants.

Thermal Desorption

Thermal desorption technologies are performed at high or low temperatures, depending on the contaminant. This technology is used in combination with incineration or another type of offgas treatment. Soil is excavated and placed into the treatment systems for either high- or low-temperature desorption to separate the contaminants from the soil, not to destroy the chemical. The volatilized contaminants enter an air stream and travel to some type of gas treatment device for contaminant destruction and/or collection. Low-temperature (200 to 600°F) thermal desorption (LTTD) is only applicable for VOCs while high-temperature (600 to 1000°F) thermal desorption (HTTD) applies to SVOCs, PAHs, PCBs, and pesticides.

Thermal Destruction/Incineration

This technology is used in conjunction with ex-situ soil technologies. Typically, the contaminant is removed from the soil matrix and transferred to an air stream. The air stream is treated with the thermal destruction on a catalyst or burned in an incinerator, or a combination of the two. High temperatures (1800 to 2000°F) are required to destroy organics such as PCBs, dioxins, furans, and pesticides.

Solidification/Stabilization

This technology is similar to the in-situ methods; however, the soil is excavated before being mixed with the chemical reagents or physical binding agents such as concrete.

In-Situ Groundwater Treatment

Bioremediation

Bioremediating contaminants in groundwater may require adding nutrients (phosphate, nitrate, etc.) and an electron acceptor (e.g., oxygen, nitrate, etc.) to the groundwater via injection wells. Typical electron acceptor addition comes from either oxygen via air sparging and/or nitrate with the addition of other nutrients.

Intrinsic Remediation

This technology, also called *natural attenuation*, simply allows naturally occurring bioremediation, oxidation, hydrolysis, dispersion, and advection to occur. No nutrients or electron acceptors are added. The site may be monitored to observe the contaminant reduction. Many case studies have demonstrated the effectiveness of this technology for TPH contaminated sites.

Ex-Situ Treatment of Groundwater

Any ex-situ treatment of groundwater requires a system of extraction wells and pumps to deliver the groundwater to an aboveground treatment location.

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, which results in the metals becoming insoluble. In other cases, chemical additives can chelate the metal and precipitate it out of the solution. In either case, the contaminants then can be removed by filtration.

Air Stripping

Groundwater can be extracted and pumped to a nearby publicly owned treatment works. While the contaminated groundwater is in the aeration basin of the water treatment plant, volatile compounds with a high Henry's law constant will undergo mass transfer from the water to the air. Steam can be used to heat the groundwater, causing additional organics to volatilize. These air vapors can be treated with an appropriate technology or discharged under an air permit.

Chemical Oxidation/UV-Ozone

Ozone is one of the most effective chemical oxidizers. Most organic compounds can be oxidized. Because ozone can be generated with UV light sources, groundwater can be directed 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 successfully be oxidized with ozone.

Effective light transmission is essential for this process. Water with high turbidity is not a good candidate for UV ozonation. Filtration and/or gravity-induced sedimentation would probably be required for extracted groundwater at NAVBASE due to the silty nature of the facility's soil.

Activated Sludge

Activated sludge treatment of wastes typically 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 given existing 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 primarily include the current and future use of the site or SWMU/AOC unit. Other characteristics include type of 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

more technology lists which will be evaluated for residential and/or Base Realignment and Closure Act (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, PCBs, dioxins, inorganic elements, and TPH. The presence of halogenated compounds, such as chlorinated benzenes or trichloroethylene, is also critical.

Where multiple types of contamination are present at a site (such as PCBs and dioxins, or pesticides and volatiles), certain technologies may be eliminated from consideration due to their inability to treat wastes effectively. For example, soil-vapor extraction (SVE) typically is not used on pesticide sites or sites with low vadose-zone permeability, although it is usually very effective on most volatiles. If both contaminants must be treated concurrently, SVE would not be considered further.

Where appropriate, contaminant concentrations will be considered to screen remedial technologies (i.e., concentrations may be too high or too low for a technology to be effective).

Technology Limitations

Technology limitations are used to assess the implementation feasibility of a particular technology. Technology limitations may include technical restrictions on application, including presence of a shallow water table, depth to bedrock, etc. Additional technology limitations include minimum or maximum process volumes, for example technologies which are cost-effective only when

contaminated soil volumes are greater than 1,000 cubic yards. Other limitations 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 differences in cleanup goals for each scenario.

9.6 Identification of Corrective Measure Alternatives

After 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 only require evaluating a single or a few alternatives. Because the NAVBASE CMS may 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 as follows.

- 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 the environment.

- Comply with all applicable standards for managing wastes.

- Consider other factors.

These standards are discussed in more detail 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 required 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 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 can achieve the remediation objective. This evaluation will estimate the time necessary for each alternative to meet these standards. The selected remedy will be required to attain media cleanup standards set by the implementing agency (SCDHEC), which may be derived from current state or federal regulations or other standards. The media cleanup standard will often play a large part in determining the extent of the remedy and technical approaches to it. In some cases, the practical capabilities of remedial technologies (or other technical aspects of the remedy) may influence to some degree the media 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, without source control measures, efforts to clean up releases may be ineffective or (at best) will essentially involve a perpetual cleanup. 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 All 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 or approving a remedy that meets the four standards listed above. These factors combine technical measures and management controls to address the environmental problems at the facility. 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 be flexible enough to deal with uncontrollable changes onsite.

This criterion will assess the proposed useful life of the overall alternative and of 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 to which each alternative reduces the toxicity, mobility, or volume of wastes. In general, preferred remedies employ treatment and can eliminate (or substantially reduce) 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 difficult or 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 re-disposal 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 (permits, rights-of-way, offsite approvals, etc.) and the length of time these activities will take.
- The constructability, time for implementation, and time required for beneficial results to be attained.
- 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 widely in cost. Cost estimates will include: engineering, site preparation, construction, materials, labor, sampling and analysis, waste management and disposal, permitting, health and safety measures, training, operations and maintenance, etc.

9.8 Ranking the Corrective Measure Alternatives

After corrective measures have been discussed for each site using each applicable scenario (residential and/or BRAC-specified future use), alternatives under each will be ranked in order of desirability. The ranking system will apply a weighting factor selected by the Navy to determine the importance of each corrective measure criterion. The weighting factors will be developed by the Navy during the CMS process. Table 9.4 shows the format of the ranking system.

The example presented in Table 9.4 considers a hypothetical site which has contaminated soil with relatively high (10 to 1,000 ppm) concentrations of PAHs. 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 illustrate the format and nature of comparisons.

After weighting factors are selected, the rankings are set by multiplying the criteria values by the weighting factor. The weighted criteria values are then summed. Alternatives are ranked with the highest total being most preferable, and the lowest total being least preferable.

Public participation and comment is an instrumental part of the RCRA Corrective Action Process. The ranked alternatives are presented to the public by way of the Restoration Advisory Board during the public meetings process. Public input is actively requested and can become an important factor during the selection of the corrective action alternative by the permitting authority.

Table 9.4
 Hypothetical Example Site - Comparison and Ranking of Alternatives

Objective & Criteria	Weighting Factor	Alternative 1		Alternative 2		Alternative 3	
		Description	Meets Criteria	Description	Meets Criteria	Description	Meets Criteria
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			XXX				XXX

Notes:

Weighting Factors will be determined by NAVBASE

LDRs = Land Disposal Restriction

USDOT = U.S. Department of Transportation

Public participation and comment will be actively solicited and has the potential for impacting remedy selection

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/objective

Table 9.4
Hypothetical Example Site - Comparison and Ranking of Alternatives

Objective & Criteria	Weighting 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
Protect human health and the environment		Protective of human health and the environment	3		Protective of human health and the environment	3		Protective of human health and the environment	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 all 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	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	