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FEASIBILITY STUDY REPORT
OPERABLE UNIT NO. 16 (SITES 89 AND 93)

MARINE CORPS BASE
CAMP LEJEUNE, NORTH CAROLINA

CONTRACT TASK ORDER 0356

NOVEMBER 21, 1997

Prepared for:

DEPARTMENT OF THE NAVY
ATLANTIC DIVISION
NAVAL FACILITIES
ENGINEERING COMMAND
Norfolk, Virginia

Under:

LANTDIV CLEAN Program
Contract N62470-89-D-4814

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LIST OF ACRONYMS AND ABBREVIATIONS

AOCs	Areas of Concern
ARARs	Applicable or Relevant and Appropriate Requirements
AWQC	Ambient Water Quality Criteria
Baker	Baker Environmental, Inc.
bgs	below ground surface
BOD	biochemical oxygen demand
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CLEAN	Comprehensive Long-Term Environmental Action Navy
CLP	Contract Laboratory Program
COCs	Contaminants of Concern
COD	chemical oxygen demand
COPCs	Contaminants of Potential Concern
CRAVE	Carcinogen Risk Assessment Verification Endeavor
CWA	Clean Water Act
DCE	Dichloroethene
DoN	Department of the Navy
DOT	Department of Transportation
DRMO	Defense Reauthorization and Marketing Office
FFA	Federal Facilities Agreement
FS	Feasibility Study
gpm	gallons per minute
HIs	Hazard Indices
IAS	insitu air sparging
ICRs	Incremental Cancer Risks
IR	Installation Restoration
IRP	Installation Restoration Program
K	hydraulic conductivity
LANTDIV	Naval Facilities Engineering Command, Atlantic Division
µg/L	micrograms per liter
µg/kg	micrograms per kilogram
MCB	Marine Corps Base
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
msl	mean sea level
mg/l	milligrams per liter

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

NCAC	North Carolina Administrative Code
NC DENR	North Carolina Department of Environment and Natural Resources
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NCWQS	North Carolina Water Quality Standard
No.	Number
NPL	National Priorities List
NPW	Net Present Worth
O&G	oil and grease
O&M	operating and maintenance
ORP	oxidation-reduction potential
OU	operable unit
PAHs	polynuclear aromatic hydrocarbons
PCBs	polychlorinated biphenyl
PCE	Tetrachloroethene
PRAP	Proposed Remedial Action Plan
QI	quotient indices
RA	risk assessment
RAAs	remedial action alternatives
RBC	Risk Based Concentration
RCRA	Resource Conservation and Recovery Act
RGOs	Remdiation Goal Options
RI/FS	Remediation Investigation/Feasibility Study
RL	Remediation Level
RME	Reasonable Maximum Exposure
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorizing Act
SDWA	Safe Drinking Water Act
SVE	soil vapor extraction
SVOCs	semivolatile organic compounds
TAL	Target Analyte List
TBC	to-be-considered
TCE	trichloroethene
TCL	Target Compound List
TCLP	Toxicity Characteristics Leaching Procedure
TDS	total dissolved solids
TOC	Total Organic Carbon
TPH	total petroleum hydrocarbon
TRC	Technical Review Committee
TSS	total suspended solids

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

UBK	uptake/biokinetic
USEPA	United States Environmental Protection Agency
UST	underground storage tank
V	Velocity
VC	vinyl chloride
VOCs	volatile organic compound

EXECUTIVE SUMMARY

INTRODUCTION

This report presents the Feasibility Study (FS) conducted at Operable Unit (OU) Number (No.) 16, for Sites 89 and 93 at Marine Corps Base (MCB) Camp Lejeune, North Carolina. Baker Environmental, Inc. (Baker) has prepared this FS for Contract Task Order (CTO) 0356 under the Department of the Navy (DoN), Atlantic Division Naval Facilities Engineering Command, Comprehensive Long-Term Environmental Action Navy (CLEAN) Program. This FS is primarily based on data collected during the Remedial Investigation (RI) conducted for Sites 89 and 93.

SITE HISTORY

Site 89 is located in the Camp Geiger section of MCB Camp Lejeune, near the intersection of "G" and Eighth Streets near the Defense Reauthorization and Marketing Office (DRMO) area of Camp Geiger. Site 89 encompasses a significant portion of Camp Geiger which includes all of the DRMO and additional area to the south and east. The site investigation focused on a small area within the DRMO which contained an underground storage tank (UST) that was identified as STC-868. The UST was a steel 550-gallon waste oil tank located between Building STC-867 (a soil storage facility) and an elevated wash rack. The tank was installed in 1983 and used for the storage of waste oil. This UST was reportedly closed by removal in 1993. Historical records of the area indicate that the site operated as a base motor pool until approximately 1988. The base motor pool was then relocated to an asphalt paved area immediately north of the DRMO facility where it operates currently.

Site 93 is located in the Camp Geiger section of MCB Camp Lejeune, near Building TC-942 at the intersection of Ninth and "E"Streets within Camp Geiger. Building TC-942 currently functions as a supply room for the Marine Infantry School. Other buildings in the area serve as classrooms for the school and barracks. Site 93 originally had a 550-gallon oil storage UST located at the southwest corner of Building TC-942. The UST at Site 93 was permanently closed as part of a tank removal in December 1993.

REMEDIAL ACTION OBJECTIVES

Remedial action objectives are medium-specific or operable unit-specific goals established for protecting human health and the environment. At OU No. 16, the specific media to be addressed by the remedial action is contaminated groundwater. At Site 89, shallow groundwater has been impacted in the area of the DRMO facility. The contaminant plume has migrated south and slightly east of the DRMO. Groundwater at the intermediate depth has also been impacted. VOCs have migrated east of the DRMO facility across White Street Extension into the wooded area. The contaminant plume at the intermediate depth extends approximately 1,500 feet east of the source area.

The areal extent of groundwater volatile contamination at Site 93 is relatively local to the original source area. The contamination is primarily located in the shallow aquifer at low concentrations.

Objectives developed for groundwater at OU No. 16 include:

- Mitigate the potential for direct exposure to the contaminated groundwater in the surficial aquifer.

- Minimize or prevent the horizontal and vertical migration of contaminated groundwater in the surficial aquifer.

- Restore the surficial and intermediate aquifers to the RLs established for the groundwater COCs.

- Maintain the quality of the deeper, Castle Hayne aquifer.

REMEDIAL ACTION ALTERNATIVES

Based upon the close proximity of Sites 89 and 93, their similar land-use characteristics, and the very similar nature of the groundwater contamination, the remedial action objectives were developed considering Sites 89 and 93 collectively. Five remedial action alternatives (RAAs) were developed and evaluated, including:

- RAA 1: No Action

- RAA 2: Institutional Controls and Natural Attenuation

- RAA 3: Extraction and On-Site Treatment

- RAA 4: Air Sparging and Soil Vapor Extraction

- RAA 5: Passive Treatment Wall

The following paragraphs briefly describe each of the five alternatives:

RAA 1: No Action

Under the no action RAA, no physical remedial actions will be performed to reduce the toxicity, mobility, or volume of contaminants identified in groundwater at Sites 89 and 93. The no action alternative is required by the NCP to provide a baseline for comparison with other RAAs that provide a greater level of response. Although this RAA does not involve physical remediation, remediation of the groundwater is expected to occur via natural attenuation of contaminants. Under the No Action RAA; however, no means are provided to monitor or confirm the natural remediation process.

Net Present Worth (NPW):	$0
Estimated Time to Implement:	None

RAA 2: Institutional Controls and Natural Attenuation

Under RAA 2, a long-term groundwater, surface water, and sediment monitoring program, along with aquifer use restrictions, will be implemented as institutional controls. In addition, remedial actions associated with the in-situ, naturally occurring biodegradation, dispersion, dilution, adsorption, volatilization, and chemical or biological stabilization/destruction of the VOCs in groundwater are expected in the form of natural attenuation. Twenty-five monitoring wells will be included under this program: eight existing shallow wells, eight existing intermediate wells, and four existing deep wells. A total of five new wells will be installed, including two new wells in the shallow aquifer, two new wells in the intermediate aquifer and one new deep well. The shallow and intermediate wells will monitor COC levels in the upper and lower portions of the surficial aquifer and the deep wells will monitor the upper portion of the Castle Hayne aquifer to ensure that COCs have not migrated vertically. Samples collected from these wells will be analyzed for TCL VOCs. As part of the monitoring program, surface water, and sediment samples will be collected from five existing and two new locations along Edwards Creek. The surface water and sediment samples will be collected and analyzed for TCL VOCs at the same frequency as note for groundwater monitoring.

In an effort to provide additional evidence that natural attenuation is occurring, RAA 2 incorporates the option of performing an annual contaminant fate and transport model. The Base Master Plan will be modified to include aquifer use restrictions. These restrictions will prohibit future use of the surficial aquifer as a potable water source.

Net Present Worth (NPW):	$ 2,680,000
Estimated Time to Implement:	0.5 Years

RAA 3: Extraction and On-Site Treatment

Extraction and on-site treatment, selected as RAA 3, is a conventional extraction alternative in which groundwater will be collected via extraction wells and an interceptor trench, and then transported to an on-site treatment plant for VOC removal. Once treated, the groundwater will then be discharged to Edwards Creek which flows westerly to the New River. Seven shallow extraction wells, four intermediate extraction wells, and a 400 linear foot shallow interceptor trench will be installed to collect groundwater from both the surficial and intermediate aquifers. The extraction wells will be positioned so that their combined zones of influence intercept the contaminated plume. Each extraction well will be screened in accordance with the depth of detected contamination (i.e., shallow ~ 10 to 20 feet bgs and intermediate ~ 40 to 50 feet bgs). The interceptor trench is estimated to be constructed from existing ground to a depth of 15 feet bgs.

The groundwater will then be transported by pipeline to the on-site treatment plant. At the treatment plant, the groundwater will undergo suspended solids and metals removal via neutralization, precipitation, flocculation, sedimentation, and filtration units, and VOC treatment via a low profile air stripper. In addition, vapor phase and liquid phase carbon adsorption will provide secondary treatment of the VOC emissions from the air stripper and of the treated groundwater. Groundwater will be discharged to Edwards Creek which flows to the New River.

RAA 3 also incorporates a long-term groundwater, surface water, and sediment monitoring program to measure the effects of this RAA over time. The monitoring wells and surface water/sediment sampling locations included under this program are those identified under RAA 2. Aquifer use restrictions prohibiting the use of the surficial aquifer as a potable water source will be implemented via the Base Master Plan.

Net Present Worth (NPW):	$ 2,900,000
Estimated Time to Implement:	1.5 to 2 Years

RAA 4: Air Sparging and Soil Vapor Extraction

An IAS system typically is comprised of the following components: 1) air injection wells; 2) an air compressor; 3) air extraction wells; 4) a vacuum pump; 5) associated piping and valving for air conveyance; and 6) an off-gas treatment system (e.g., activated carbon, combustion, or oxidation). Under RAA 4, a line of air sparging wells will be installed along the leading edge of the contaminated groundwater plume identified in the shallow aquifer of Site 93. In addition, a series of air sparging wells will be located within the DRMO facility; adjacent to the confluence of Edwards Creek and the northern drainage swale; and along the east side of White Street Extension. The air emissions from the off-gas treatment system will be sampled monthly to ensure that all applicable air emissions standards are being met. A field pilot test is recommended to determine specific design parameters including: the loss of efficiency due to oxidation, the radius of influence of the wells under various heads of injection air pressure, and the rate of off-gas organic contaminant removal via carbon adsorption and carbon breakthrough.

RAA 4 assumes that the Base Master Plan will be modified to include restrictions on the use of the surficial aquifer in the vicinity of Sites 89 and 93. In addition to aquifer-use restrictions, long-term groundwater, surface water, and sediment monitoring is to be included under this RAA to measure the effects of this RAA over time.

Net Present Worth (NPW):	$ 3,340,000
Estimated Time to Implement:	2 Years

RAA 5: Passive Treatment Wall

Under RAA 5, groundwater will be treated in situ via a passive wall unit. This RAA also includes institutional controls such as monitoring and aquifer-use restriction. Each passive wall system proposed will be excavated and installed within locations of the highest VOC detections, as well as, along the most prominent discharge locations detected along Edwards Creek. The trenches will be located so as to minimize disturbance of the surrounding functional areas of Sites 89 and 93. In general, two shallow walls (20 foot approximate depths) and two deeper walls (50 foot approximate depths) are proposed for treatment of the contamination detected in the shallow and intermediate aquifers, respectively. The shallow and deeper treatment walls will consist of the following:

Shallow Wall Systems

- For Site 89, approximately 150 linear feet of wall adjoined with two 25 linear feet impermeable funnel gates (sheet pilings).
- For Site 93, approximately 200 linear feet of wall adjoined by one (southern) impermeable funnel gate.

Deeper Wall Systems (Site 89 only)

- Both walls are estimated to be approximately 300 linear feet long. These walls will be located to channel groundwater within, the suspected source area of the DRMO and along Edwards Creek. Funnel gates are expected to extend at least 50 feet on either side of both gates.

A bench-scale and/or pilot-scale testing will be necessary prior to initiating the full-scale system. In addition to in situ treatment, RAA 5 includes a long-term groundwater, surface water, and sediment monitoring program to measure the effects of this RAA over time. The monitoring wells, surface water, and sediment sampling locations included under this program are those initially identified under RAA 2. Aquifer-use restrictions prohibiting the use of the surficial aquifer as a potable water source will be implemented under this RAA. These restrictions will be spelled out in the Base Master Plan.

Net Present Worth (NPW):	$ 34,150,000
Estimated Time to Implement:	1.5 to 2 Years

1.0 INTRODUCTION

This Feasibility Study (FS) has been prepared by Baker Environmental, Inc. (Baker) for the Department of the Navy (DoN), Atlantic Division Naval Facilities Engineering Command, Comprehensive Long-Term Environmental Action Navy (CLEAN) Program. Activities associated with this FS have been conducted in accordance with the requirements delineated in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) [40 Code of Federal Regulations (CFR) 300.430] for Operable Unit (OU) No. 16 at Marine Corps Base (MCB), Camp Lejeune, North Carolina. The NCP guidelines which dictate the FS process were promulgated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly referred to as Superfund, and amended by the Superfund Amendments and Reauthorization Act (SARA). The United States Environmental Protection Agency (USEPA) document entitled Conducting Remedial Investigations and Feasibility Studies Under CERCLA (USEPA, 1988) provided guidance during the preparation of this report.

MCB, Camp Lejeune was placed on the Superfund National Priorities List (NPL) on October 4, 1989 (86 Federal Register 41015, 1989). Subsequent to this listing, USEPA Region IV; the North Carolina Department of Environment and Natural Resources (NC DENR); and the DoN entered into a Federal Facilities Agreement (FFA). The continuing purpose of the FFA is to ensure that environmental impacts associated with past and present activities at MCB, Camp Lejeune are thoroughly investigated and appropriate CERCLA response/Resource Conservation and Recovery Act (RCRA) corrective action alternatives are developed and implemented, as necessary, to protect public health, welfare, and the environment (FFA, 1989).

The Fiscal Year 1996 Site Management Plan for MCB, Camp Lejeune is the primary document referenced in the FFA. This Site Management Plan identifies 34 sites that require Remedial Investigations/Feasibility Study (RI/FS) activities. An RI was conducted at OU No. 16, Sites 89 and 93, during 1997. This report collectively provides the FS conducted for Sites 89 and 93. Figure 1-1 depicts the location of the two sites that comprise OU No. 16.

1.1 Report Purpose and Organization

The subsections which follow describe the purpose and organization of the FS report.

1.1.1 Purpose of the Feasibility Study

The primary purpose of this FS report is to identify the remedial alternatives that are protective of human health and the environment, and that cost-effectively attain appropriate Federal and state requirements. In general, the FS process under CERCLA serves to ensure that appropriate remedial alternatives are developed and evaluated, such that pertinent information concerning the remedial action options can be presented and an appropriate remedy selected. The FS involves two major functions:

1. Development and screening of remedial action alternatives, and
2. Detailed analysis of remedial action alternatives.

The first phase includes the following activities:

- Developing remedial action objectives and remediation levels
- Developing general response actions
- Identifying volumes or areas of affected media
- Identifying and screening potential technologies and process options
- Evaluating process options
- Assembling alternatives
- Defining alternatives
- Screening and evaluating alternatives

Section 121(b)(1) of CERCLA requires that an assessment be conducted to investigate possible solutions and alternative treatment technologies or resource recovery technologies that, in whole or in part, will result in a permanent and significant decrease in the toxicity, mobility, or volume of the hazardous substance, pollutant, or contaminant. In addition, according to CERCLA, treatment alternatives should be developed ranging from an alternative that, to the degree possible, would eliminate the need for long-term management of alternatives which involve treatment that would reduce toxicity, mobility, or volume as their principal element. A containment option involving little or no treatment and a no-action alternative should also be developed.

The second phase of the FS consists of: (1) evaluating the potential alternatives in detail with respect to nine evaluation criteria that address statutory requirements and preferences of CERCLA; and (2) performing a comparison analysis of the evaluated alternatives.

1.1.2 Report Organization

This FS is organized in five sections. The Introduction (Section 1.0) presents the purpose of the report, a brief discussion of the FS process, and pertinent site background information including a summary of the nature and extent of contamination at Sites 89 and 93. Information from both the RI human health and ecological risk assessments are also presented in Section 1.0. Section 2.0 contains the remedial action objectives and remediation levels that have been established for these sites. Section 3.0 contains the identification of general response actions, and the identification and preliminary screening of the remedial action technologies and process options. Sections 4.0 and 5.0 contain the development, detailed analysis, and comparison of remedial action alternatives for Sites 89 and 93. The detailed analysis is based on a set of nine criteria including short- and long-term effectiveness, implementability, cost, acceptance, compliance with applicable regulations, and overall protection of human health and the environment. References are provided within each of the five sections.

1.2 Background and Setting

The subsections that follow summarize information concerning the background and setting of both Sites 89 and 93. Further information of this type can be found in the Final Project Plans (Baker, 1996). Since OU No. 16 is comprised of two individual sites (Sites 89 and 93), each will be presented separately.

1.2.1 Site Location and Setting

1.2.1.1 Site 89

Site 89 is located in the Camp Geiger section of MCB Camp Lejeune (Figure 1-1). As shown on Figure 1-2, Site 89 is located near the intersection of "G" and Eighth Streets near the Defense Reauthorization and Marketing Office (DRMO) area of Camp Geiger. Site 89 is the larger of the two sites within OU No. 16. It encompasses a significant portion of Camp Geiger, which includes all of the DRMO and additional area to the south and east (Figure 1-2).

Originally, the site investigation focused on a small area within the DRMO which contained an underground storage tank (UST) that was identified as STC-868. The UST was a steel 550-gallon waste oil tank located between Building STC-867 (a soil storage facility) and an elevated wash rack. The tank was installed in 1983 and used for the storage of waste oil. This UST was reportedly closed by removal in 1993. Initially, two monitoring wells were installed in the area of the former UST. Based upon elevated levels of both total petroleum hydrocarbons (TPH) and oil and grease (O&G), a third well was installed in June 1994.

The major finding of the initial UST investigation at Site 89 was the detection of several chlorinated solvents in the groundwater. Historical records of the area indicate that the site operated as a base motor pool until approximately 1988. The base motor pool was then relocated to an asphalt paved area immediately north of the DRMO facility where it operates currently.

The initial findings of the UST investigation led to the inclusion of Site 89 into MCB, Camp Lejeune's Installation Restoration (IR) Program. The site presently includes the entire DRMO and additional area outside the DRMO fence, including the wooded areas to the south and the east. The approximate site boundary is defined on Figure 1-2.

The majority of the western portion of Site 89 is primarily covered by asphalt, roads, and gravel parking areas. The eastern portion of Site 89, is heavily wooded as is the area immediately south of the DRMO. Edwards Creek is located approximately 525 feet south of the former UST location. The land surface of Site 89 slopes in the direction of Edwards Creek, which begins near 8th Street as a series of drainage ditches within Camp Geiger, before turning to the west where it tends to widen as it flows through the wooded area of Site 89. The eastern portion of the stream flows through a low lying, swampy area.

1.2.1.2 Site 93

Site 93 is located in the Camp Geiger section of MCB Camp Lejeune (Figure 1-1). As shown on Figure 1-3, Site 93 is located near Building TC-942 at the intersection of Ninth and "E"Streets within Camp Geiger. The total area of Site 93 is much smaller than Site 89. Building TC-942 currently functions as a supply room for the Marine Infantry School. Items such as field jackets, ponchos, and canteens are stored in the building. Other buildings in the area serve as classrooms for the school and barracks. Site 93 originally had a 550-gallon oil storage UST located at the southwest corner of Building TC-942.

Although there is no documentation available concerning the installation date of the UST, the UST at Site 93 was permanently closed as part of a tank removal in December 1993. Based on elevated concentrations of O&G at the time of tank removal, a release is suspected to have occurred. An investigation of the former tank area was conducted in June 1995. The investigation included the installation of five monitoring wells around the former UST and the collection of soil and groundwater samples. Since the time of the UST investigation, the area of Site 93 includes area to the north, south, east, and west of Buildings TC-940 and TC-942.

1.2.2 Geology

The geology at Sites 89 and 93 is described together because of the close proximity of these sites. The geology is also placed in context of the regional geology, as described in the "Hydrogeologic Framework of U.S. Marine Corps Base at Camp Lejeune, North Carolina", (Cardinell, et al., 1993).

A fairly consistent depositional sequence was observed in the borings throughout Sites 89 and 93. This observed sequence is similar to the generalized North Carolina coastal plain sequence which shows that the Yorktown, Eastover, and Pungo River Formations lie between the Undifferentiated and Belgrade Formations. The Yorktown, Eastover, and Pungo River Formations, however, have not been identified at Camp Lejeune.

During the RI, the Undifferentiated and River Bend Formations were encountered. The Belgrade Formation did not appear to be consistent at OU No. 16; however, a description of this unit has been included. It appears that the shallow temporary wells installed during this investigation are screened in the Undifferentiated Formation (surficial aquifer) and the intermediate wells are screened in the upper portions of the River Bend Formation (Castle Hayne aquifer).

The Undifferentiated Formation is comprised of loose to medium dense sands and soft to medium stiff clay. This formation is comprised of several units of Holocene and Pleistocene ages and can consist of a fine to coarse sand, with lesser amounts of silt and clay. At Sites 89 and 93, this formation typically extends to a depth between 20 and 30 feet below ground surface (bgs). The silt and clay lenses present within this formation may be correlated to the regional geology as the Belgrade Formation, or Castle Hayne confining unit. This unit, however, did not appear consistent at Sites 89 and 93.

The Belgrade Formation is comprised of fine sand with some shell fragments, silt, and clay of the Miocene age. Identifying this formation at OU No. 16 was difficult due to its inconsistency. Overall, the Undifferentiated Formation (surficial aquifer) appears to lie immediately above the River Bend Formation (upper portion of the Castle Hayne aquifer), with little to no presence of the Belgrade Formation (Castle Hayne confining unit). The inconsistent nature of the Belgrade Formation suggests that a significant hydraulic connection exists between the Undifferentiated Formation (surficial aquifer) and the upper portions of the River Bend Formation (Castle Hayne aquifer). At best, the Belgrade Formation at OU No. 16 can be classified as a semi-confining unit or a "retarding layer", as it is laterally discontinuous and does not exhibit completely confining conditions to the River Bend Formation below (Castle Hayne aquifer).

Beneath the Undifferentiated Formation and the limited Belgrade Formation lies the River Bend Formation (upper potion of the Castle Hayne aquifer). This unit, which is predominantly composed of dense to very dense shell and fossil fragments interbedded with calcareous sands, is present at OU No. 16 approximately 25 to 50 feet bgs.

1.2.3 Hydrogeology

The surficial aquifer resides within the Undifferentiated Formation, the Castle Hayne confining unit resides within the Belgrade Formation, and the Castle Hayne aquifer resides within the River Bend Formation. United States Geological Society (USGS) documents the thickness of the surficial aquifer to be 18 to 23 feet and the thickness of the Castle Hayne confining layer as 4 to 7 feet in the vicinity of OU No. 16 (based on RI supply well boring logs). This places the elevation of the Castle Hayne confining unit from 0 to 8 feet above mean sea level (msl), although a definite confining layer which separates the surficial aquifer from the Castle Hayne aquifer is not present at OU No. 16. General descriptions of the 1993 USGS document and site-specific geologic conditions place the top of the Castle Hayne aquifer at approximately -10 feet msl.

Groundwater levels within RI monitoring wells ranged from 2.15 feet below msl to 13.52 feet above msl. Groundwater level measurements for Sites 89 and 93 are presented within the RI; however, three groundwater elevation maps are included herein for the shallow monitoring wells (Figure 1-4), intermediate monitoring wells (Figure 1-5), and the deep monitoring wells (Figure 1-6).

The groundwater elevation data suggest that the flow patterns observed for the surficial and upper portions of the Castle Hayne aquifers display similar trends. Overall, elevations are higher in the northern portion of the OU, with decreasing elevations in the direction of Edwards Creek and in the wooded area to the east. Groundwater flow in the surficial aquifer shows a pronounced localized flow to the south as Edwards Creek serves as a groundwater discharge boundary (Figure 1-4, shallow wells). Edwards Creek effects flow within the surficial aquifer and upper portions of the Castle Hayne aquifer more than in the deeper portion of the aquifer. Groundwater flow in the upper portions of the Castle Hayne (Figure 1-5, intermediate wells) is affected somewhat by the local discharge area of Edwards Creek, but there is also a trend eastward demonstrating the effects of the surface water bodies associated with the New River. The New River, located east of the OU, apparently influences the groundwater flow of the deeper portions of the Castle Hayne aquifer, causing groundwater at depth to move east, toward the river (Figure 1-6, deep wells).

Groundwater head differentials between the shallow and intermediate wells were evaluated to determine if a vertical component of flow underlies the OU. In general, elevations in shallow temporary wells are greater than the associated elevation in the intermediate temporary wells in those wells located north of Edwards Creek. This data demonstrates a downward component of groundwater movement from the surficial aquifer to the Castle Hayne aquifer north of Edwards Creek. This information supports the assumption that confining conditions of the Castle Hayne aquifer in this area are not likely.

The average estimated hydraulic conductivity (K value) from the shallow wells at Site 89 was 8.4 feet/day. The average hydraulic conductivity in the intermediate well was 64.6 feet/day, one order of magnitude greater than the values measured in the shallow wells. The estimated K values at Site 93 in the shallow and intermediate wells show similar results to the Site 89 K values.

The hydraulic gradient at Site 89 was estimated from groundwater measurements in intermediate wells IR89-MW03IW and IR89-MW04IW on May 29, 1997 to be 0.005 ft/ft. Published effective porosity values indicate a range of 25 to 50 percent for sands and silts (Freeze/Cherry, 1979). Using the average K value from the intermediate wells, the average linear groundwater velocity (V) in a northwest to southeast direction is estimated to be 0.64 to 1.29 ft/day (233 to 470 ft/year). Using a saturated thickness of approximately 45 feet, which corresponds to the depth of the first semi-confining layer at Sites 89 and 93, and an average K value taken from the intermediate wells, the approximate transmissivity value for the aquifer in this direction is 2,907 ft^2/day.

1.2.4 Site History

OU No. 16 is located within the Camp Geiger area which comprises a total of 216 acres. The majority of Camp Geiger is taken up by troop housing, supply, storage and administrative buildings. Other land utilization areas consist of operations, training, maintenance, and utility. Classroom training facilities and instruction areas are scattered throughout the Camp Geiger area, making up approximately 7 percent or 15 acres of the developed area.

Site 93 is located in the developed portion of Camp Geiger, while Site 89 consists of the DRMO area and portions of the wooded area east of White Street Extension.

Water supply wells within a one-mile radius of Sites 89 and 93 were identified by reviewing Base information. A total of 13 supply wells were identified within a one-mile radius of Sites 89 and 93. The location of the wells relative to the sites are shown on Figure 1-7. The supply wells near OU No. 16 range in depths from 70 feet bgs to 250 feet bgs. Although supply well PSWTC-1256 falls just beyond the boundary of the 1-mile radius, this well is included on Figure 1-7 as additional information.

1.3 Previous Investigations

The following subsections provide information concerning the previous UST investigations completed at Sites 89 and 93. The information is summarized to provide the reader with the historical framework from which the sites have been investigated.

1.3.1 Site 89

The former UST at Site 89 was installed in 1983 and was reportedly used until 1993 for the storage of waste oil. The tank was removed in 1993 and an initial investigation was conducted by installing two monitoring wells. Sampling activities at the site revealed elevated levels of both TPH and O&G.

An additional site check was conducted in June 1994. This investigation included one soil boring southeast of the tank excavation area, which was then converted to a monitoring well. Groundwater samples were collected from the new and existing monitoring wells. The results indicated:

- Soil sample detections of 1,400,000 micrograms per kilogram (µg/kg) of O&G
- Halogenated solvents in the soil samples below the detection limits for all parameters
- Groundwater samples with concentrations of:

cis-1,2-dichloroethene	2,130 micrograms per liter (µg/L)
trans-1,2-dichloroethene	1,580 µg/L
1,1,2,2-tetrachloroethane	8,600 µg/L
trichloroethene	1,500 µg/L

- Semivolatile organic compounds (SVOCs) and toxicity characteristic leachate procedure (TCLP) analyses below the method detection limits in all samples

1.3.2 Site 93

One 550-gallon UST was removed from Site 93 in December 1993. Based on elevated levels of O&G at the time of tank removal, a release was suspected to have occurred.

A subsequent investigation was conducted in June 1995, which included the installation of five monitoring wells around the former UST excavation and the collection of soil and groundwater samples. The results of the sampling are summarized below:

- O&G results from the soil samples ranged from 56,100 to 8,126,000 µg/kg.

- Naphthalene and tetrachloroethene were detected in the soil sample at 0.049 and 20 µg/kg, respectively.

- Groundwater samples detected concentrations of several chlorinated solvents:

cis-1,2-dichloroethene	250 µg/L
chlorobenzene	90 µg/L
tetrachloroethene	90 µg/L
trichloroethene	30 µg/L

- Several SVOCs were detected at concentrations which were below regulatory limits.

- Total cadmium concentrations in each well and lead concentrations in one well exceeded regulatory levels. It should be noted that, soils found within the coastal plain of North Carolina are naturally rich in metals. The observed total metal concentrations in groundwater are typically due more to geologic conditions (i.e., naturally occurring metals bound to unconsolidated soil particles) and sample acquisition methods than to mobile metal concentrations in groundwater. The presence of these metals are suspected to be a result of existing natural conditions, and not site operations.

1.4 Remedial Investigation

The RI field investigation activities for Sites 89 and 93 were conducted in two phases. The initial phase of RI field investigation sampling activities commenced on July 26, 1996 and continued through August 21, 1996. The second phase of RI field investigation sampling activities commenced on April 18, 1997 and continued through June 2, 1997. The RI field program activities at Sites 89 and 93 primarily consisted of a site survey, subsurface soil investigation, and groundwater investigation. The surface water and sediment investigation was completed for Site 89 only. The following sections summarize the various investigative activities which were implemented during the RI. Locations of samples for each media are shown on Figures 1-8 and 1-9 for Sites 89 and 93, respectively.

1.4.1 Site Survey

The site survey task was performed during both phases of the RI at Sites 89 and 93. Surface features (i.e., buildings, structures, tree lines, drainage ways, utilities, roads, parking areas, fences, etc.) at both sites were surveyed during the Phase I investigation. Following both phases, the location (longitude and latitude) and elevation (referenced to msl) of each final sample point was surveyed. All surveying was referenced to the North Carolina State Plane Coordinates System.

1.4.2 Soil Investigation

Subsurface soil samples were collected to assess site contamination and to provide lithological information for the evaluation of geologic and hydrogeological conditions. Subsurface soil samples were collected from each monitoring well (permanent and temporary) that was advanced at Sites 89 and 93.

All subsurface soil samples were classified in the field using the Unified Soil Classification System via visual-manual methods. Lithologic descriptions of the site soils are provided on the Test Boring and Well Construction Records which are presented in the RI.

Site 89

During the Phase I investigation, a total of 30 soil borings were advanced at Site 89 with temporary monitoring wells installed in each of the soil borings. During the Phase II investigation, a total of 21 soil borings were advanced at the site with temporary monitoring wells installed in seven of the soil borings, while permanent monitoring wells were installed in 14 soil borings.

Site 93

A total of 15 soil borings were advanced at Site 93 during the Phase I investigation. Temporary monitoring wells were installed in each of these soil borings. During the Phase II investigation, a total of 11 soil borings were advanced with permanent monitoring wells installed in each of the borings.

None of the subsurface soil samples collected at either site during the Phase I investigation were submitted for on-site fixed base laboratory analysis. Select subsurface soil samples collected during the Phase II investigation were submitted for one or more of the following laboratory analyses:

Parameter	Site 89	Site 93
Target Compound List (TCL) volatiles	26 samples	22 samples
TCL SVOCs	26 samples	22 samples
TCL pesticides/polychlorinated biphenyls (PCBs)	5 samples	4 samples
Target Analyte List (TAL) metals	26 samples	22 samples
Engineering parameters including:		
▸ Total organic carbon (TOC)	1 sample	1 sample
▸ Grain size	3 samples	1 sample
▸ Bulk density	3 samples	1 sample
Vertical permeability	3 samples	0 samples

1.4.3 Groundwater Investigation

A Phase I and II groundwater investigation was conducted at Sites 89 and 93 to define the nature and extent of contamination in the surficial aquifer and in the Castle Hayne aquifer which may have resulted from past site activities. The groundwater investigation included the following activities which are discussed in the proceeding sections:

- Temporary monitoring well installation
- Permanent monitoring well installation
- On-site laboratory analysis
- Fixed-base laboratory analysis

1.4.3.1 Temporary Monitoring Wells

Site 89

During the Phase I investigation a total of 30 temporary monitoring wells were installed at Site 89. A total of 14 of these wells were temporary shallow monitoring wells, ranging in depths of 10 to 19 feet bgs. A total of 16 intermediate temporary monitoring wells were installed during the Phase I investigation ranging in depths from 35.0 to 47.0 feet below bgs. During the Phase II investigation, seven temporary monitoring wells were installed at depths ranging from 10.5 to 41.0 feet bgs.

Site 93

Fourteen temporary monitoring wells were installed at Site 93 including seven shallow and seven intermediate wells. Shallow temporary monitoring wells at Site 93 ranged in depth from 14.5 to 24.5 feet bgs. The intermediate wells ranged in depth from 50 to 53.5 feet bgs.

1.4.3.2 Permanent Monitoring Wells

During the RI at Sites 89 and 93, the shallow permanent monitoring wells were screened across the water table (i.e., a portion of the monitoring well screen is above the level of the groundwater surface) to facilitate monitoring of the upper zone of the surficial aquifer. The intermediate permanent monitoring wells were installed to monitor the zone just above the first semi-confining layer within the Castle Hayne aquifer. The deep permanent monitoring wells were installed to monitor the zone just above the second semi-confining layer within the Castle Hayne aquifer.

Site 89

There were no permanent monitoring wells installed at Site 89 during the Phase I investigation; however, a total of 14 permanent monitoring wells were installed during the Phase II investigation. Two shallow permanent monitoring wells were installed, each to a depth of 14.0 feet bgs. A total of six intermediate permanent monitoring wells were installed at depths ranging from 37.0 to 41.5 feet bgs. Six deep permanent monitoring wells were installed at depths ranging from 70.0 to 90.0 feet bgs.

Groundwater samples were collected from three monitoring wells (IR89-MW01, IR89-MW02, and IR89-MW03) that were installed as part of a previous UST investigation. The wells, which were originally identified as STC868-MW01, STC868-MW02, and STC868-MW03, were installed in June 1994. Groundwater samples were also collected from two monitoring wells (IR35-MW42B and

IR36-GW05), which were installed as part of investigations for other IR Program sites, due to their close proximity to Site 89.

Site 93

No permanent monitoring wells were installed at Site 93 during the Phase I investigation. However, a total of 11 permanent monitoring wells were installed at Site 93 during the Phase II investigation. Five shallow permanent monitoring wells were installed at depths ranging from 12.0 to 14.0 feet bgs. A total of five intermediate permanent monitoring wells were installed at depths ranging from 40.0 to 50.0 feet bgs. One deep permanent monitoring well was installed at a depth of 71.0 feet bgs.

1.4.3.3 On-site Laboratory Analysis

A total of 33 groundwater samples collected during the Phase I investigation from Site 89 temporary monitoring wells were subjected to on-site laboratory analysis of VOCs. One additional sample (IR89-MW42B-02) was collected from an existing permanent monitoring well. During Phase II of the investigation, seven groundwater samples collected from Site 89 were subjected to on-site laboratory analysis of VOCs.

At Site 93, a total of 15 groundwater samples collected during Phase I were subjected to on-site laboratory analysis of VOCs. On-site laboratory analysis was not utilized during Phase II of the Site 93 investigation.

1.4.3.4 Fixed-base Laboratory Analysis

During Phase I of the investigation, four samples from Site 89 and three samples from Site 93 were submitted for fixed-base laboratory analysis of TCL VOCs. These samples, which were collected from temporary monitoring wells, were also subjected to on-site analysis of VOCs. During Phase II of the investigation, groundwater samples which were collected from permanent monitoring wells were submitted for fixed-base laboratory analysis of one or more of the following laboratory analyses: TCL VOCs, TCL SVOCs, TCL pesticides/PCBs, TAL metals, total suspended solids (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), methane, and natural attenuation parameters including nitrate, nitrite, sulfate, chloride, Fe^{+2}, and sulfide.

1.4.4 Surface Water and Sediment Investigation

Surface water and sediment samples for Site 89 were collected from various reaches of Edwards Creek. Figure 1-10 shows the locations of the surface water and sediment sample locations within Edwards Creek. Sampling of surface water and sediment was completed at the downstream sample locations first and then proceeded upstream. No surface water or sediment samples were collected for Site 93.

A total of 11 surface water samples were collected during the Phase I investigation. Each of these samples were subjected to on-site laboratory analysis for VOCs. Five of these samples were shipped to the fixed-based laboratory and analyzed for TCL VOCs, TCL SVOCs and TAL metals according to Contact Laboratory Program (CLP) protocol. Another surface water sample was analyzed for TCL pesticides and PCBs in addition to the aforementioned parameters.

Five surface water samples were collected during the Phase II investigation from the upper portions of Edwards Creek near the DRMO facility and at locations downstream where the stream approaches the New River. These five samples were submitted to the fixed-based laboratory for the analysis of chlorides.

Ten sediment samples were collected subsequent to the surface water samples to minimize sediment suspension that might falsely contaminate the surface water samples. The sediment samples were collected from the five stations from which fixed-base laboratory surface water samples were collected. Two sediment samples were collected at each of these locations for a total of ten samples. The first sample was collected below the water surface from the surface of the stream bed to approximately six inches bgs, and the second sample was collected from the 6 to 12 inch bgs interval. The sediment samples were analyzed for TCL VOCs, TCL SVOCs, and TAL metals. One of these sediment samples was analyzed for TCL pesticides and PCBs in addition to the aforementioned parameters.

1.5 Nature and Extent of Possible Site Contaminants

This section summarizes the analytical results of the RI performed at OU No. 16 (Sites 89 and 93). The nature and extent of contamination detected within the soil, groundwater, surface water and/or sediments at Sites 89 and 93 was accomplished by specific laboratory analysis of environmental samples. The data are presented for both sites by media as listed below:

- Site 89
    - soil
    - groundwater
    - surface water
    - sediment
- Site 93
    - soil
    - groundwater

1.5.1 Site 89

Investigative activities at Site 89 included the collection of soil and groundwater samples in the area of the DRMO and the wooded area east of White Street Extension. Surface water and sediment samples were collected from Edwards Creek near the DRMO facility and from downstream portions of the stream as it flows to the New River. Figure 1-11 illustrates the location of all groundwater, surface water, and sediment sample points at Site 89. The results of each of the media sampled are presented separately, including soil, groundwater, surface water, and sediment.

1.5.1.1 Soil - Site 89

A total of 26 soil samples were collected from Site 89 and analyzed for VOCs, SVOCs, and metals. Five of the samples were analyzed for pesticides and PCBs. Nine VOCs were detected in the soil samples collected from Site 89. The detected compounds include 1,1,2,2-tetrachloroethane, 1,2-

dichloroethene (total), 2-butanone, acetone, benzene, carbon disulfide, tetrachloroethene, toluene, and trichloroethene. The distribution and extent of these compounds are not discussed in detail because they are not considered to be site related. None of the organic compounds exceeded the USEPA Region III Risk-Based Concentrations (RBCs) for soil.

SVOCs were detected sporadically across the study area at locations IR89-MW06 and IR89-MW03. Three compounds were detected including bis(2-ethylhexyl)phthalate, fluoranthene, and pyrene. The presence of the polynuclear aromatic hydrocarbons (PAHs) in the soil at Site 89 is more likely related to various anthropogenic processes than to specific site activities. Additionally, none of the detections of SVOCs in the soil samples exceeded the Region III RBCs.

Three pesticides were detected in soil sample IR89-MW03IW-02. The compounds and concentrations included 4,4'-DDD, 4,4-'DDE, 4,4'-DDT at concentrations of 19J µg/kg, 17J µg/kg, and 91 µg/kg, respectively. None of these concentrations exceeded the Region III RBCs for soil. Pesticides have been used extensively in the past at MCB Camp Lejeune. The presence of pesticides at Site 89 is not unusual based on the fact that these compounds have been detected in various background areas and their documented historic use at the base. Their presence in the soil samples is not considered to be related to specific activities at Site 89.

Inorganic compounds were detected across the site in a uniform pattern. Results of the analytical data were compared to both the Region III RBCs for residential soil and twice the average Base background values. Many of the inorganics detected in the soil samples exceeded both the Region III RBCs and the Base background values. However, the detections of the inorganics in the soil is considered to be a result of natural soil conditions and not site operations or disposal activities. The detections of inorganics in the soil samples do not exhibit excessive concentrations or present a pattern which would indicate specific inorganic disposal activities.

1.5.1.2 Groundwater - Site 89

The groundwater investigation at Site 89 entailed the collection of groundwater samples from the surficial and Castle Hayne aquifer. Shallow and intermediate wells were screened at approximately 25 and 40 feet bgs, respectively; while the deep wells were screened approximately 70 feet bgs. Groundwater samples were collected from both temporary and permanent monitoring wells to assess site conditions.

Twelve VOCs were detected in the groundwater samples collected at Site 89. They included, 1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, 1,1-dichloroethene, 1,2-dichloroethene (total), chloroform, cis-1,2-dichloroethene, tetrachloroethene, toluene, trans-1,2-dichloroethene, trichloroethene, and vinyl chloride.

The majority of these VOCs are considered to be a result of previous site operations; however, the detection of chloroform in the groundwater samples is not considered to be site related. The presence of chloroform in the groundwater samples is most likely related to the potable water source (i.e., introduced during the potable water chlorination process) that was used during drilling operations of the temporary monitoring wells.

Concentrations of the VOCs ranged from 0.1 µg/L of tetrachloroethene to 880 µg/L of 1,2-dichloroethene (total). The highest concentration of trichloroethene was 744.3 µg/L, detected in the sample collected from monitoring well IR89-MW02 which is located near the former UST SCT-868 located inside the DRMO facility. Of the VOCs detected, six were detected at concentrations which exceeded either the Federal Maximum Contaminant Level (MCL) or the North Carolina Water Quality Standard (NCWQS). The compounds which exceeded criteria included, chloroform, cis-1,2-dichloroethene, tetrachloroethene, trans-1,2-dichloroethene, trichloroethene, and vinyl chloride.

Only one SVOC, bis(2-ethylhexyl)phthalate, was detected in the groundwater samples obtained from the monitoring wells at Site 89. This compound is not considered to be site related as it is a common laboratory contaminant and may also be attributed to materials used during the field program. There were no pesticides/PCBs detected in any of the groundwater samples collected from Site 89.

Inorganics were detected in the majority of the groundwater samples obtained from Site 89. Iron and manganese concentrations exceeded their respective Federal MCLs and NCWQS. The maximum concentrations of iron and manganese occurred in the sample collected from monitoring well IR89-MW05. Iron was detected at a concentration of 20,000J µg/L while manganese was detected in the sample at 379 µg/L. The detections of iron and manganese, while above the water quality standards, are not considered to be contaminants of potential concern at the site. The presence of potential inorganics in groundwater, particularly iron and manganese, are believed to be the result of the natural site conditions, and not due to the influence of site operations.

1.5.1.3 Surface Water - Site 89

Eight VOCs were detected in the samples obtained from Edwards Creek; including 1,1,2,2-tetrachloroethane, 1,2-dichloroethene (total), chloroform, cis-1,2-dichloroethene, tetrachloroethene, trans-1,2-dichloroethene, trichloroethene, and vinyl chloride. Concentrations of the VOCs ranged from 0.1 µg/L of tetrachloroethene to a high of 150J µg/L of 1,1,2,2-tetrachloroethane. The sample stations recording the highest number of maximum detections were sample stations IR89-EC-SW02 and IR89-EC-SW04. These stations are located south and hydraulically downgradient of the DRMO area. Sample station IR89-EC-SW06, located to the west of the DRMO area and at the headwaters of Edwards Creek, was the only station where VOCs were not detected. Four of the compounds including 1,1,2,2-tetrachloroethane, tetrachloroethene, trichloroethene, and vinyl chloride were detected at concentrations exceeding the Federal Ambient Water Quality Criteria (AWQC).

There were no SVOCs or pesticides/PCBs detected in the surface water samples collected from Edwards Creek. Metals including iron and manganese were detected in the samples at concentrations which exceeded the Federal AWQCs. Given the nature of the soils and the detected inorganic concentrations within the surface water, the presence of metals is most likely attributed to natural conditions. Metals in the surface water is not considered to be a result of site operations.

1.5.1.4 Sediment - Site 89

The maximum detection of VOCs occurred at sediment sample stations IR89-EC-SD03 and IR89-EC-SD10. Nine VOCs were detected in the sediment samples collected from the stream bed. The majority of the detections occurred in the samples collected from the 0 to 6 inch sample depth. However, there were detections of VOCs in the samples taken from 6 to 12 inches. The detected VOCs included the following: 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, 1,1-dichloroethene, 1,2-dichloroethene (total), cis-1,2-dichloroethene, toluene, trans-1,2-dichloroethene, trichloroethene, and vinyl chloride. Concentrations of the VOCs ranged from 1 µg/kg of trans-1,2-dichloroethene to 2,400 µg/kg of trichloroethene. At present, there are no USEPA Region IV sediment screening levels for VOCs in sediment.

All ten of the sediment samples collected had SVOC detections. Eleven different SVOCs were detected in the samples, however, only benzo(a)pyrene was detected at a concentration which exceeded its Region IV sediment screening level. The type of SVOCs which were detected are ubiquitous in the environment and can be a result of decomposition of organic material or combustion of fossil fuels. Further, the concentrations detected are similar to what is normally expected in environments where soil has a high organic content. Therefore, the SVOC results are not considered to be related to site operations.

Analysis for pesticide/PCBs was performed at station IR89-EC-SD05 only. There were no PCBs detected in the sample, however, several pesticide compounds were detected including 4,4'-DDD, 4,4'-DDE, 4,4'-DDT, alpha-chlordane, and gamma-chlordane. Concentrations of 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT exceeded the Region IV sediment screening levels. As noted, pesticide compounds were commonly used in the past at MCB, Camp Lejeune, and have been detected in many samples at various sites across the Base. Their presence in the sediment samples are most likely due to overland runoff and to organic matter present in the sediment samples. The reported concentrations of these organic compounds are not considered to be related to site operations, but rather previous basewide applications.

Inorganics were detected in all ten of the sediment samples from sampling stations IR89-EC-SD01 through IR89-EC-SD05. Only lead, with a maximum concentration of 35.4J milligrams per kilogram (mg/kg), exceeded the Region IV sediment screening level of 35 mg/kg. Based upon the natural occurrence of metals in soil and sediment, occasional exceedences of relative standards are to be expected. The concentrations of the metals observed in the sediment samples are similar to concentrations observed in other samples throughout the Base. Their presence is most likely a result of natural conditions, and therefore; metals detected in the sediment are not considered to be related to site activities.

1.5.2 Site 93

The investigation at Site 93 involved the collection of soil and groundwater samples in the area centered around Building TC-942. The results of each media sampled are presented separately. The locations of the sampling points at Site 93 are shown on Figure 1-12.

1.5.2.1 Soil - Site 93

Twenty-two soil samples were collected at Site 93 and analyzed for VOCs, SVOCs, and metals. Of these 22 samples, 3 were analyzed for pesticides/PCBs. Two VOCs were detected in the soil samples collected from Site 93, including 2-butanone and acetone. Neither acetone or 2-butanone exceeded the Region III RBCs for soil. In addition, these compounds are not believed to be related to specific site operations. They are typically a result of laboratory and/or field procedures and are not considered to be related to site conditions.

Two SVOCs were detected including bis(2-ethylhexyl)phthalate and benzo(a)pyrene. Bis(2-ethylhexyl)phthalate was detected in 5 of 22 samples however, none of the detections exceeded the Region III RBCs for residential soil. Benzo(a)pyrene was detected only once, in sample IR93-MW02IW-04, at a concentration of 400J µg/kg which is greater than the Region III RBC of 88 µg/kg.

Three pesticides were detected in the samples collected at Site 93. All three detections occurred from sample IR89-MW02DW-02. The compounds and concentrations included 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT at concentrations of 55 µg/kg, 22 µg/kg, and 33 µg/kg, respectively. None of these concentrations exceeded the Region III RBCs for soil.

Inorganic compounds were detected across the site in a uniform pattern. Results of the analytical data were compared to both the Region III RBCs for residential soil and twice the average Base background values. Many of the inorganics detected in the soil samples exceeded both the Region III RBCs and the Base background values. Although exceedences of inorganics in the soil samples were present, the metals are not considered to be related to operations at Site 93.

1.5.2.2 Groundwater - Site 93

The groundwater investigation at Site 93 included collection of groundwater samples from the surficial and Castle Hayne aquifers. Shallow and intermediate wells were screened at approximately 25 and 40 feet bgs, respectively while the deep monitoring wells were screened approximately 70 feet bgs. Groundwater samples were collected from both temporary and permanent monitoring wells to assess site conditions.

Six separate VOCs were detected in the groundwater samples collected at Site 93. They included, 1,2-dichloroethene (total), chloroform, cis-1,2-dichloroethene, tetrachloroethene, trans-1,2-dichloroethene, and trichloroethene. Concentrations ranged from 0.1 µg/L of tetrachloroethene to 175 µg/L of cis-1,2-dichloroethene. The highest concentration of trichloroethene was 39.4 µg/L, detected in the sample collected from monitoring well IR93-TW01 which is located in the gravel parking area, immediately south of Building TC-942 and the original UST location. Of the VOCs present, chloroform, cis-1,2-dichloroethene, tetrachloroethene, and trichloroethene were detected at concentrations which exceeded either the Federal MCLs or NCWQS.

Two SVOCs, including bis(2-ethylhexyl)phthalate and naphthalene, were detected in the groundwater samples obtained from the monitoring wells at Site 93. Bis(2-ethylhexyl)phthalate was detected in 4 of 11 samples, however, only one of the detections exceeded the NCWQS. Bis(2-ethylhexyl)phthalate is not considered to be site related as it is a common laboratory contaminant. Naphthalene was detected at a concentration of 6J µg/L in the sample collected from IR93-MW05. This concentration was below the NCWQS. There were no pesticides/PCBs detected in any of the groundwater samples from Site 93.

Inorganics were detected in the majority of the groundwater samples obtained from Site 93. Of the metals detected, iron, manganese, and lead were present at concentrations above the Federal MCLs and NCWQS. Lead exceeded both the Federal MCL and the NCWQS in one sample which was collected from monitoring well IR93-MW02IW. The concentration of lead in this sample was 164 µg/L as compared to its corresponding Federal MCL and NCWQS of 15 µg/L. Iron exceeded the Federal MCL and the NCWQS in each of the eleven groundwater samples analyzed. The maximum concentration of iron, 4,330 µg/L, occurred in the sample taken from monitoring well

IR93-MW01IW. Manganese exceeded the Federal MCL and NCWQS in 2 of the 11 groundwater samples. The maximum concentrations of manganese occurred in the sample collected from monitoring well IR93-MW01. The detections of iron, manganese, and lead, while above standards, are not considered to be contaminants of potential concern at the site. As previously discussed, the presence of inorganics in groundwater, particularly iron, and manganese, are a result of the natural site conditions, and not due to site operations.

1.6 VOC Analytical Results

The sections below summarize the extent of contamination to the media sampled during the RI at OU No. 16 (Sites 89 and 93). The material presented focuses on the impact of volatile contamination detected in the soil, groundwater, surface water, and sediment. From this point through the conclusion of the FS, SVOCs, pesticides/PCBs, and metals are not presented on figures or discussed in detail. They are excluded from the remaining discussions based upon their observed infrequency of detection at concentrations greater than established standards or they were detected sporadically across the sites.

Figures related to the VOC extent of contamination are presented to illustrate the spatial relationships of the volatile analytical data only. Information presented on the figures focuses on the detections which exceed relevant standards, such as the Federal MCLs and NCWQS. Tables have been included with the figures to provide information concerning the specific compounds detected in the various media and their respective concentrations.

1.6.1 Site 89

Sampling activities at Site 89 included the collection of soil and groundwater samples in the area of the DRMO and the wooded area east of White Street Extension. In addition, surface water and sediment samples were collected from Edwards Creek. The extent of volatile contamination concerning each of these media are discussed separately in the following sections.

1.6.1.1 Soil - Site 89

The majority of the detections of VOCs occurred at monitoring well clusters IR89-MW03 and IR89-MW05, both of which are located in the western portion of Site 89. Monitoring well cluster IR89-MW03 is located near the original UST location within the DRMO, which is considered to be one of the potential source areas of site contamination. Impact to the soil was also apparent at monitoring well location IR89-MW05 located just west of the DRMO facility at the end of F Street. Monitoring well IR89-MW04, located in the wooded area immediately east of White Street Extension, noted an elevated detection of 1,2-dichloroethene (total; 27 μg/L) in a soil sample collected from 9 to 11 feet bgs.

In general, the data demonstrated that contaminated soil occurs at depth, and is most likely due to VOCs which are present in the groundwater affecting the local soil conditions. The majority of the maximum detections occur from the samples collected from approximately 11 to 13 feet bgs, which is within the saturated zone. Impacted soil is primarily concentrated in the area of the DRMO and is in general, present at depths of approximately 10 to 15 feet bgs.

This area of the DRMO was a former motor pool facility. In addition to the original UST, typical day to day operations of the motor pool, such as parts cleaning, washing or occasional spills may have impacted soil in specific areas of the site. These potential sources may be present in soil within select areas local to the DRMO facility. There were no significant areas of soil contamination identified in the wooded portion of Site 89.

1.6.1.2 Groundwater - Site 89

Groundwater in the surficial and upper portions of the Castle Hayne aquifers at Site 89 has been impacted by VOCs. Groundwater contamination in the surficial aquifer has been defined by the shallow monitoring wells which are screened at approximately 15 to 20 feet bgs. Intermediate wells have detected groundwater contamination at approximately 40 to 50 feet bgs. The intermediate wells are screened in the upper portions of the Castle Hayne aquifer, immediately above the first semi-confining layer. Figure 1-13 presents the results of the VOCs detected in groundwater samples collected from the shallow wells. Figure 1-14 provides information on the extent of VOC groundwater contamination detected in the intermediate wells at the site. The figures present results from temporary and permanent monitoring wells in which groundwater samples contained concentrations of VOCs greater than the Federal MCLs and/or the NCWQS.

As shown on Figure 1-13, the majority of the VOCs detected in samples collected from the shallow monitoring wells at Site 89 are concentrated in the area of the DRMO facility and to the south in the direction of Edwards Creek. Areas to the west and slightly north (hydraulically upgradient) of the DRMO have also been impacted, but at lower concentrations compared to down gradient locations. The shallow groundwater in the wooded area east of the DRMO and White Street Extension has not been significantly affected. Several VOCs were detected in monitoring well IR89-MW04 which exceeded the water quality standards, demonstrating that the VOC contaminant plume has migrated beyond White Street Extension at this portion of the site. However, additional sample points east of the road demonstrate that the shallow groundwater plume is mostly limited to the area beneath the DRMO.

Detections of tetrachloroethene and trichloroethene from temporary monitoring well IR89-TW13 at concentrations greater than the applicable groundwater standards indicates that VOCs have migrated as far south as Edwards Creek. Based upon these results and the presence of VOCs in surface water, it appears that Edwards Creek acts as an intercept for contaminants moving with shallow groundwater. Groundwater samples from temporary wells located further south did not detect contaminants which exceeded the water quality standards. In addition, historical analytical data from permanent monitoring wells located in the housing area shown in the southeast portion of the aerial photograph (Figure 1-13) have not detected VOCs in the groundwater. These results collectively indicate that Edwards Creek is acting as a natural barrier as the VOCs migrate south of the DRMO facility.

Figure 1-14 presents the results of the groundwater samples collected from the intermediate wells at Site 89. As shown, VOCs are present in the groundwater at the intermediate depth in the area of the DRMO and in the wooded area, east of White Street Extension. The eastern boundary of groundwater contamination at the intermediate depth has been confirmed via results of the samples collected from both temporary and permanent monitoring well clusters. Specifically, permanent well clusters IR89-MW06 and IR89-MW07 define the easternmost extent of groundwater contamination. The furthest permanent sample point east of the DRMO area is monitoring well cluster IR89-MW08 which did not detect any VOCs in the samples. Likewise, groundwater samples collected from temporary monitoring wells installed in this region of the study area did not detect any VOCs. The samples collected in the wooded portion of Site 89 have established the eastern most edge of the plume to extend approximately 1,500 feet from the suspected DRMO source area.

Permanent deep monitoring wells extending to depths of approximately 70 feet bgs were installed at monitoring well clusters IR89-MW03, MW04, MW05, MW06, MW07, and MW08. VOCs were not detected in any groundwater samples collected from deep monitoring wells. The absence of VOCs in the deep monitoring wells establishes the vertical extent of groundwater contamination to the depth of the intermediate wells (i.e., approximately 40 to 50 feet bgs).

1.6.1.3 Surface Water - Site 89

Figure 1-15 illustrates the presence of VOCs in the portion of Edwards Creek downgradient of the DRMO facility. Contaminant concentrations were relatively consistent in each of the samples obtained. The creek appears to be receiving VOC contamination via migration of the shallow groundwater. Analytical findings indicate that the creek is acting as a natural barrier, significantly limiting the migration of VOCs in the shallow groundwater further to the south.

Surface water samples collected from the discharge point of the northern drainage swale which flows from the DRMO toward Edwards Creek detected similar concentrations of VOCs as those observed from samples collected within Edwards Creek. This drainage swale was apparently constructed to alleviate drainage problems within the DRMO. Based upon observations noted during the RI, it appears that the swale almost always contains some standing water. During storm events this swale discharges significant amounts of surface water runoff to Edwards Creek. Surface water sample IR89-SW08 was collected from the drainage swale which flows into Edwards Creek from the south, just west of the northern drainage swale. This sample detected a very low concentration of one VOC, suggesting that this southern drainage swale is not another source of contamination.

The detections of VOCs in Edwards Creek and the drainage swale which borders the eastern edge of the DRMO (previously described northern drainage swale contributing to Edwards Creek), coupled with the detection of a low concentration of only tetrachloroethene in the water discharging into Edwards Creek from the south, suggest that the source of the VOC contamination impacting Edwards Creek is located in the vicinity of the DRMO. It appears that VOCs enter the stream via contaminated groundwater which provides base flow to Edwards Creek and by groundwater which is channeled directly to the stream from the northern drainage swale.

1.6.1.4 Sediment - Site 89

As shown on Figure 1-16, VOCs were detected at sediment sample stations IR89-EC-SD03, SD09, SD10, and SD11. However, the contaminants were detected most frequently at sample station IR89-EC-SC03 which is located near the discharge point of the northern drainage swale.

1.6.2 Site 93

Sampling activities at Site 93 involved the collection of soil and groundwater samples in the area of Camp Gieger local to Building TC-942. The following subsections detail the extent of site VOC contamination per media.

1.6.2.1 Soil - Site 93

Only two VOCs were detected in the soil at Site 93, including 2-butanone and acetone. Acetone was most likely introduced to the samples during laboratory analysis or during decontamination procedures used during the field program. It is not considered to be site related. The compound 2-butanone was detected in only one sample at an estimated concentration of 13J μg/kg.

In general, the analytical results demonstrated that soil at Site 93 has not been significantly impacted by organic compounds. The majority of the detections were reasonably low and most likely attributable to non-site related activities. In addition, none of the detections exceeded the Region III RBCs for residential soils.

1.6.2.2 Groundwater - Site 93

Figure 1-17 presents the locations of the VOCs detected in the shallow groundwater samples at Site 93 that were above standards. Impact to the groundwater at Site 93 is concentrated in the shallow aquifer in the area of the former UST near Building TC-942. Analytical findings indicate contaminated groundwater is confined to this area and has not migrated substantially from the original source area. In addition, low concentrations of VOCs were detected in groundwater samples collected from the intermediate wells, demonstrating that little vertical migration of the contaminants has occurred. Impact of the shallow groundwater was evident south and west of the site, but decreased readily in these directions. The detected concentrations that were below the applicable groundwater standards are not presented on Figure 1-17.

1.6.3 Summary of VOC Results

Figure 1-18 shows the estimated boundary of shallow groundwater contamination for OU No. 16, including both Sites 89 and 93. This figure is presented to illustrate that two separate contaminant plumes are present at OU No. 16, one at Site 89 and one at Site 93. Although contaminants are similar at both sites, the data indicate that the plumes are a result of two different source areas. One being the DRMO facility at Site 89 and the other being the former UST located near Building TC-942 at Site 93. The contaminant plumes have been defined separately following evaluation of the results from the site-specific monitoring well installations.

1.7 Human Health Risk Assessment

A human health risk assessment was completed within the RI for Sites 89 and 93. Results of the Phase I investigation, including groundwater, surface water, and sediment results, were used in this evaluation of risk. Similarly, the results of the groundwater and subsurface soil samples collected during the Phase II investigation were also used to evaluate human health risks. As previously noted, all four media were investigated at Site 89, while only subsurface soil and groundwater were investigated at Site 93.

The following sections present an overview of the analytical data obtained for each environmental medium during the RI and the subsequent retention or elimination of contaminants of potential concern (COPCs). The primary criterion used in selecting a chemical as a COPC at each site was based upon the comparison of the maximum detected sample concentration to the USEPA Region III RBCs (USEPA, 1997). In conjunction with these concentration comparisons, an evaluation of laboratory contaminants, chemical prevalence, and site history was conducted. Furthermore, calcium, magnesium, potassium, and sodium were detected in almost every sample, regardless of the medium; however, these constituents were considered to be essential nutrients and were therefore, not retained as COPCs in any medium under investigation at Sites 89 or 93.

Table 1-1 presents a detailed summary of COPCs identified in each environmental medium that was sampled at Sites 89 and 93. The "•" on the table represents the contaminants detected in the media at the sites, while the "X" represents a COPC selected for the human health risk assessment. Information related to the selection of the COPCs can be found in greater detail within Section 6.0 of the RI (Baker, 1997). A discussion of the COPCs selected for each site is presented below per media.

1.7.1 Site 89

1.7.1.1 Subsurface Soil

Twenty-six subsurface soil samples were analyzed for VOCs. The following VOCs were detected at maximum concentrations less than their respective residential soil RBCs: 1,1,2,2-tetrachloroethane, 1,2-dichloroethene (total), 2-butanone, acetone, benzene, carbon disulfide, tetrachloroethene, toluene, and trichloroethene. Therefore, these VOCs were not retained as Site 89 subsurface soil COPCs.

Twenty-six subsurface soil samples were analyzed for SVOCs. Bis(2-ethylhexyl)phthalate, fluoranthene, and pyrene were detected at maximum concentrations less than their respective residential soil RBCs. These SVOCs were, therefore, not retained as Site 89 subsurface soil COPCs.

Five subsurface soil samples were analyzed for pesticides and PCBs. 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT were detected at concentrations less than corresponding residential soil RBCs. There were no PCBs detected in the subsurface soil samples. Therefore, no pesticides or PCBs were retained as Site 89 subsurface soil COPCs.

Twenty-six subsurface soil samples were analyzed for inorganic analytes. Inorganics were detected in every sample. Aluminum, arsenic, beryllium and iron were detected in almost every sample. The maximum detected concentrations of these four analytes exceeded their respective background levels and residential soil RBCs. Consequently, aluminum, arsenic, beryllium, and iron were retained as Site 89 subsurface soil COPCs.

1.7.1.2 Groundwater

A maximum of 55 groundwater samples were analyzed for VOCs. 1,1,1-Trichloroethane and toluene were detected at maximum concentrations less than corresponding tap water RBCs and were not retained as COPCs. Chloroform was detected at in 26 out of 54 samples at a maximum concentration that exceeded its tap water RBC. However, chloroform was also detected in blanks at a concentration of 12 µg/L. Therefore, chloroform was not retained as a COPC. 1,1,2,2-Tetrachloroethane, 1,1,2-trichloroethane, 1,1-dichloroethene, 1,2-dichloroethene (total), cis-1,2-dichloroethene, tetrachloroethene, trans-1,2-dichloroethene, trichloroethene, and vinyl chloride were all detected at maximum concentrations that exceeded their respective tap water RBCs. Therefore, these VOCs were retained as Site 89 groundwater COPCs.

Fourteen groundwater samples were analyzed for SVOCs. Bis(2-ethylhexyl)phthalate was detected in four out of fourteen samples at maximum concentration that exceeded its tap water RBCs. However, it was detected in blanks at a concentration of 120 µg/L. Therefore, bis(2-ethylhexyl)phthalate was not retained as a Site 89 COPC.

Two groundwater samples were analyzed for pesticides and PCBs. There were no pesticides or PCBs detected in the groundwater samples. Therefore, no pesticides or PCBs were retained as Site 89 groundwater COPCs.

Fourteen groundwater samples were analyzed for inorganic analytes. Inorganics were detected in every sample. Antimony, iron, and manganese were detected frequently. The maximum detected concentrations of these three analytes exceeded their respective tap water RBCs. Consequently, antimony, iron, and manganese were retained as Site 89 groundwater COPCs.

1.7.1.3 Surface Water

A maximum of eleven surface water samples were analyzed for VOCs. Chloroform was detected at a maximum concentration less than its respective NCWQS and was not retained as a surface water COPC. 1,1,2,2-Tetrachloroethane, was detected at a maximum detected concentration that exceeded its respective NCWQS and was retained as a COPC. 1,2-Dichloroethene (total), cis-1,2-dichloroethene, tetrachloroethene, trans-1,2-dichloroethene, trichloroethene, and vinyl chloride were detected at maximum concentrations below corresponding NCWQS. However, these VOCs were re-included as COPCs based on their toxicity and the fact that they are site related.

There were no SVOCs detected in the five surface water samples. Therefore, no SVOCs were retained as Site 89 surface water COPCs.

There were no pesticides or PCBs detected in the five surface water samples. Therefore, no pesticides or PCBs were retained as Site 89 surface water COPCs.

Inorganics were detected in each of the five surface water samples analyzed. Aluminum, copper, iron, and vanadium were detected frequently. The maximum detected concentrations of these four analytes exceeded their respective NCWQS. Consequently, aluminum, copper, iron, and vanadium were retained as Site 89 surface water COPCs.

1.7.1.4 Sediment

A maximum of sixteen sediment samples were analyzed for VOCs. Several VOCs were detected at maximum concentrations less than corresponding residential soil RBCs. These VOCs were not retained as Site 89 sediment COPCs.

Ten sediment samples were analyzed for SVOCs. Four noncarcinogenic PAHs were detected at maximum concentrations less than their respective residential soil RBCs and were not retained as sediment COPCs. Also, bis(2-ethylhexyl)phthalate was detected at a maximum concentration less than its residential soil RBC and was not retained as a sediment COPC. Six carcinogenic PAHs were detected in Site 89 sediment samples. Of these six, benzo(a)pyrene was detected at a maximum concentration that exceeded its residential soil RBC and was therefore, retained as a Site 89 sediment COPC.

Two sediment samples were analyzed for pesticides and PCBs. 4,4'-DDD, 4,4'-DDE, 4,4'-DDT, alpha-chlordane, and gamma-chlordane were detected at maximum concentrations less than corresponding residential soil RBCs. Therefore, these pesticides were not retained as Site 89 sediment COPCs. There were no PCBs detected in the sediment samples. Therefore, no PCBs were retained as Site 89 sediment COPCs.

Ten sediment samples were analyzed for inorganic analytes. Inorganics were detected in every sample. Aluminum, arsenic, beryllium and iron were detected in almost every sample. The maximum detected concentrations of these four analytes exceeded their respective residential soil RBCs. Consequently, aluminum, arsenic, beryllium, and iron were retained as Site 89 sediment COPCs.

1.7.2 Site 93

1.7.2.1 Subsurface Soil

Twenty-two subsurface soil samples were analyzed for VOCs. The following VOCs were detected at maximum concentrations less than their respective residential soil RBCs: 2-butanone and acetone. Therefore, these VOCs were not retained as Site 93 subsurface soil COPCs.

Twenty-two subsurface soil samples were analyzed for SVOCs. Bis(2-ethylhexyl)phthalate was detected at a maximum concentration less than its residential soil RBC. This SVOC was, therefore, not retained as a Site 93 subsurface soil COPC.

Benzo(a)pyrene was detected at a concentration that exceeded its residential soil RBC and was therefore, retained as a subsurface soil COPC.

Three subsurface soil samples were analyzed for pesticides and PCBs. 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT were detected at concentrations less than corresponding residential soil RBCs. There were no PCBs detected in the subsurface soil samples. Therefore, no pesticides or PCBs were retained as Site 93 subsurface soil COPCs.

Twenty-two subsurface soil samples were analyzed for inorganic analytes. Inorganics were detected in every sample. Aluminum, arsenic, beryllium, iron, and vanadium were detected in almost every sample. The maximum detected concentrations of these five analytes exceeded their respective background levels and residential soil RBCs. Consequently, aluminum, arsenic, beryllium, iron, and vanadium were retained as Site 93 subsurface soil COPCs.

1.7.2.2 Groundwater

A maximum of 26 groundwater samples were analyzed for VOCs. Chloroform was detected at in 7 out of 26 samples at a maximum concentration that exceeded its tap water RBC. However, chloroform was also detected in blanks at a concentration of 12 µg/L. Therefore, chloroform was not retained as a COPC. 1,2-Dichloroethene (total), cis-1,2-dichloroethene, tetrachloroethene, trans-1,2-dichloroethene, and trichloroethene were all detected at maximum concentrations that exceeded their respective tap water RBCs. Therefore, these five VOCs were retained as Site 93 groundwater COPCs.

Eleven groundwater samples were analyzed for SVOCs. Bis(2-ethylhexyl)phthalate was detected in four out of eleven samples at maximum concentration that exceeded its tap water RBC. However, it was detected in blanks at a concentration of 120 µg/L. Therefore, bis(2-ethylhexyl)phthalate was not retrained as a Site 93 COPC. Naphthalene was detected at a maximum concentration less than its tap water RBC and was not retained as a Site 93 groundwater COPC.

Two groundwater samples were analyzed for pesticides and PCBs. There were no pesticides or PCBs detected in the groundwater samples. Therefore, no pesticides or PCBs were retained as Site 93 groundwater COPCs.

Eleven groundwater samples were analyzed for inorganic analytes. Inorganics were detected in every sample. Antimony, arsenic, iron, lead, and manganese were detected frequently. The maximum detected concentrations of these five analytes exceeded their respective tap water RBCs. Consequently, antimony, arsenic, iron, lead, and manganese were retained as Site 93 groundwater COPCs.

1.7.3 Exposure Assessment

For both sites, each medium was assessed to identify potential risks to human receptors. A conceptual site model of potential sources, migration pathways and human receptors was developed to encompass all current and future routes for potential exposure at Sites 89 and 93. Inputs to the conceptual model included qualitative descriptions of current and future land use patterns in the vicinity of the sites. The following list of receptors was evaluated for the quantitative health risk analysis:

- Current on-site residents (child [1-6 years] and adult)
- Future on-site residents (child [1-6 years] and adult)
- Future construction workers

Available toxicological information indicates that many COPCs have both carcinogenic and noncarcinogenic health effects in humans and/or experimental animals. Although COPCs may cause adverse health and environmental effects, dose-response relationships and exposure must be evaluated before receptor risk can be determined. An important component in risk assessment is the relationship between the dose of a compound and the potential for adverse health effects resulting from the exposure to that dose. Dose-response relationships provide a means by which potential public health impacts may be evaluated.

Estimated incremental lifetime cancer risks (ICRs) and hazard indices (HIs) were computed within the RI for the identified receptor groups. Quantitative risk calculations for carcinogenic compounds estimate ICR levels for individuals in a given population. An ICR of $1x10^{-6}$, for example, indicates that, within a lifetime of exposure to site-specific contamination, one additional case of cancer may occur per one million exposed individuals. A cancer risk range of $1x10^{-6}$ to $1x10^{-4}$ is used to evaluate calculated ICR levels. Any ICR value within this range is considered "acceptable"; an ICR greater than $1x10^{-4}$ denotes an existing cancer risk. A noncarcinogenic risk (HI = 1.0) is used as an upper limit to which calculated HI values are compared. Any HI exceeding 1.0 indicates an existing noncarcinogenic risk (USEPA 1989). A summary of the ICRs and HIs calculated for each potential receptor at each site is presented below.

1.7.3.1 Site 89

Current Residential Child

The current residential child was evaluated for potential noncarcinogenic and carcinogenic risk from exposure to surface water and sediment. The noncarcinogenic and carcinogenic risks for surface water (i.e., HI=0.12 and ICR=$1.6x10^{-5}$) and sediment (i.e., HI=0.06 and ICR=$3.0x10^{-6}$) were within the acceptable risk levels (i.e., HI<1 and $1x10^{-6}<ICR<1x10^{-4}$).

Current Residential Adult

In the current residential scenario, a resident adult receptor was evaluated for potential risk from exposure to site surface water and sediment. The potential noncarcinogenic and carcinogenic risks from exposure to the surface water (i.e., HI=0.04 and ICR=$4.7x10^{-6}$) and sediment (i.e., HI=0.01 and ICR=$5.3x10^{-7}$) were within acceptable risk levels.

Future Residential Child

The future residential child receptor was evaluated for potential risk from exposure to groundwater, surface water, and sediment in the future scenario. The potential noncarcinogenic and carcinogenic risks from exposure to the surface water (i.e., HI=0.12 and ICR=$2.3x10^{-5}$) and sediment (i.e., HI=0.06 and ICR=$4.4x10^{-6}$) were within acceptable risk levels.

In the groundwater exposure scenario, there are potential carcinogenic and noncarcinogenic risks from ingestion for the child receptor. The total groundwater carcinogenic risk level was $1.4x10^{-3}$. This was due primarily to the groundwater ingestion pathway (ICR=$1.4x10^{-3}$). Primarily, vinyl chloride (95 percent of the ingestion pathway) in groundwater contributed to this risk.

The total groundwater noncarcinogenic risk level was 28. This was due primarily to the groundwater ingestion pathway (HI=27). Trichloroethene, 1,2-dichloroethene (total), cis-1,2-dichloroethene, and iron contributed 30, 23, 20, and 16 percent (ingestion pathway), respectively, of this elevated noncarcinogenic risk.

Future Residential Adult

The future residential adult receptor was evaluated for potential risk from exposure to groundwater, surface water, and sediment in the future scenario. The potential noncarcinogenic and carcinogenic risks from exposure to the surface water (i.e., HI=0.04 and ICR=$3.7x10^{-5}$) and sediment (i.e., HI=0.01 and ICR=$4.0x10^{-6}$) were within acceptable risk levels.

In the groundwater exposure scenario, there are potential carcinogenic and noncarcinogenic risks from ingestion for the adult receptor. The total groundwater carcinogenic risk level was $3.1x10^{-3}$. This was due primarily to the groundwater ingestion pathway (ICR=$3.0x10^{-3}$). Primarily, vinyl chloride (95 percent of the ingestion pathway) in groundwater contributed to this risk.

The total groundwater noncarcinogenic risk level was 12.5. This was due primarily to the groundwater ingestion pathway (HI=12). Trichloroethene, 1,2-dichloroethene (total), cis-1,2-dichloroethene, and iron contributed 30, 23, 20, and 16 percent (ingestion pathway), respectively, of this elevated noncarcinogenic risk.

Future Construction Workers

The future construction worker was evaluated for potential noncarcinogenic and carcinogenic risk from exposure to subsurface soil in the future scenario. The noncarcinogenic and carcinogenic risks (i.e., HI=0.14 and ICR=$1.9x10^{-7}$) from exposure to subsurface soil were below the acceptable risk levels.

1.7.3.2 Site 93

Future Residential Child

The future residential child receptor was evaluated for potential risk from exposure to groundwater in the future scenario. The potential carcinogenic risk from groundwater (ICR=$5.9x10^{-5}$) was within the acceptable risk range. In the groundwater exposure scenario, there are potential noncarcinogenic risks from ingestion for the child receptor. The total groundwater noncarcinogenic risk level (HI) was 6.4. This was due primarily to the groundwater ingestion pathway (HI=6.2). Manganese and cis-1,2-dichloroethene contributed 19 and 18 percent (ingestion pathway), respectively, of this elevated noncarcinogenic risk.

Future Residential Adult

The future residential adult receptor was evaluated for potential risk from exposure to groundwater in the future scenario. In the groundwater exposure scenario, there are potential carcinogenic and noncarcinogenic risks from ingestion for the adult receptor. The total groundwater carcinogenic risk level was $1.3x10^{-4}$. This was due primarily to the groundwater ingestion pathway (ICR=$1.2x10^{-4}$). Primarily, arsenic and tetrachloroethene (63 and 33 percent of the ingestion pathway, respectively) in groundwater contributed to this risk.

The total groundwater noncarcinogenic risk level (HI) was 2.8. This was due primarily to the groundwater ingestion pathway (HI=2.7). Manganese and cis-1,2-dichloroethene contributed 19 and 18 percent (ingestion pathway), respectively, of this elevated noncarcinogenic risk.

Future Construction Workers

The future construction worker was evaluated for potential noncarcinogenic and carcinogenic risk from exposure to subsurface soil in the future case. The noncarcinogenic and carcinogenic risks (i.e., HI=0.2 and ICR=3.2×10^{-7}) from exposure to subsurface soil were below the acceptable risk levels.

1.7.4 Lead Uptake/Biokinetic (UBK) Model Results

Lead was detected in the groundwater at Site 93 at a maximum detected concentrations of 164 µg/L. The USEPA lead UBK model was used to determine if exposure to site media would result in unacceptable levels in younger children upon exposure to groundwater at Site 93. The maximum detected concentration of lead was used in the model. Blood lead levels are considered unacceptable when a greater than five percent probability exists that the blood lead levels will exceed 10 µg/dl. The UBK model results indicated a 69.83 percent probability of the blood lead levels exceeding 10 µg/dl, which exceeds acceptable levels.

1.7.5 Iron

Although the studies that prompted the recent addition of a RBC value for iron are provisional only and have not undergone formal review by the USEPA, iron was given a RBC value and toxicity values with which to evaluate potential human health risks. However, iron is still considered an essential nutrient. For these reasons, the selection of iron as a COPC for evaluation in human health risk assessments is associated with some uncertainty. Through the evaluation of iron in the risk assessment, a conservative approach is taken and potential toxic effects are not expected to be underestimated.

1.8 Ecological Risk Assessment

During the RI, a focused ecological risk screening was conducted on the aquatic environment at OU No. 16 (Site 89). The objectives included the desire to determine whether past site operations at Site 89 have caused unacceptable risks to aquatic receptors inhabiting the site, and to determine whether additional ecological studies were warranted at this site.

The habitat assessed in this ecological risk screening was the aquatic habitat of Edwards Creek, which is a freshwater headwater to the estuarine New River. Edwards Creek is classified as a nutrient sensitive, high water quality, saltwater (SC HQW NSW) (NC DENR, 1994). However, it is acknowledged that the segment of Edwards Creek sampled for this investigation is a freshwater habitat; therefore, freshwater screening values were used to assess the aquatic habitat.

Surface water and sediment samples collected from Edwards Creek (upstream, downstream, and adjacent to Site 89) were analyzed for TCL organics and TAL inorganics. The surface water and sediment samples were collected during the Phase I RI. Additional surface water samples were collected during the Phase II RI and analyzed for chloride ion content.

The screening level assessment was conducted only on the aquatic habitat at Site 89. The terrestrial habitat was not evaluated at the site because the primary contaminated media are groundwater and subsurface soil. Therefore, the surface water and sediment were evaluated to determine potential impacts from groundwater seepage into the surface water body.

The ultimate receptor to contaminants detected in Edwards Creek is the New River. The following subsections summarize the results of the ecological risk assessment.

1.8.1 Surface Water

The surface water concentrations detected in Edwards Creek were evaluated by a comparison to benchmark screening values for the protection of aquatic species. Quotient indices (QIs) greater than one were calculated for aluminum, iron, and lead. All of the QIs were below five. As indicated by the elevated QI values, concentrations of aluminum, iron, and lead pose a slight potential risk to aquatic receptors.

In addition, surface water concentrations of 1,2-DCE (cis- and total), TCE, vinyl chloride, antimony, barium, and magnesium also potentially pose a risk to the aquatic environment. There are no screening values available to assess the detected concentrations.

The highest VOC concentrations were detected at the surface water stations adjacent to the site (IR89-EC-SW02 and IR89-EC-SW03). However, the VOCs detected are not likely to bioconcentrate in the aquatic food chain.

1.8.2 Sediment

The sediment concentrations detected in Edwards Creek were evaluated by a comparison to benchmark screening values for the protection of aquatic species. Moderate QIs (10 to 70 times the screening value) were calculated for benzo(a)pyrene, DDD, DDE, and DDT (Region IV QIs). QIs between one and ten were calculated for 1,1,2,2-tetrachloroethane, TCE, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, alpha-chlordane, gamma-chlordane, cadmium, copper, and lead.

The elevated Region IV QI was primarily a result of sediment concentrations of the pesticides and benzo(a)pyrene (one sample exceeded screening levels). The elevated Ecotox QI was primarily the result of sediment concentrations of DDT, along with 1,1,2,2-tetrachloroethane, TCE, benzo(a)pyrene, copper, and secondarily from concentrations of fluoranthene, cadmium, and lead. As indicated by the elevated QIs, concentrations of pesticides, 1,1,2,2-tetrachloroethane, TCE, benzo(a)pyrene, fluoranthene, cadmium, copper, and lead may pose a risk to aquatic receptors. In addition, concentrations of DCE, 1,1,2-trichloroethane, vinyl chloride, the benzofluoranthenes, benzo(g,h,i)perylene, bis(2-ethylhexyl)phthalate, indeno(1,2,3-cd)pyrene, aluminum, barium, beryllium, iron, manganese and vanadium may also pose a risk. However, there are no screening values available to assess the detected concentrations.

The VOCs in sediment were primarily detected at one station adjacent to Site 89 (IR89-EC- SD03). The VOC concentrations detected in the shallow sediment were higher than the concentrations detected in the deeper sediments, with the exception of vinyl chloride. There were no VOCs detected in the sediment collected downstream of the site. The VOCs detected are not likely to bioconcentrate in the aquatic food chain.

The SVOCs in the sediment were detected at one station immediately downstream of the railroad tracks (IR89-EC-SD04). Pesticides were only analyzed at one station (two depths) in Edwards Creek (IR89-EC-SD05). The pesticide concentrations were higher in the deeper sediment collected. The majority of the inorganic ecological COPCs were detected in the deep sediment sample collected immediately downstream of the site (IR89-EC-SD04). It is noted that the highest cadmium concentration was detected in the shallow sediment collected upstream of Site 89 (IR89-EC-SD01).

1.9 RI Conclusions

The following conclusions for OU No. 16 (Sites 89 and 93) were presented in the RI and were based on the results of the site investigations, and the human and ecological risk assessments.

- Soil at Site 89 has been impacted mainly by VOCs. The majority of the detections of volatile compounds occurred at monitoring well clusters IR89-MW03 and IR89-MW05 both of which are located in the western portion of Site 89. Impact to the soil is also apparent at monitoring well location IR89-MW05 located just west of the DRMO facility at the end of F Street. Monitoring well IR89-MW04, located in the wooded area, immediately east of White Street Extension, noted one detection of 1,2-dichloroethene (total). There were no significant areas of soil contamination identified in the wooded portion west of the DRMO area.

- In general, the data demonstrated that contaminated soil at Site 89 occurs at depth, and is most likely due to VOCs which are present in the groundwater affecting the local soil conditions. The majority of the maximum detections occur from the samples collected from approximately 11 to 13 feet bgs, which is within the saturated zone. Impacted soil is primarily concentrated in the area of the DRMO and is in general, present at depths of approximately 10 to 15 feet bgs.

- Groundwater in the surficial and upper portions of the Castle Hayne aquifers at Site 89 has been impacted by volatile contamination. This includes groundwater to depths of approximately 40 to 50 feet bgs. Groundwater contamination in the surficial aquifer has been defined by the shallow monitoring wells which are screened at approximately 15 to 20 feet bgs. Intermediate wells have detected groundwater contamination at approximately 40 to 50 feet bgs. The intermediate wells are screened in the upper portions of the Castle Hayne aquifer, immediately above the first semi-confining layer.

  The majority of the volatile contamination detected was in samples collected from the shallow monitoring wells at Site 89 that are located in the area of the DRMO facility and to the south in the direction of Edwards Creek. Areas to the west and slightly north (hydraulically upgradient) of the DRMO have also been impacted, but at lower concentrations. The shallow groundwater in the wooded area east of the DRMO and White Street Extension has not been significantly effected. Several volatile compounds were detected in monitoring well IR89-MW04 which exceeded the water quality standards, demonstrating that the contaminant plume has migrated beyond White Street Extension at this portion of the site. However additional sample points east of the road demonstrate that the shallow groundwater plume is mostly limited to the area beneath the DRMO.

Tetrachloroethene and trichloroethene were detected in temporary monitoring well IR89-TW13, which is just north of Edwards Creek, at concentrations greater than the applicable groundwater standards. This data indicates that VOCs have migrated as far south as Edwards Creek. Based upon these results and the presence of volatile contamination in surface water, it appears that Edwards Creek acts as a intercept for contaminants moving with shallow groundwater. Groundwater samples from temporary wells located further south did not detect contaminants which exceeded the water quality standards. In addition, historical analytical data from permanent monitoring wells located in the housing area south of Edwards Creek have not detected VOCs in the groundwater. These analytical results indicate that Edwards Creek is acting as a natural barrier for the majority of volatile contamination migrating south of the DRMO facility.

Volatile contamination was not detected in any groundwater samples collected from deep monitoring wells. The absence of volatile contamination in the deep monitoring wells establishes the vertical extent of groundwater contamination to the depth of the intermediate wells (i.e., approximately 40 to 50 feet bgs).

- The detection of volatile compounds in the surface water samples collected from Edwards Creek and the drainage swale which borders the eastern edge of the DRMO, coupled with the detection of a low concentration of only tetrachloroethene in the water discharging into Edwards Creek from the south, suggest that the source of the volatile contamination impacting Edwards Creek is located in the vicinity of the DRMO. It appears that volatile contamination enters the stream by contaminated groundwater which provides base flow to Edwards Creek and by groundwater which is channeled directly to the stream from the northern drainage swale.

- In general, the analytical results demonstrate that soil at Site 93 has not been significantly impacted by organic compounds. The majority of the detections are reasonably low and are most likely attributable to non-site related activities. In addition, none of the detections exceeded the RBCs for residential soils.

- Impact to the groundwater at Site 93 is concentrated in the shallow aquifer in the area of the former UST near Building TC-942. Analytical findings indicate contaminated groundwater is confined to this area and has not migrated substantially from the original source area. In addition, low concentrations of VOCs were detected in groundwater samples collected from the intermediate wells, demonstrating that very little vertical migration of the contaminants has occurred. Impact of the shallow groundwater was evident south and west of the site, but decreased readily in these directions.

- Although groundwater contaminants are similar at both sites, the data indicate that the groundwater plumes are a result of two different source areas. One being the

DRMO facility at Site 89 and the other being the former UST located near Building TC-942 at Site 93.

In general, the areal extent of the VOC-contaminated groundwater plume at Site 89 is significantly larger. In addition, contaminants at Site 89 have migrated vertically to the upper portions of the Castle Hayne aquifer. Vertical migration of groundwater contaminants at Site 93 is insignificant.

- In the current scenario evaluated for the human health risk assessment, the following receptors were assessed: adult and child residents. Receptor exposure to surface water and sediment at Site 89 was examined. The risks calculated for all exposure pathways for the current on-site residents were within acceptable risk ranges.

- In the Site 89 groundwater exposure scenario, there are residential potential carcinogenic and noncarcinogenic risks from ingestion for the future residential child receptor. The total groundwater carcinogenic risk level for the future child resident at Site 89 was $1.4x10^{-3}$. This was due primarily to the groundwater detections of vinyl chloride (95 percent of the ingestion pathway) in groundwater. The total groundwater noncarcinogenic risk level was 28. This was due primarily to the groundwater ingestion pathway with trichloroethene, 1,2-dichloroethene (total), cis-1,2-dichloroethene, and iron contributing 30, 23, 20, and 16 percent, respectively, of this elevated noncarcinogenic risk.

  In the Site 89 groundwater exposure scenario, there are potential carcinogenic and noncarcinogenic risks from ingestion for the future residential adult receptor. The total groundwater carcinogenic risk level for the future adult resident at Site 89 was $3.1x10^{-3}$. This risk was due primarily to the groundwater ingestion pathway with vinyl chloride (95 percent of the ingestion pathway) in groundwater contributing to this risk. The total groundwater noncarcinogenic risk level was 12.5. This was due primarily to the groundwater ingestion pathway with trichloroethene, 1,2-dichloroethene (total), cis-1,2-dichloroethene, and iron contributing 30, 23, 20, and 16 percent, respectively, of this elevated noncarcinogenic risk.

- In the Site 93 groundwater exposure scenario, there are potential noncarcinogenic risks from ingestion for the future residential child receptor. The total groundwater noncarcinogenic risk level was 6.4. This risk was due primarily to the groundwater ingestion pathway with manganese and cis-1,2-dichloroethene contributed 19 and 18 percent, respectively, of this elevated noncarcinogenic risk.

  In the Site 93 groundwater exposure scenario, there are potential carcinogenic and noncarcinogenic risks from ingestion for the residential adult receptor. The total groundwater carcinogenic risk level was $1.3x10^{-4}$, and was due primarily to the groundwater ingestion pathway. Primarily, arsenic and tetrachloroethene (63 and 33 percent of the ingestion pathway, respectively) in groundwater contributed to this risk. The total groundwater noncarcinogenic risk level for the future residential adult at Site 93 was 2.8. This was due primarily to the groundwater ingestion pathway with manganese and cis-1,2-dichloroethene contributing 19 and 18 percent, respectively, of this elevated noncarcinogenic risk.

- The surface water concentrations detected in Edwards Creek were evaluated by a comparison to benchmark screening values for the protection of aquatic species. QIs greater than one were calculated for aluminum, iron, and lead. All of the QIs were below five.

- As indicated by the elevated QIs, concentrations of pesticides, 1,1,2,2-tetrachloroethane, trichloroethene, benzo(a)pyrene, fluoranthene, cadmium, copper, and lead detected in sediment samples collected from Edwards Creek may pose a risk to aquatic receptors. In addition, concentrations of dichloroethene, 1,1,2-trichloroethane, vinyl chloride, the benzofluoranthenes, benzo(g,h,i)perylene, bis(2-ethylhexyl)phthalate, indeno(1,2,3-cd)pyrene, aluminum, barium, beryllium, iron, manganese and vanadium may also pose an aquatic risk. However, there are no screening values available to assess the detected concentrations.

  The volatile contaminants in sediment collected from Edwards Creek were primarily detected at one station adjacent to Site 89 (IR89-EC- SD03). The volatile contaminant concentrations detected in the shallow sediment were higher than the concentrations detected in the deeper sediments, with the exception of vinyl chloride. There were no VOCs detected in the sediment collected downstream of the site. The VOCs detected are not likely to bioconcentrate in the aquatic food chain.

1.10 References

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SECTION 1.0 TABLE

TABLE 1-1

SUMMARY OF COPCs IN ENVIRONMENTAL MEDIA OF CONCERN
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB, CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

	Site 89								Site 93			
Contaminant	Subsurface Soil		Groundwater		Surface Water		Sediment		Subsurface Soil		Groundwater	
Volatiles												
Acetone	●								●			
Carbon disulfide	●											
Chloroform			●		●						●	
1,1-Dichloroethene			●	X			●					
cis-1,2-Dichloroethene			●	X	●	X	●				●	X
trans-1,2-Dichloroethene			●	X	●	X	●				●	X
1,2-Dichloroethene (total)	●		●	X	●	X	●				●	X
2-Butanone	●								●			
Vinyl Chloride			●	X	●	X	●					
1,1,2-Trichloroethane			●	X			●					
Trichloroethene	●		●	X	●	X	●				●	X
1,1,2,2-Tetrachloroethane	●		●	X	●	X	●					
Tetrachloroethene	●		●	X	●	X					●	X
Toluene	●		●				●					
Benzene	●											
1,1,1-Trichloroethane			●									
Semivolatiles												
Naphthalene											●	
Phenanthrene							●					
Fluoranthene	●						●					
Pyrene	●						●					
Benzo(a)anthracene							●					
Chrysene							●					
bis(2-Ethylhexyl)phthalate	●		●				●		●		●	

TABLE 1-1 (Continued)

SUMMARY OF COPCs IN ENVIRONMENTAL MEDIA OF CONCERN
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Contaminant	Site 89								Site 93			
	Subsurface Soil		Groundwater		Surface Water		Sediment		Subsurface Soil		Groundwater	
Benzo(b)fluoranthene							●					
Benzo(k)fluoranthene							●					
Benzo(a)pyrene							●	X	●	X		
Benzo(g,h,i)perylene							●					
Indeno(1,2,3-cd)pyrene							●					
Pesticides/PCBs												
4,4'-DDE	●						●		●			
4,4'-DDD	●						●		●			
4,4'-DDT	●						●		●			
Alpha Chlordane							●					
Gamma Chlordane							●					
Metals												
Aluminum	●	X			●	X	●	X	●	X	●	
Antimony	●		●	X	●				●		●	X
Arsenic	●	X					●	X	●	X	●	X
Barium	●		●		●		●		●		●	
Beryllium	●	X					●	X	●	X		
Cadmium	●						●		●		●	
Calcium	●		●		●		●		●		●	
Chromium	●		●		●		●		●		●	
Cobalt	●								●		●	
Copper	●				●	X	●		●		●	
Iron	●	X	●	X	●	X	●	X	●	X	●	X
Lead	●				●		●		●		●	X
Magnesium	●		●		●		●		●		●	

TABLE 1-1 (Continued)

SUMMARY OF COPCs IN ENVIRONMENTAL MEDIA OF CONCERN
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

	Site 89								Site 93			
Contaminant	Subsurface Soil		Groundwater		Surface Water		Sediment		Subsurface Soil		Groundwater	
Manganese	●		●	X	●		●		●		●	X
Mercury							●					
Nickel	●		●				●		●		●	
Potassium	●		●		●				●		●	
Selenium	●		●						●		●	
Silver	●								●			
Sodium	●		●		●		●		●		●	
Vanadium	●		●		●	X	●		●	X	●	
Zinc	●				●		●		●		●	

Notes:

● = Detected in media; compared to relevant criteria and standards.
X = Selected as a COPC for human health risk assessment.

SECTION 1.0 FIGURES

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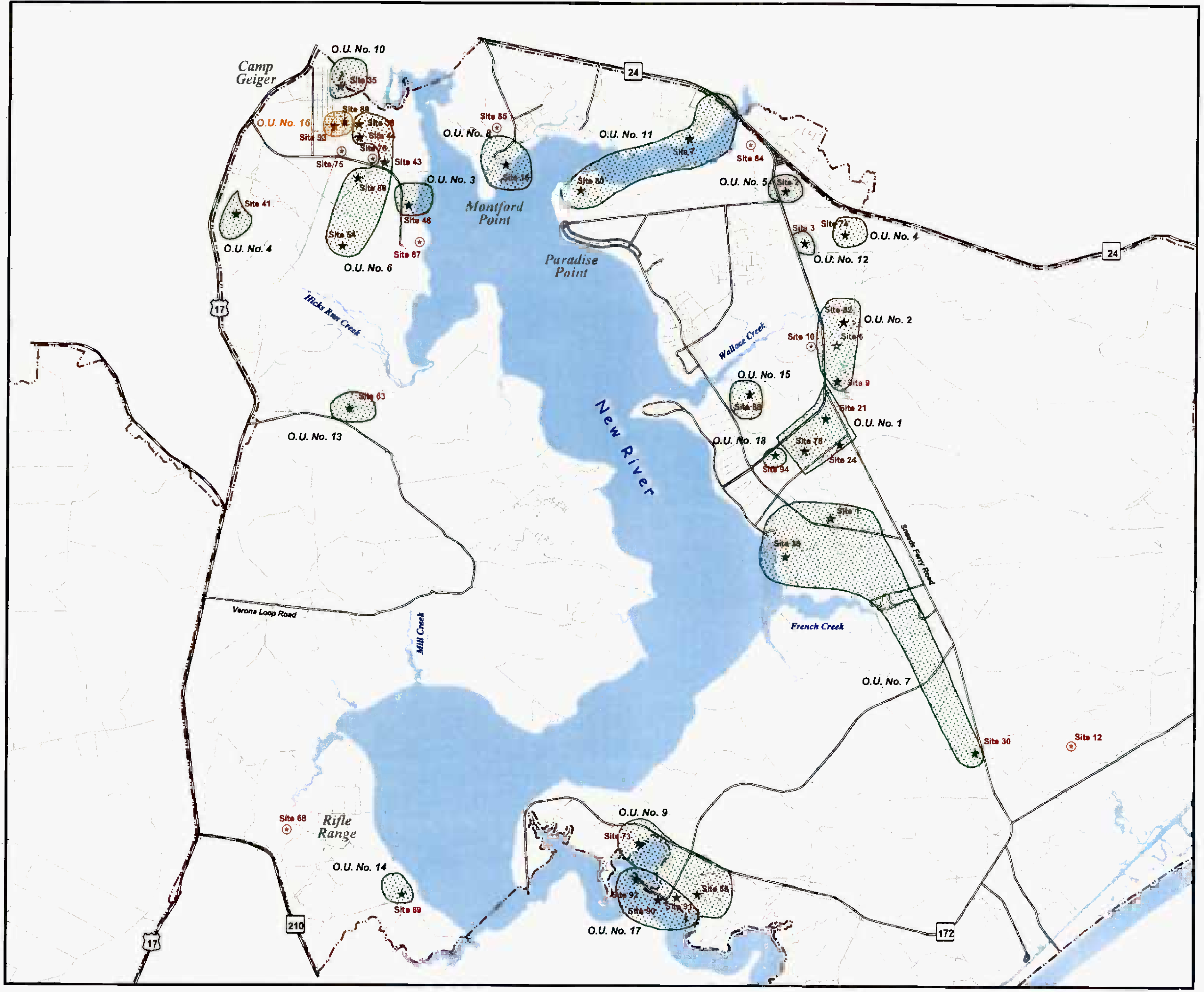


LEGEND

★ Remedial Investigation Site

⊛ Pre-Remedial Investigation Site

▨ Operable Unit Boundary

▨ Operable Unit No. 16 Boundary

Secondary Highway

Primary Highway

Light Duty Road

Camp Lejeune Boundary

N
W E
S

Scale

4000 0 4000 8000 12000 Feet

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

OPERABLE UNITS and SITE LOCATIONS
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 1

LEGEND

- DRMO Fence Line
- Edwards Creek with Flow Direction
- Approximate Site Boundary

Scale

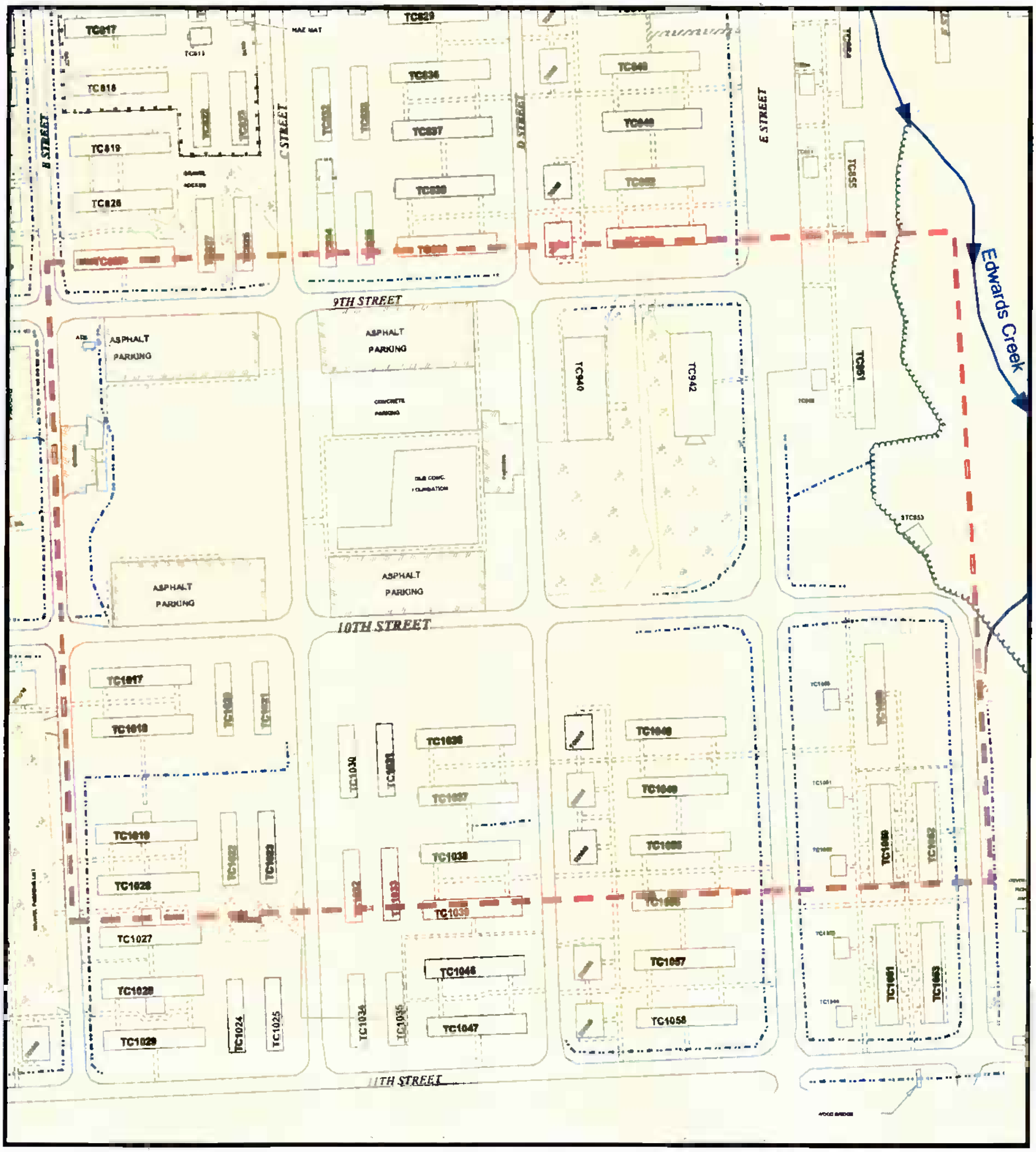
300 0 300 600 Feet

**MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA**

SITE PLAN
OPERABLE UNIT NO. 16 (SITE 89)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 2

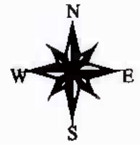


LEGEND

	Swale
	Edwards Creek with Flow Direction
	Approximate Site Boundary

Scale

100 0 100 200 300 400 Feet

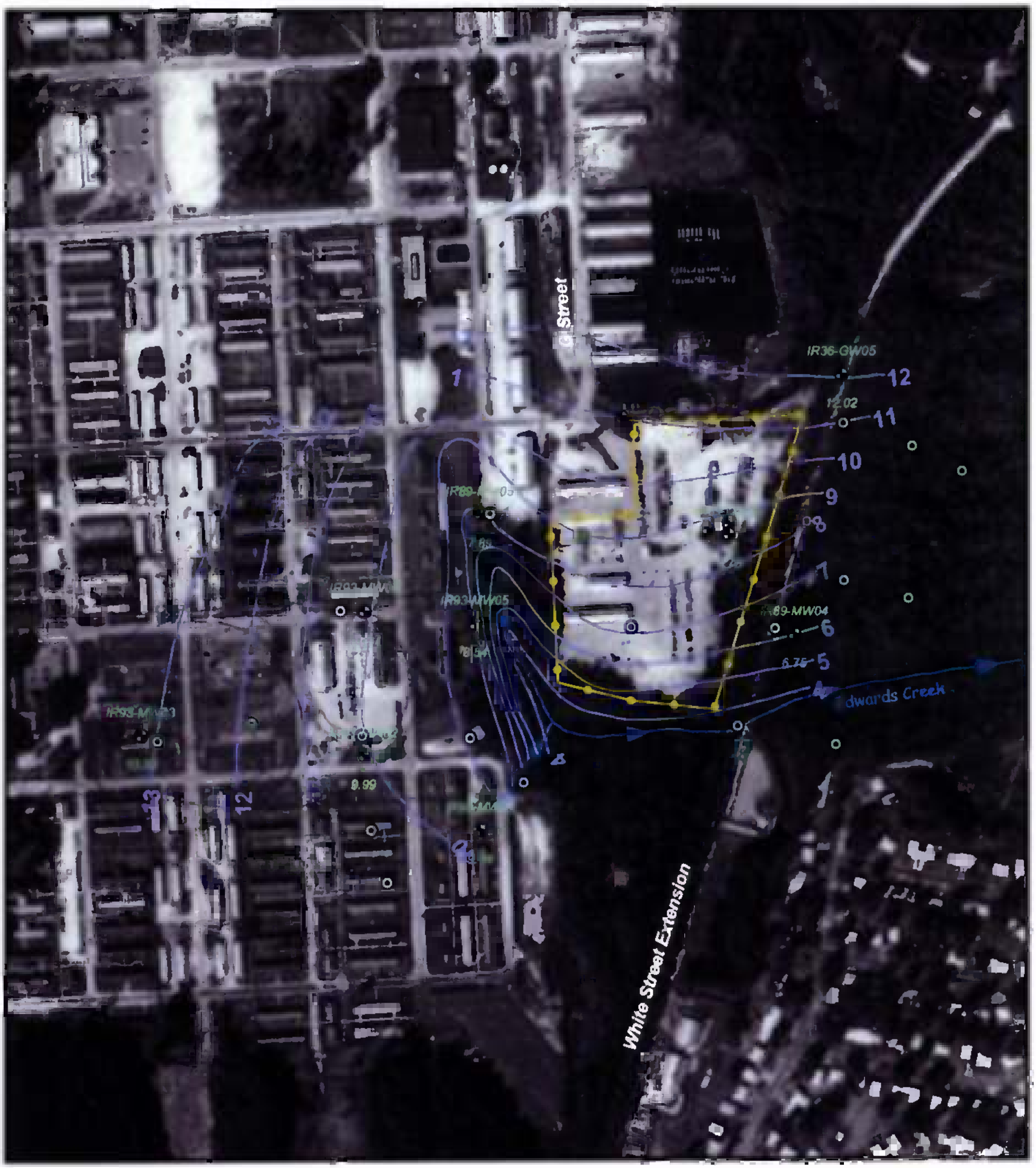


MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

SITE PLAN
OPERABLE UNIT NO. 16 (SITE 93)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 3



LEGEND

IR89-MW01 ● 10.47 Monitoring Well Location with Ground Water Elevation

╱╲╱ Contour Line

Scale

300 0 300 600 Feet

N W E S

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

POTENTIOMETRIC SURFACE
(SHALLOW WELLS)
OPERABLE UNIT NO. 16 (SITES 89 & 93)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 4

LEGEND

IR89-MW01 ● 10.47 Monitoring Well Location with Ground Water Elevation

Contour Line

Scale

600 0 600 1200 Feet

N W E S

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

POTENTIOMETRIC SURFACE
(INTERMEDIATE WELLS)
OPERABLE UNIT NO. 16 (SITES 89 & 93)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 5

LEGEND

IR89-MWD01 ● 10.47	Monitoring Well Location with Ground Water Elevation
╱╲╱	Contour Line

Scale
400 0 400 800 Feet

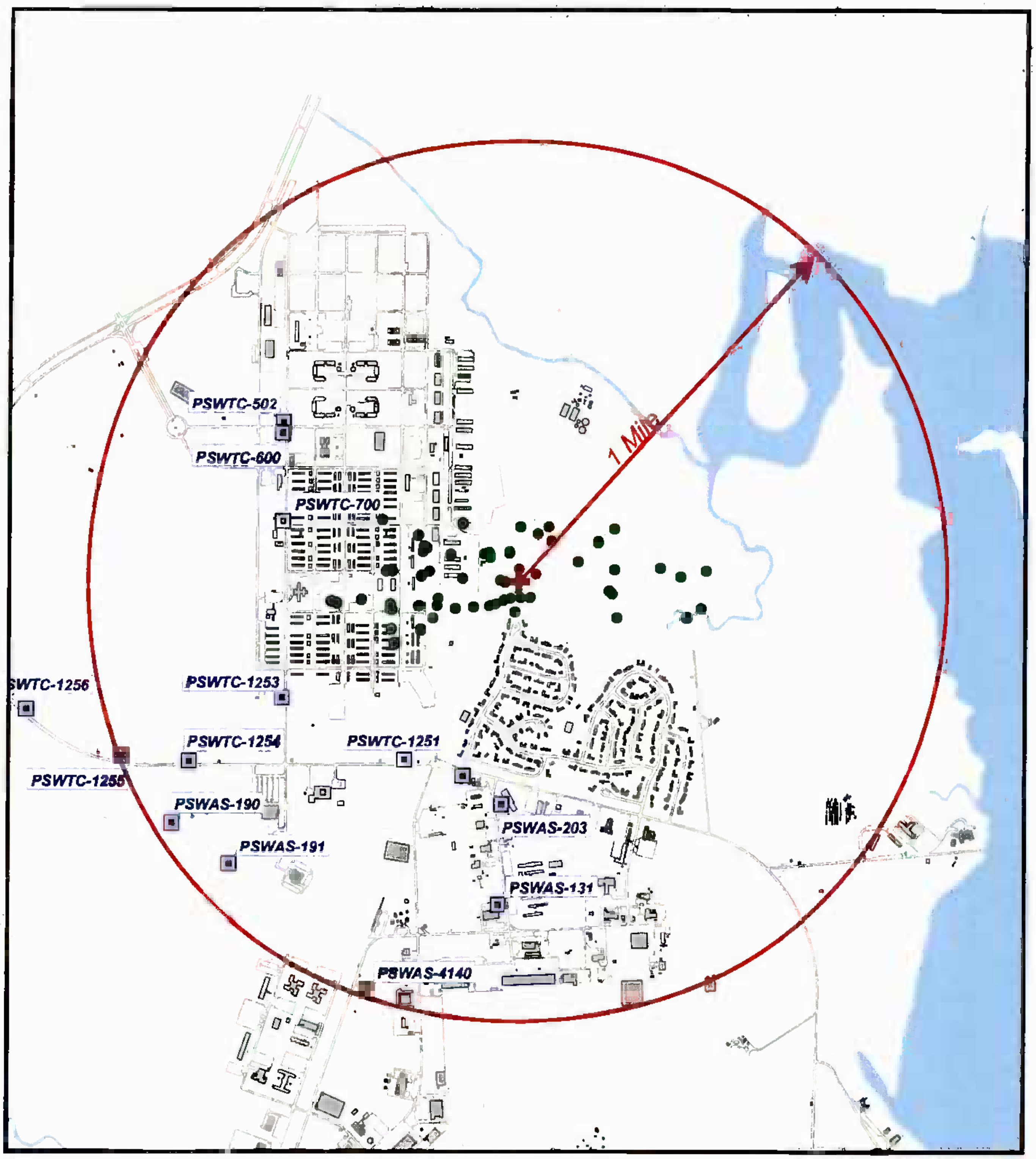
N
W E
S

MARINE CORPS BASE, CAMP LEJEUNE NORTH CAROLINA

POTENTIOMETRIC SURFACE
(DEEP WELLS)
OPERABLE UNIT NO. 16 (SITE 89 & 93)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 6



LEGEND

● Monitoring Well Related to RI

PSWTC-1253
▣ Potable Supply Well (Typical)

Scale
1000 0 1000 2000 3000 Feet

N
W E
S

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

POTABLE SUPPLY WELLS
WITHIN 1 MILE RADIUS
OPERABLE UNIT NO. 16 (SITES 89 & 93)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 7

LEGEND

DRMO Fence Line

Edwards Creek with Flow Direction

TW04 Temporary Monitoring Well Location with Location ID

MW01 Permanent Monitoring Well Location with Location ID

Scale

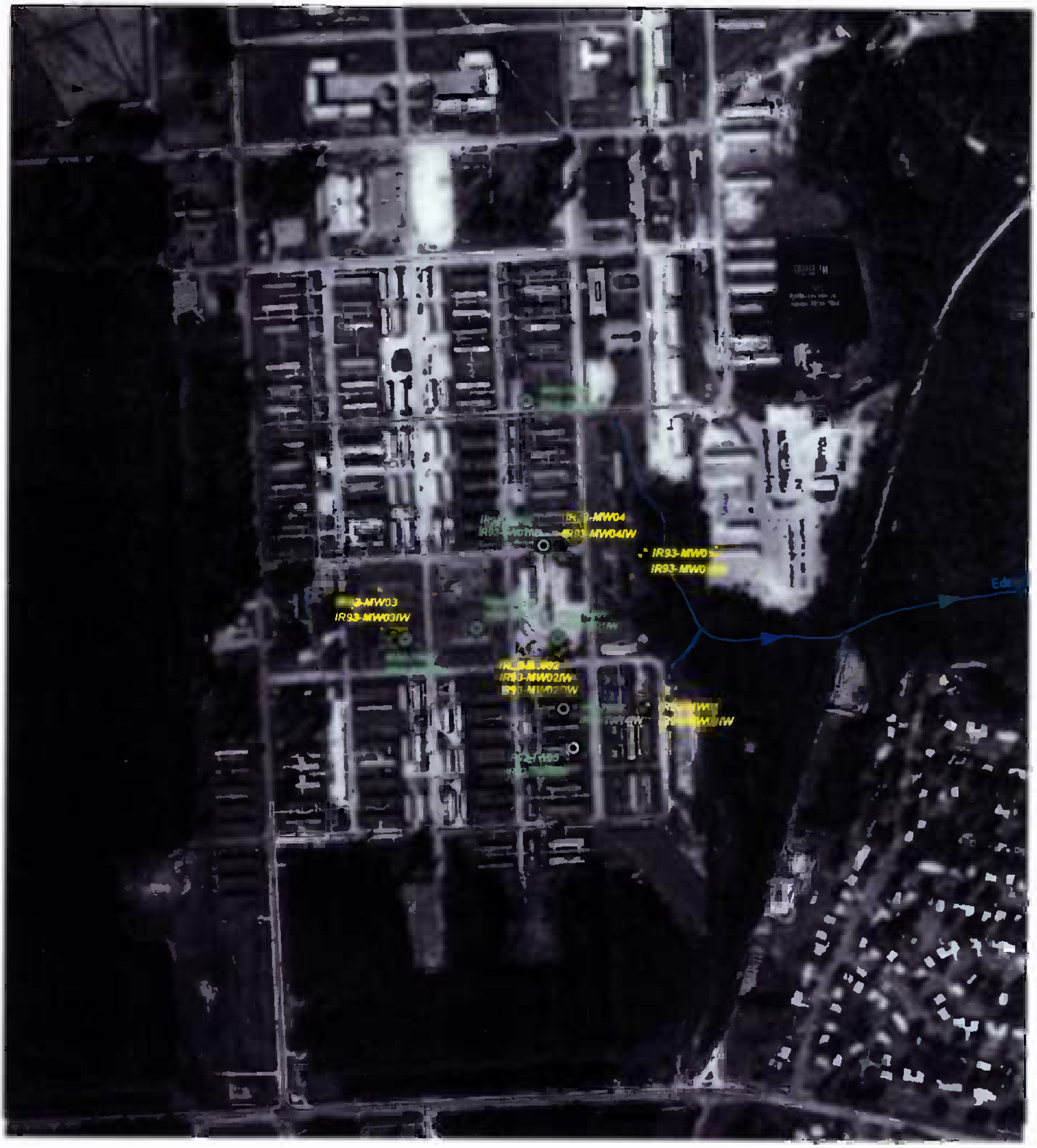
500 0 500 1000 Feet

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

TEMPORARY & PERMANENT MONITORING
WELL LOCATIONS
OPERABLE UNIT NO. 16 (SITE 89)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 8



LEGEND

	DRMO Fence Line
	Edwards Creek with Flow Direction
TW04 ⊙	Temporary Monitoring Well Location with Location ID
MW01 ●	Permanent Monitoring Well Location with Location ID

Scale

600 0 600 1200 Feet

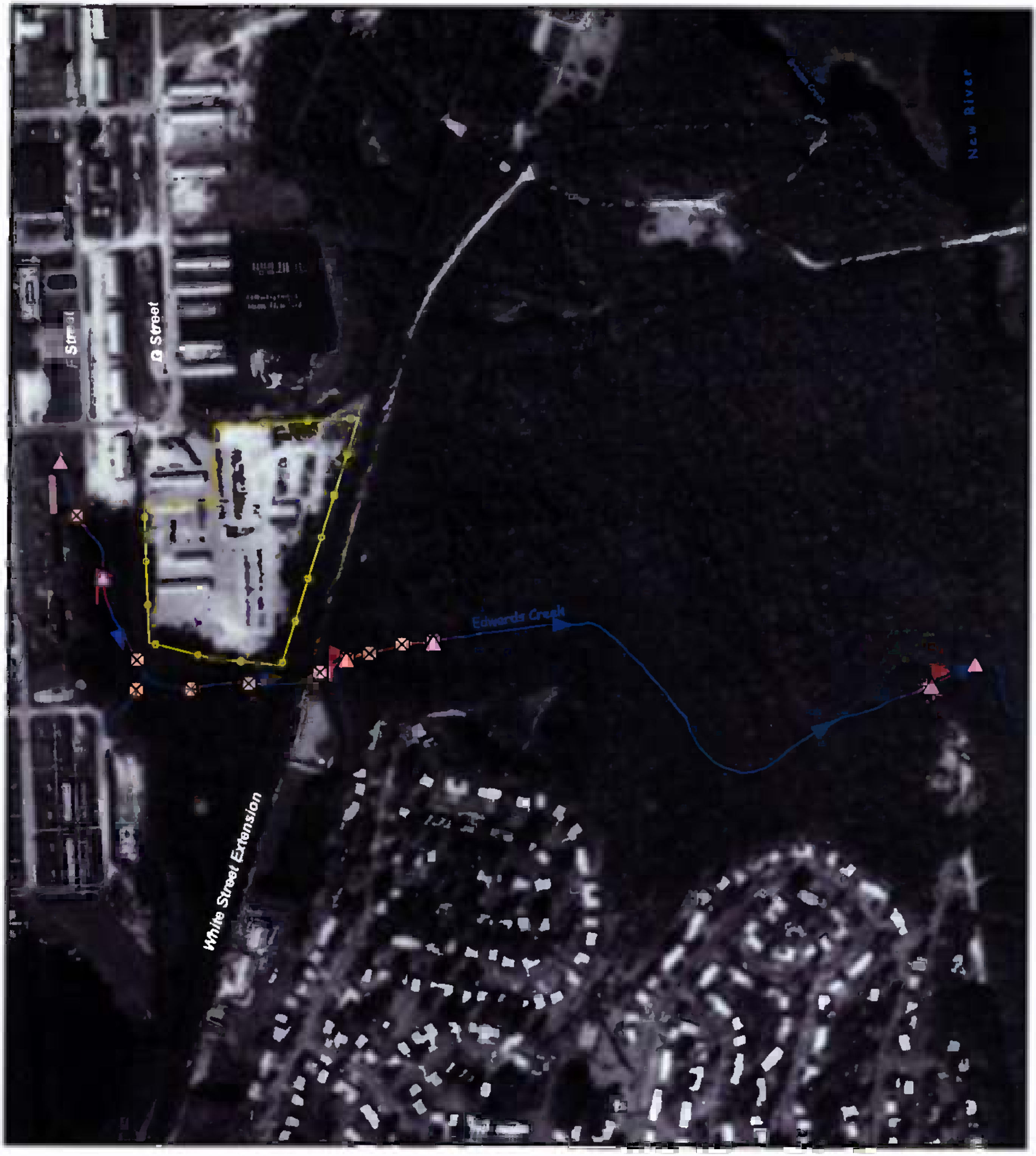
N
W E
S

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

TEMPORARY & PERMANENT MONITORING
WELL LOCATIONS
OPERABLE UNIT NO. 16 (SITE 93)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 9



LEGEND

⚑	Staff Gauge
△	Surface Water Sample
☒	Surface Water/Sediment Sample
⁄\/	DRMO Fence Line

Scale

300 0 300 600 Feet

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

SURFACE WATER and SEDIMENT
SAMPLE LOCATIONS
OPERABLE UNIT NO. 16 (SITE 89)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 10

LEGEND

✳ Staff Gauge
◕ Permanent Monitoring Well
⨷ Surface Water Sample
☒ Surface Water/Sediment Sample
⊙ Temporary Monitoring Well

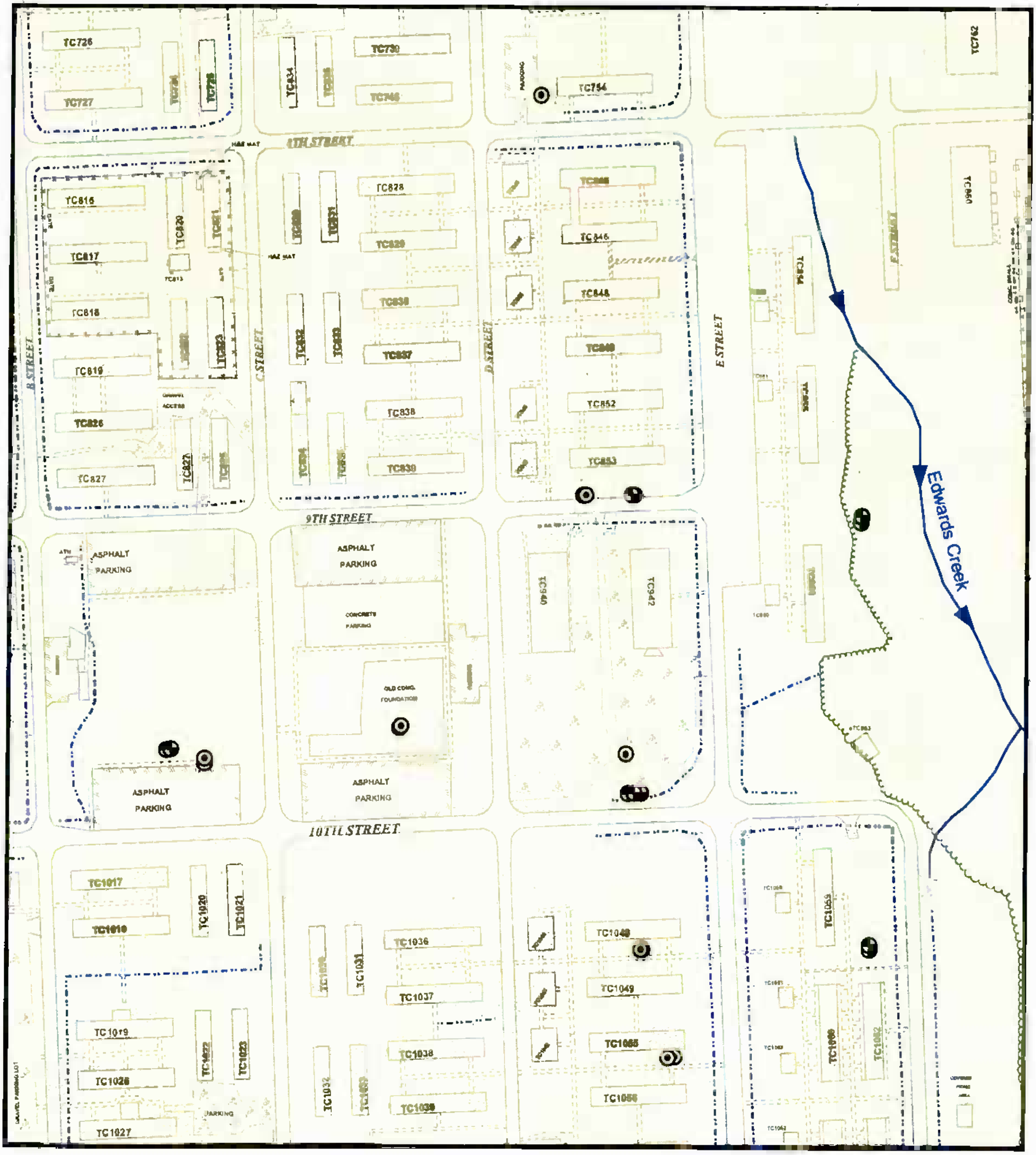
Scale
300 0 300 600 Feet

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

SAMPLE LOCATIONS
OPERABLE UNIT NO. 16 (SITE 89)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 11



LEGEND

● Permanent Monitoring Well Location

⊙ Temporary Monitoring Well Location

Edwards Creek with Flow Direction

Swale

Scale

200 0 200 400 Feet

N
W E
S

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

SAMPLE LOCATIONS
OPERABLE UNIT NO. 16 (SITE 93)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 12

GROUNDWATER EXCEEDANCES - SITE 89 SHALLOW WELLS

Loc_ID	Parameter	Qualifier	Result	Units	Date	NCWQS	MCL
IR89-MW01	TETRACHLOROETHENE		42.4000	UG/L	7/31/96	0.7000	5.0000
IR89-MW01	TETRACHLOROETHENE	J	4.0000	UG/L	05/28/97	0.7000	5.0000
IR89-MW01	TRICHLOROETHENE		323.1000	UG/L	7/31/96	2.8000	5.0000
IR89-MW01	TRICHLOROETHENE		67.0000	UG/L	05/28/97	2.8000	5.0000
IR89-MW01	CIS-1,2-DICHLOROETHENE		261.0000	UG/L	7/31/96	70.0000	70.0000
IR89-MW01	TRANS-1,2-DICHLOROETHENE		177.0000	UG/L	7/31/96	70.0000	100.0000
IR89-MW02	VINYL CHLORIDE		130.0000	UG/L	7/30/96	0.0150	2.0000
IR89-MW02	TETRACHLOROETHENE		9.4000	UG/L	7/30/96	0.7000	5.0000
IR89-MW02	TRICHLOROETHENE		744.3000	UG/L	7/30/96	2.8000	5.0000
IR89-MW02	CIS-1,2-DICHLOROETHENE		818.0000	UG/L	7/30/96	70.0000	70.0000
IR89-MW02	TRANS-1,2-DICHLOROETHENE		451.0000	UG/L	7/30/96	70.0000	100.0000
IR89-MW03	TETRACHLOROETHENE		13.1000	UG/L	7/31/96	0.7000	5.0000
IR89-MW03	TRICHLOROETHENE		131.0000	UG/L	7/31/96	2.8000	5.0000
IR89-MW03	CIS-1,2-DICHLOROETHENE		150.0000	UG/L	7/31/96	70.0000	70.0000
IR89-MW03	TRANS-1,2-DICHLOROETHENE		82.0000	UG/L	7/31/96	70.0000	100.0000
IR89-MW04	VINYL CHLORIDE		43.0000	UG/L	05/29/97	0.0150	2.0000
IR89-MW04	TETRACHLOROETHENE	J	7.0000	UG/L	05/29/97	0.7000	5.0000
IR89-MW04	TRICHLOROETHENE		640.0000	UG/L	05/29/97	2.8000	5.0000
IR89-MW05	VINYL CHLORIDE	J	6.0000	UG/L	05/28/97	0.0150	2.0000
IR89-MW05	TRICHLOROETHENE		280.0000	UG/L	05/28/97	2.8000	5.0000
IR89-TW08	TETRACHLOROETHENE		23.0000	UG/L	08/06/96	0.7000	5.0000
IR89-TW08	TETRACHLOROETHENE		27.0000	UG/L	8/3/96	0.7000	5.0000
IR89-TW08	TRICHLOROETHENE		670.0000	UG/L	08/06/96	2.8000	5.0000
IR89-TW08	TRICHLOROETHENE		638.4000	UG/L	8/3/96	2.8000	5.0000
IR89-TW08	CIS-1,2-DICHLOROETHENE		253.0000	UG/L	8/3/96	70.0000	70.0000
IR89-TW13	TETRACHLOROETHENE		4.8000	UG/L	8/5/96	0.7000	5.0000
IR89-TW13	TRICHLOROETHENE		136.9000	UG/L	8/5/96	2.8000	5.0000
IR89-TW15	TETRACHLOROETHENE		13.7000	UG/L	8/6/96	0.7000	5.0000
IR89-TW15	TRICHLOROETHENE		355.9000	UG/L	8/6/96	2.8000	5.0000
IR89-TW15	CIS-1,2-DICHLOROETHENE		162.0000	UG/L	8/6/96	70.0000	70.0000
IR89-TW16	TETRACHLOROETHENE		42.7000	UG/L	8/6/96	0.7000	5.0000
IR89-TW16	TRICHLOROETHENE		562.9000	UG/L	8/6/96	2.8000	5.0000
IR89-TW16	CIS-1,2-DICHLOROETHENE		102.0000	UG/L	8/6/96	70.0000	70.0000
IR89-MW42B	TRICHLOROETHENE		85.8000	UG/L	7/31/96	0.7000	5.0000

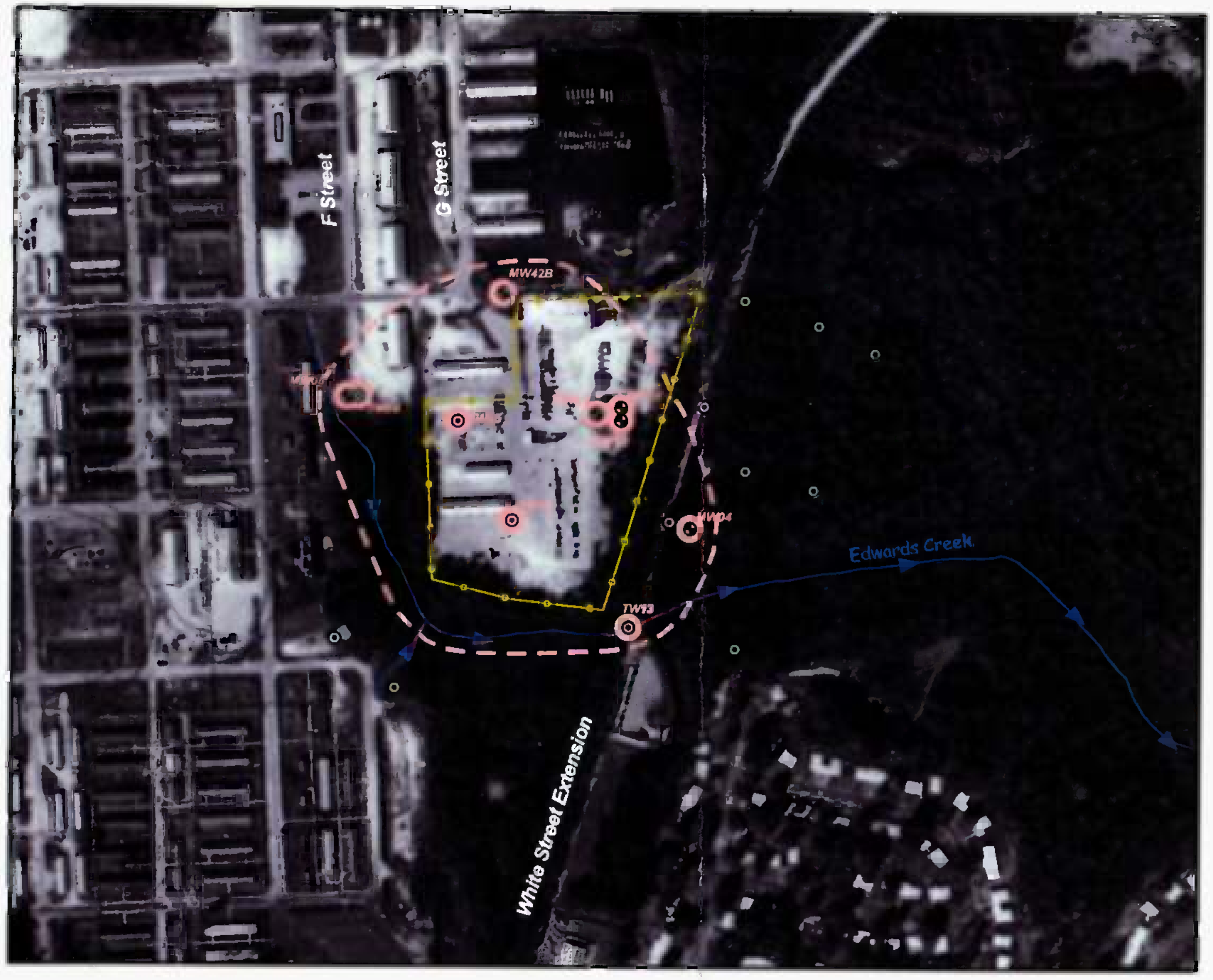
Footnotes:

Table presents concentrations above NCWQS/MCLs

UG/L - Microgram per liter (ppb)

NCWQS - North Carolina Water Quality Standard

MCL - Federal Drinking Water Regulations Maximum Containment Level



LEGEND

● Permanent Monitoring Well Location

⊙ Temporary Monitoring Well Location

Monitoring Well Location and Well ID with concentrations exceeding NCWQS/MCLS

Estimated Boundary of Groundwater Contamination above Applicable Standards

DRMO Facility

N
W E
S

Graphic Scale

90 0 90 180 Feet

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

VOLATILE ORGANIC COMPOUNDS
IN GROUNDWATER (SHALLOW WELLS)
OPERABLE UNIT NO. 16 (SITE 89)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 13

GROUNDWATER EXCEEDANCES - SITE 89 INTERMEDIATE WELLS

Loc_ID	Parameter	Qualifier	Result	Units	Date	NCWQS	MCL
IR89-MW03IW	TRICHLOROETHENE		400.0000	UG/L	05/28/97	2.8000	5.0000
IR89-MW04IW	VINYL CHLORIDE	J	9.0000	UG/L	05/29/97	0.0150	2.0000
IR89-MW04IW	TRICHLOROETHENE		510.0000	UG/L	05/29/97	2.8000	5.0000
IR89-MW06IW	TRICHLOROETHENE		18.0000	UG/L	05/19/97	2.8000	5.0000
IR89-MW07IW	TRICHLOROETHENE	J	10.0000	UG/L	05/20/97	2.8000	5.0000
IR89-TW09IW	TETRACHLOROETHENE		8.8000	UG/L	8/3/96	0.7000	5.0000
IR89-TW09IW	TRICHLOROETHENE		260.0000	UG/L	08/07/96	2.8000	5.0000
IR89-TW09IW	TRICHLOROETHENE		233.4000	UG/L	8/3/96	2.8000	5.0000
IR89-TW09IW	CIS-1,2-DICHLOROETHENE		114.0000	UG/L	8/3/96	70.0000	70.0000
IR89-TW10IW	TRICHLOROETHENE		36.3000	UG/L	8/4/96	2.8000	5.0000
IR89-TW11IW	TRICHLOROETHENE		3.3000	UG/L	8/4/96	2.8000	5.0000
IR89-TW13IW	TETRACHLOROETHENE		7.4000	UG/L	8/5/96	0.7000	5.0000
IR89-TW13IW	TRICHLOROETHENE		57.9000	UG/L	8/5/96	2.8000	5.0000
IR89-TW15IW	TRICHLOROETHENE		6.0000	UG/L	8/6/96	2.8000	5.0000
IR89-TW17IW	TETRACHLOROETHENE		1.5000	UG/L	8/7/96	0.7000	5.0000
IR89-TW17IW	TRICHLOROETHENE		390.0000	UG/L	08/07/96	2.8000	5.0000
IR89-TW17IW	TRICHLOROETHENE		425.7000	UG/L	8/7/96	2.8000	5.0000
IR89-TW17IW	CIS-1,2-DICHLOROETHENE		287.0000	UG/L	8/7/96	70.0000	70.0000
IR89-TW17IW	TRANS-1,2-DICHLOROETHENE		90.0000	UG/L	8/7/96	70.0000	100.0000
IR89-TW19IW	TRICHLOROETHENE		3.8000	UG/L	8/13/96	2.8000	5.0000
IR89-TW20IW	TRICHLOROETHENE		59.1000	UG/L	8/14/96	2.8000	5.0000
IR89-TW21IW	TRICHLOROETHENE		10.4000	UG/L	8/15/96	2.8000	5.0000
IR89-TW22IW	TETRACHLOROETHENE		13.0000	UG/L	8/16/96	0.7000	5.0000
IR89-TW22IW	TRICHLOROETHENE		293.9000	UG/L	8/16/96	2.8000	5.0000
IR89-TW22IW	CIS-1,2-DICHLOROETHENE		106.0000	UG/L	8/16/96	70.0000	70.0000
IR89-TW23IW	TRICHLOROETHENE		123.9000	UG/L	8/21/96	2.8000	5.0000
IR89-TW23IW	CIS-1,2-DICHLOROETHENE		84.0000	UG/L	8/21/96	70.0000	70.0000

Footnotes:

Table presents concentrations above NCWQS/MCLs

UG/L - Microgram per liter (ppb)

NCWQS - North Carolina Water Quality Standard

MCL - Federal Drinking Water Regulations Maximum Containment Level

LEGEND

- ● Permanent Monitoring Well Location
- ⊙ Temporary Monitoring Well Location
- ● Monitoring Well Location and Well ID with concentrations exceeding NCWQS/MCLS
- ╱ Estimated Boundary of Groundwater Contamination above Applicable Standards
- ╱ DRMO Facility

N W E S

Graphic Scale
90 0 90 180 Feet

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

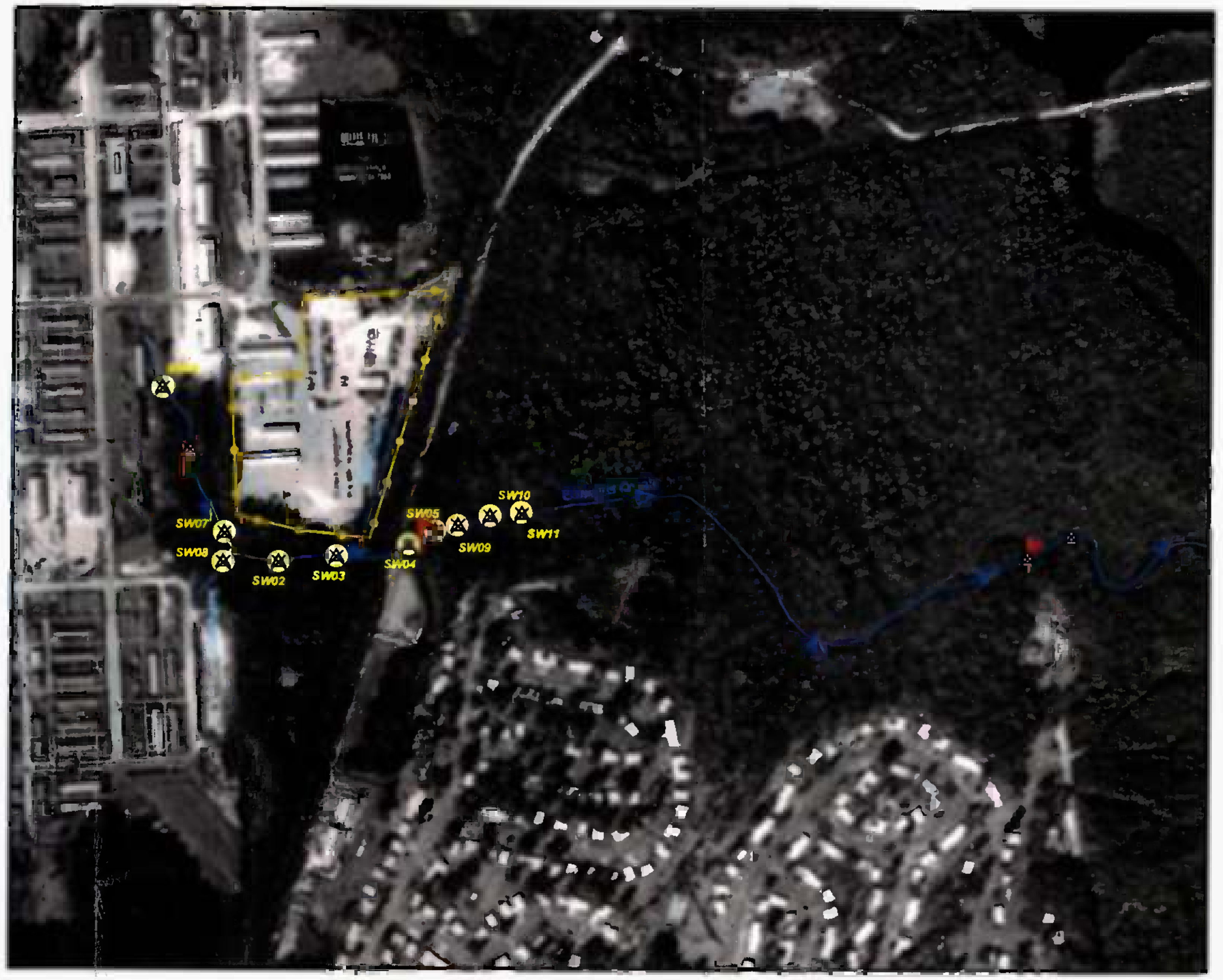
VOLATILE ORGANIC COMPOUNDS
IN GROUNDWATER (INTERMEDIATE WELLS)
OPERABLE UNIT NO. 16 (SITE 89)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 14

SURFACE WATER DETECTIONS - VOLATILE ORGANIC COMPOUNDS

Loc_ID	Parameter	Qualifier	Result	Units	Date
IR89-SW01	CHLOROFORM		0.3000	UG/L	8/15/96
IR89-SW01	TETRACHLOROETHENE		0.2000	UG/L	8/15/96
IR89-SW01	TRICHLOROETHENE	J	3.0000	UG/L	07/27/96
IR89-SW01	TRICHLOROETHENE		3.8000	UG/L	8/15/96
IR89-SW01	CIS-1,2-DICHLOROETHENE		2.0000	UG/L	8/15/96
IR89-SW02	VINYL CHLORIDE		25.0000	UG/L	07/27/96
IR89-SW02	CHLOROFORM		0.2000	UG/L	8/15/96
IR89-SW02	TETRACHLOROETHENE		0.2000	UG/L	8/15/96
IR89-SW02	TRICHLOROETHENE		18.0000	UG/L	07/27/96
IR89-SW02	TRICHLOROETHENE		7.3000	UG/L	8/15/96
IR89-SW02	CIS-1,2-DICHLOROETHENE		48.0000	UG/L	8/15/96
IR89-SW02	TRANS-1,2-DICHLOROETHENE		37.0000	UG/L	8/15/96
IR89-SW02	1,1,2,2-TETRACHLOROETHANE	J	150.0000	UG/L	07/27/96
IR89-SW02	1,2-DICHLOROETHENE (TOTAL)		120.0000	UG/L	07/27/96
IR89-SW03	VINYL CHLORIDE		21.0000	UG/L	07/27/96
IR89-SW03	CHLOROFORM		0.1000	UG/L	8/15/96
IR89-SW03	TETRACHLOROETHENE		0.2000	UG/L	8/15/96
IR89-SW03	TRICHLOROETHENE		16.0000	UG/L	07/27/96
IR89-SW03	TRICHLOROETHENE		6.4000	UG/L	8/15/96
IR89-SW03	CIS-1,2-DICHLOROETHENE		44.0000	UG/L	8/15/96
IR89-SW03	TRANS-1,2-DICHLOROETHENE		31.0000	UG/L	8/15/96
IR89-SW03	1,1,2,2-TETRACHLOROETHANE	J	130.0000	UG/L	07/27/96
IR89-SW03	1,2-DICHLOROETHENE (TOTAL)		100.0000	UG/L	07/27/96
IR89-SW04	CHLOROFORM		0.4000	UG/L	8/15/96
IR89-SW04	TETRACHLOROETHENE		0.2000	UG/L	8/15/96
IR89-SW04	TRICHLOROETHENE		26.0000	UG/L	07/26/96
IR89-SW04	TRICHLOROETHENE		32.9000	UG/L	8/15/96
IR89-SW04	CIS-1,2-DICHLOROETHENE		52.0000	UG/L	8/15/96
IR89-SW04	TRANS-1,2-DICHLOROETHENE		19.0000	UG/L	8/15/96
IR89-SW04	1,1,2,2-TETRACHLOROETHANE		72.0000	UG/L	07/26/96
IR89-SW04	1,2-DICHLOROETHENE (TOTAL)		80.0000	UG/L	07/26/96
IR89-SW05	CHLOROFORM		0.3000	UG/L	8/15/96
IR89-SW05	TETRACHLOROETHENE		0.1000	UG/L	8/15/96
IR89-SW05	TRICHLOROETHENE		24.0000	UG/L	07/26/96
IR89-SW05	TRICHLOROETHENE		27.3000	UG/L	8/15/96
IR89-SW05	CIS-1,2-DICHLOROETHENE		44.0000	UG/L	8/15/96
IR89-SW05	TRANS-1,2-DICHLOROETHENE		15.0000	UG/L	8/15/96
IR89-SW05	1,1,2,2-TETRACHLOROETHANE		80.0000	UG/L	07/26/96
IR89-SW05	1,2-DICHLOROETHENE (TOTAL)		78.0000	UG/L	07/26/96
IR89-SW07	TETRACHLOROETHENE		1.2000	UG/L	8/1/96
IR89-SW07	TRICHLOROETHENE		14.8000	UG/L	8/1/96
IR89-SW07	CIS-1,2-DICHLOROETHENE		27.0000	UG/L	8/1/96
IR89-SW07	TRANS-1,2-DICHLOROETHENE		21.0000	UG/L	8/1/96
IR89-SW08	TETRACHLOROETHENE		0.4000	UG/L	8/1/96
IR89-SW09	CHLOROFORM		0.4000	UG/L	8/15/96
IR89-SW09	TETRACHLOROETHENE		0.2000	UG/L	8/15/96
IR89-SW09	TRICHLOROETHENE		28.5000	UG/L	8/15/96
IR89-SW09	CIS-1,2-DICHLOROETHENE		44.0000	UG/L	8/15/96
IR89-SW09	TRANS-1,2-DICHLOROETHENE		16.0000	UG/L	8/15/96
IR89-SW10	CHLOROFORM		0.4000	UG/L	8/15/96
IR89-SW10	TETRACHLOROETHENE		0.1000	UG/L	8/15/96
IR89-SW10	TRICHLOROETHENE		27.9000	UG/L	8/15/96
IR89-SW10	CIS-1,2-DICHLOROETHENE		43.0000	UG/L	8/15/96
IR89-SW10	TRANS-1,2-DICHLOROETHENE		15.0000	UG/L	8/15/96
IR89-SW11	CHLOROFORM		0.4000	UG/L	8/15/96
IR89-SW11	TETRACHLOROETHENE		0.2000	UG/L	8/15/96
IR89-SW11	TRICHLOROETHENE		27.6000	UG/L	8/15/96
IR89-SW11	CIS-1,2-DICHLOROETHENE		43.0000	UG/L	8/15/96
IR89-SW11	TRANS-1,2-DICHLOROETHENE		14.0000	UG/L	8/15/96



LEGEND

▲	Surface Water Sample	●	Sample Location and Well ID with concentrations
⊠	Surface Water / Sediment Sample	◀╱╲╱	Edwards Creek with Flow Direction
⚑	Staff Gauge	⁄⁄	Drainage Swale

NOTE:
Phase II surfacewater samples not shown.
(Chloride ion only)

Graphic Scale
90 0 90 180 Feet

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MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

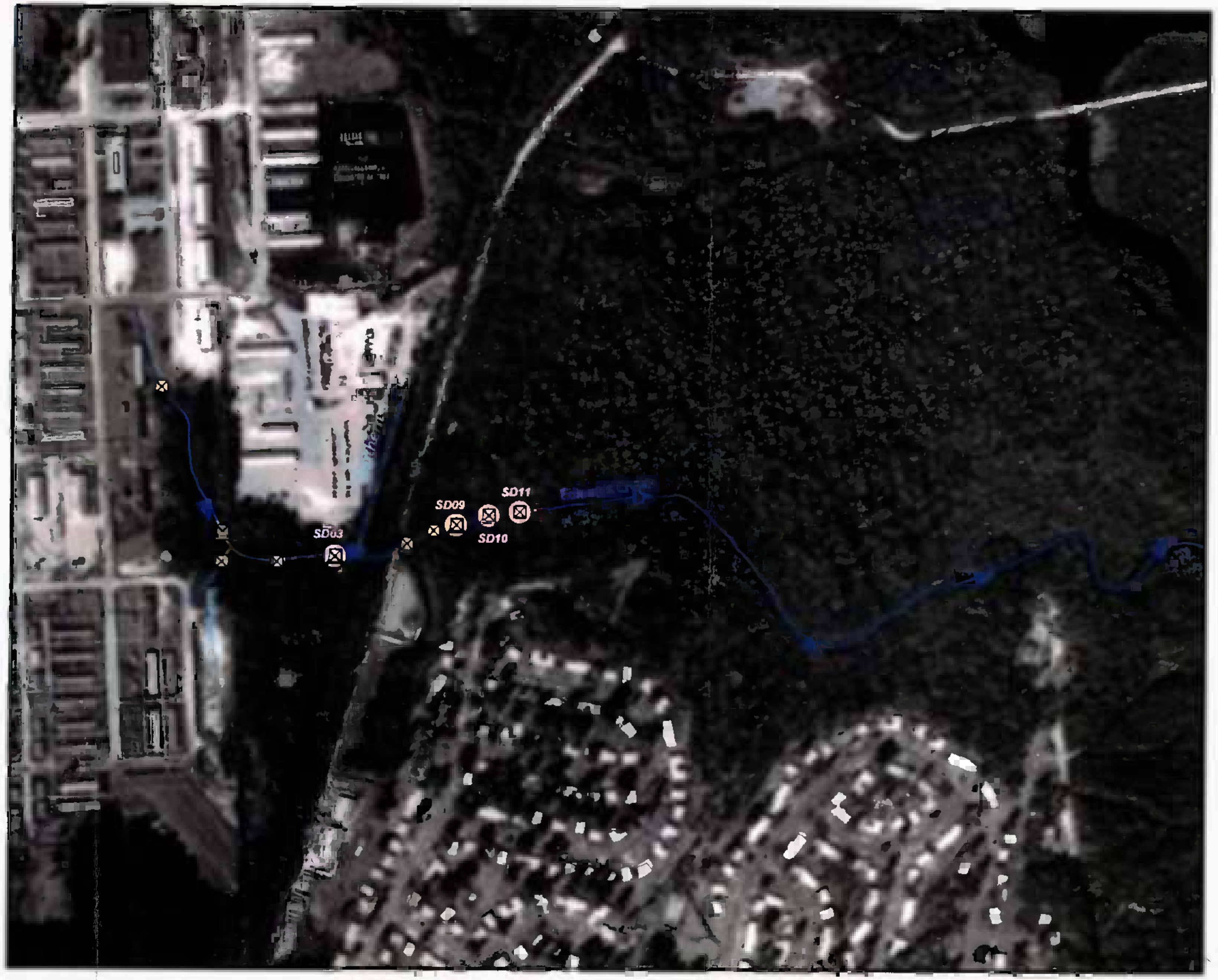
VOLATILE ORGANIC COMPOUNDS
IN SURFACEWATER
OPERABLE UNIT NO. 16 (SITE 89)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 15

SEDIMENT DETECTIONS - VOLATILE ORGANIC COMPOUNDS

Loc_ID	Parameter	Qualifier	Result	Units	Date
IR89-SD03	VINYL CHLORIDE		35.0000	UG/KG	07/27/96
IR89-SD03	VINYL CHLORIDE		230.0000	UG/KG	07/27/96
IR89-SD03	TRICHLOROETHENE		2400.0000	UG/KG	07/27/96
IR89-SD03	TRICHLOROETHENE		120.0000	UG/KG	07/27/96
IR89-SD03	1,1-DICHLOROETHENE	J	37.0000	UG/KG	07/27/96
IR89-SD03	TOLUENE	J	7.0000	UG/KG	07/27/96
IR89-SD03	1,1,2,2-TETRACHLOROETHANE		1700.0000	UG/KG	07/27/96
IR89-SD03	1,1,2,2-TETRACHLOROETHANE		550.0000	UG/KG	07/27/96
IR89-SD03	1,1,2-TRICHLOROETHANE		19.0000	UG/KG	07/27/96
IR89-SD03	1,1,2-TRICHLOROETHANE		13.0000	UG/KG	07/27/96
IR89-SD03	1,2-DICHLOROETHENE (TOTAL)		1600.0000	UG/KG	07/27/96
IR89-SD03	1,2-DICHLOROETHENE (TOTAL)		1500.0000	UG/KG	07/27/96
IR89-SD09	TRICHLOROETHENE		2.2000	UG/KG	8/15/96
IR89-SD09	CIS-1,2-DICHLOROETHENE		5.0000	UG/KG	8/15/96
IR89-SD09	TRANS-1,2-DICHLOROETHENE		1.0000	UG/KG	8/15/96
IR89-SD10	TRICHLOROETHENE		11.3000	UG/KG	8/15/96
IR89-SD10	TRICHLOROETHENE		0.6000	UG/KG	8/15/96
IR89-SD10	CIS-1,2-DICHLOROETHENE		16.0000	UG/KG	8/15/96
IR89-SD10	TRANS-1,2-DICHLOROETHENE		5.0000	UG/KG	8/15/96
IR89-SD11	TRICHLOROETHENE		0.9000	UG/KG	8/15/96
IR89-SD11	TRICHLOROETHENE		0.3000	UG/KG	8/15/96



LEGEND

☒ Sediment Sample Location

● Sediment Sample Location and Well ID with Dectections

DRMO Facility

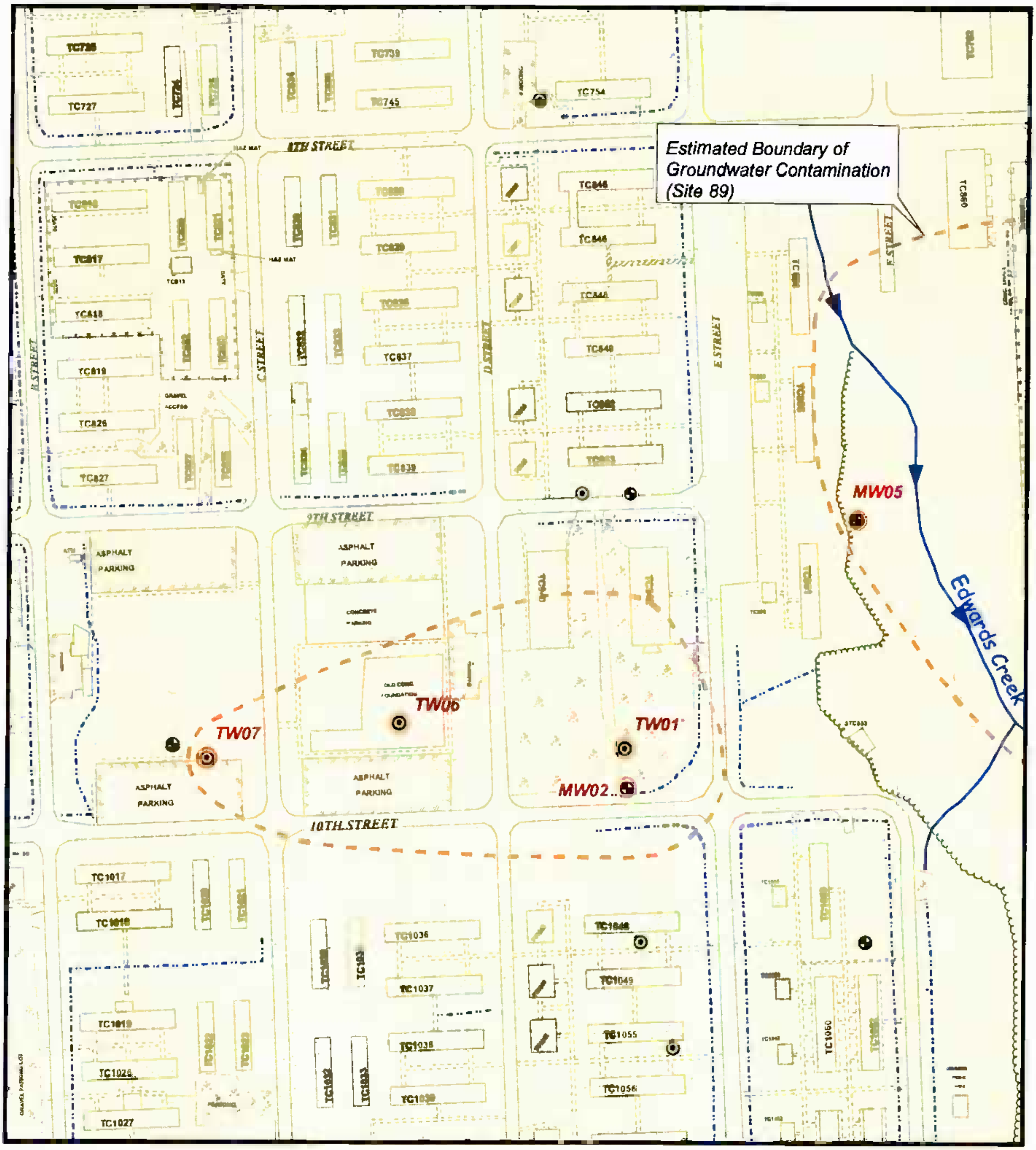
Graphic Scale
90 0 90 180 Feet

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

VOLATILE ORGANIC COMPOUNDS
IN SEDIMENT SAMPLES
OPERABLE UNIT NO. 16 (SITE 89)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 16



LEGEND

- ⊕ Permanent Monitoring Well Location
- ⊙ Temporary Monitoring Well Location
- MW01 ● Monitoring Well Location and Well ID with concentrations exceeding NCWQS/MCLS
- / \ / Estimated Boundary of Groundwater Contamination above Applicable Standards

Scale

200 0 200 400 Feet

N
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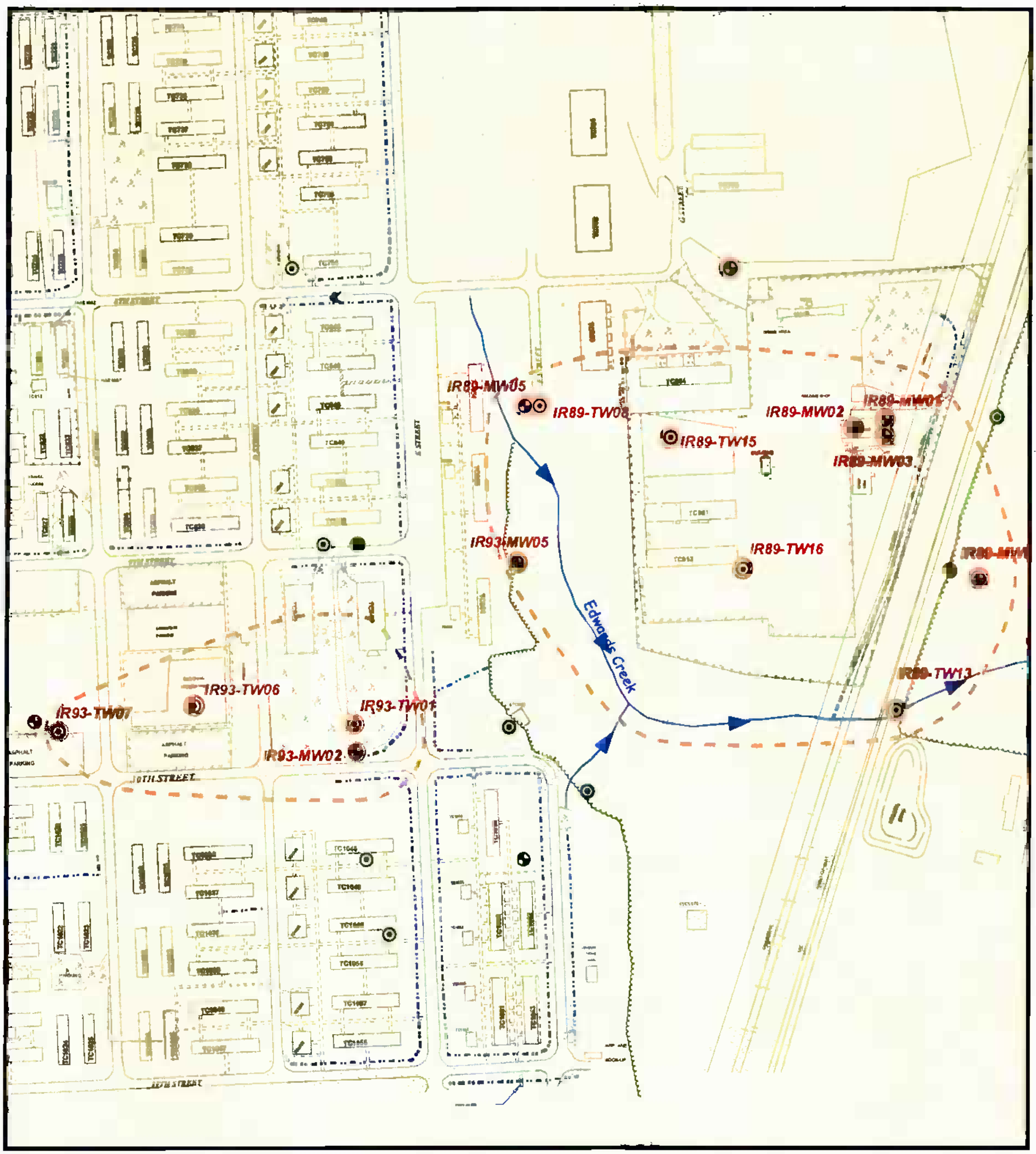
MARINE CORPS BASE, CAMP LEJEUNE NORTH CAROLINA

VOLATILE ORGANIC COMPOUNDS
IN GROUNDWATER (SHALLOW WELLS)
OPERABLE UNIT NO. 16 (SITE 93)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 17



LEGEND

⊕	Permanent Monitoring Well Location
⊙	Temporary Monitoring Well Location
MW01 ●	Monitoring Well Location and Well ID with concentrations exceeding NCWQS/MCLS
⁄ ⁄	Estimated Boundary of Groundwater Contamination above Applicable Standards

Scale
200 0 200 400 Feet

N
W E
S

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

VOLATILE ORGANIC COMPOUNDS
IN GROUNDWATER (SHALLOW WELLS)
OPERABLE UNIT NO. 16 (SITE 89 & 93)
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 1 - 18

2.0 REMEDIATION GOAL OPTIONS, REMEDIATION LEVELS, AND REMEDIAL ACTION OBJECTIVES

This section presents remediation goal options (RGOs), remediation levels (RLs), and remedial action objectives for OU No. 16 (Sites 89 and 93). Due to the geographic proximity and the similar nature of contaminants detected at each site, RLs will be developed for the entire OU. Section 2.1 describes the media and contaminants of concern (COCs) based on findings presented in the RI report (Baker, 1997). Section 2.2 presents the exposure routes and receptors evaluated in the human health risk assessment conducted for OU No. 16. In Section 2.3, RGOs and final RLs are developed. Section 2.3 also includes a final set of COCs for the FS. Based on the RLs, remedial action objectives and areas of concern are identified in Section 2.4.

2.1 Media of Concern/Contaminants of Concern

The results of the baseline human health risk assessment presented in the RI report indicate that the total carcinogenic and noncarcinogenic risks exceed the USEPA acceptable risk range for certain receptors and exposure scenarios. This exceedence is driven by future potential exposure to the surficial groundwater.

COPCs initially selected and evaluated in the risk assessment prepared for the RI were selected on the basis of comparison to USEPA Region III RBCs, comparison to established criteria or standards, frequency of detection, and toxicity.

The COPCs that contributed to unacceptable risks were considered COCs for this FS and are presented in Table 2-1. However, the COPCs 1,1-Dichloroethene, 1,1,2-Trichloroethane, 1,1,2,2-Tetrachloroethane, iron, lead, and manganese were not considered in the list of COCs for the following reasons:

- The COPCs, 1,1-Dichloroethene, 1,1,2-Trichloroethane, and 1,1,2,2-Tetrachloroethane, did not exceed their corresponding RGOs.
- There is no historical record of any use or disposal of iron or manganese at either site.
- Groundwater in the Camp Lejeune area is naturally rich in iron and manganese.
- Lead was detected in 1 out of 11 groundwater samples collected at Site 93 and not detected in any groundwater samples collected at Site 89. This infrequent occurrence of lead justifies elimination as a COC.

Detected concentrations of the COCs will be compared to the RLs to be developed in Section 2.3.4 to generate a final list of COCs for this FS. Any COC that does not exceed its applicable regulatory or health-based RL will be eliminated from the final list of COCs, thus eliminating it from consideration in this FS. The final list of COCs will become the basis for a set of remedial action objectives applicable to the site.

2.2 Exposure Routes and Receptors

Potential exposure pathways and receptors used to determine RGOs were site-specific and consider the future land use of these sites. For this FS, the most conservative exposure pathway, groundwater ingestion, was used in the development of RGOs. Although exposure to groundwater can occur via dermal contact and inhalation of volatile contaminants, these exposure pathways were not included. Groundwater does not appear to pose an appreciable risk with respect to dermal contact or inhalation. The RGOs were selected for future (adult and child) residential receptors in order to provide RGOs from which remedial alternatives could be generated.

2.3 Remediation Goal Options and Remediation Levels

RGOs are established based on Federal and state criteria and risk-based RGOs. Section 2.3.1 presents the definition of applicable or relevant and appropriate Federal and state requirements (ARARs) and "to be considered" (TBCs) requirements. Section 2.3.2 provides an evaluation of Federal and state criteria applicable to the COCs for OU No. 16. Development of site-specific risk-based RGOs for the COCs at OU No. 16 are provided in Section 2.3.3. The Federal and state criteria for each COC and risk-based RGOs developed for each COC are all considered RGOs. From these, one RGO is chosen for each COC to develop a final set of RLs for the FS.

2.3.1 Definition of Applicable or Relevant and Appropriate Federal and State Requirements and "To Be Considered" Requirements

Under Section 121(d)(1) of CERCLA, remedial actions must attain a degree of cleanup which assures protection of human health and the environment. Additionally, CERCLA remedial actions that leave any hazardous substances, pollutants, or contaminants on site must meet, upon completion of the remedial action, a level or standard of control that at least attains standards, requirements, limitations, or criteria that are "applicable or relevant and appropriate" under the circumstances of the release. These requirements are known as "ARARs" or applicable or relevant and appropriate requirements. ARARs are derived from both Federal and state laws. USEPA Interim Guidance (52 Fed. Reg. 32496, 1987) provides the following definition of "Applicable Requirements":

> ...cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site.

Drinking water criteria may be an applicable requirement for a site with contaminated groundwater that is used as a drinking water source. The definition of "Relevant and Appropriate Requirements" is:

> ...cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or state law that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.

There are three types of ARARs: chemical-specific, location-specific, and action-specific. Chemical-specific ARARs include requirements which set health or risk-based concentration limits or ranges for specific hazardous substances, pollutants, or contaminants. Federal MCLs established under the Safe Drinking Water Act (SDWA) are examples of chemical-specific ARARs.

Location-specific ARARs set restrictions on activities based upon the characteristics of the site and/or the nearby suburbs. Examples include Federal and state siting laws for hazardous waste facilities and sites on the National Register of Historic Places.

The third classification of ARARs, action-specific, refers to requirements that set controls or restrictions on particular activities related to the management of hazardous substances, pollutants, or contaminants. RCRA regulations for closure of hazardous waste storage units, RCRA incineration standards, and pretreatment standards under the Clean Water Act (CWA) for discharges to publicly owned treatment works are examples of action-specific ARARs.

Subsection 121(d) of CERCLA requires that the remedial action meet a level or standard which at least attains Federal and state substantive requirements that qualify as ARARs. Federal, state, or local permits are not necessary for removal or remedial actions to be implemented on-site, but their substantive requirements or ARARs must be met. "On-site" is interpreted by the USEPA to include the areal extent of contamination and all suitable areas in reasonable proximity to the contamination necessary for implementation of the response action.

ARARs can be identified only on a site-specific basis. They depend on the detected contaminants at a site, site-specific characteristics, and particular remedial actions proposed for the site. Potential ARARs identified for OU No. 16 are presented in Section 2.3.2.

The preamble to the proposed rule in 40 CFR Part 300.400(g)(3) states that "advisories, criteria, or guidance TBC that do not meet the definition of ARAR may be necessary to determine what is protective or may be useful in developing Superfund remedies. The ARARs preamble described three types of TBCs: health effects information with a high degree of credibility, technical information on how to perform or evaluate site investigations or remedial actions, and policy" (USEPA, 1990a).

2.3.2 Potential ARARs and TBCs Identified for OU No. 16

A set of chemical-specific, location-specific, and action-specific ARARs were identified and evaluated for OU No. 16 and are discussed below.

2.3.2.1 Chemical-Specific ARARs and TBCs

Potential chemical-specific ARARs and TBCs identified for the COCs at OU No. 16 are listed on Table 2-2. These ARARs/TBCs are Federal MCLs and NCWQSs applicable to groundwater. A brief description of these standards is presented below.

Federal Maximum Contaminant Levels - MCLs are enforceable standards for public water supplies promulgated under the SDWA and are designed for the protection of human health. MCLs are based on laboratory or epidemiological studies and apply to drinking water supplies consumed by a minimum of 25 persons. These standards are designed for prevention of human health effects associated with a lifetime exposure (70-year lifetime) of an average adult (70 kg) consuming

2 liters of water per day. MCLs also consider the technical feasibility of removing the contaminant from the public water supply. As shown in Table 2-2, MCLs have been established for all of the groundwater COCs.

North Carolina Water Quality Standards (Groundwater) - Under the North Carolina Administrative Code (NCAC), Title 15A, Subchapter 2L, Section .0200, (15A NCAC 2L.0200) the NC DENR has established groundwater standards (NCWQSs) for three classifications of groundwater within the state: GA, GSA, and GC. Class GA waters are those groundwaters in the state naturally containing 250 milligram per liter (mg/L) or less of chloride. These waters are an existing or potential source of drinking water supply for humans. Class GSA waters are those groundwaters in the state naturally containing greater than 250 mg/L of chloride. These waters are an existing or potential source of water supply for potable mineral water and conversion to fresh water. Class GC water is defined as a source of water supply for purposes other than drinking. The NCAC T15A:02L.0300 has established sixteen river basins within the state as Class GC ground waters (15A NCAC 2L.0201 and 2L.0300).

The water quality standards for groundwater are the maximum allowable concentrations resulting from any discharge of contaminants to the land or water of the state, which may be tolerated without creating a threat to human health or which would otherwise render the groundwater unsuitable for its intended best usage. If the water quality standard of a substance is less than the limit of detectability, the substance shall not be permitted in detectable concentrations. If naturally occurring substances exceed the established standard, the standard will be the naturally occurring concentration as determined by the state. Substances which are not naturally occurring and for which no standard is specified are not permitted in detectable concentrations for Class GA or Class GSA groundwaters (15A NCAC 2L.0202).

The NCWQS for substances in Class GA and Class GSA groundwaters are established as the lesser of:

- Systemic threshold concentration (based on reference dose and average consumption)
- Concentration which corresponds to an ICR of 1×10^{-6}
- Taste threshold limit value
- Odor threshold limit value
- MCL
- National Secondary Drinking Water Standard

Note that the water quality standards for Class GA and Class GSA ground waters are the same except for chloride and total dissolved solids concentrations (15A NCAC 2L.0202).

The Class GA groundwater NCWQS for the groundwater COCs for OU No. 16 are listed on Table 2-2. The NCWQS will be considered an ARAR for OU No. 16.

2.3.2.2 Location-Specific ARARs

Potential location-specific ARARs identified for OU No. 16 are listed on Table 2-3. An evaluation determining the applicability of these location-specific ARARs with respect to OU No. 16 is also presented and summarized on Table 2-3. Based on this evaluation, specific sections of the following location-specific ARARs may be applicable to OU No. 16:

- Fish and Wildlife Coordination Act
- Federal Endangered Species Act
- North Carolina Endangered Species Act
- Executive Order 11990 on Protection of Wetlands
- Executive Order 11988 on Floodplain Management
- RCRA Location Requirements

Please note that the citations listed on Table 2-3 should not be interpreted to indicate that the entire citation is an ARAR. The citation listing is provided on the table as a general reference.

2.3.2.3 Action-Specific ARARs

Action-specific ARARs are typically evaluated following the development of alternatives since they are dependent on the type of action being considered. Therefore, at this step in the FS process, potential action-specific ARARs have only been identified, not evaluated, for OU No. 16. A set of potential action-specific ARARs are listed on Table 2-4. These ARARs are based on RCRA, CWA, SDWA, and Department of Transportation (DOT) requirements. Note that the citations listed on Table 2-4 should not be interpreted to indicate that the entire citation is an ARAR. The citation listing is provided on the table as a general reference.

These ARARs will be evaluated after the remedial alternatives have been identified for OU No. 16. Additional action-specific ARARs may also be identified and evaluated at that time.

2.3.3 Site-Specific Risk-Based RGOs

In this section of the FS, site-specific risk-based RGOs are developed for the COCs. The determination of derived RGOs for OU No. 16 involves establishing acceptable human health risk criteria, determining allowable risk associated with the COCs, and back calculating media-specific concentrations for the established risk levels. However, because NCWQS or MCL have been promulgated for each identified COC the estimation of risk-based RGOs will not be necessary.

The NCWQSs are established to provide the maximum allowable concentration resulting from discharge of a contaminant to land or waters of the state, which may be tolerated without creating a threat to human health or which otherwise render the groundwater unsuitable for its intended purpose. MCLs are enforceable standards for public water supplies promulgated under the Safe Drinking Water Act and are designed for the protection of human health. MCLs are designed for prevention of human health effects associated with a lifetime exposure (70-year lifetime) of an average adult (70 kg) consuming 2 liters of water per day. MCLs also consider the technical feasibility of removing the contaminant from the public water supply.

Exposure parameters (i.e., frequency, duration, amount ingested) used to estimate NCWQS and MCLs are the same as those used to estimate risk to future adult receptors in the groundwater ingestion scenario presented in the RA for OU No. 16. Due to exposure frequency, exposure duration, and amount ingested, risks to adults from groundwater ingestion are greater than risks to children. Consequently, RGOs that are protective of excess risks to adults will be protective of children. Because NCWQS and MCLs have been promulgated to be protective of human health, they will be applied as RGOs.

2.3.3.1 Comparison of RGOs to Maximum Contaminant Concentrations in Groundwater

In order to decrease uncertainties in estimating the reasonable maximum exposure (RME) (i.e., the maximum exposure that is reasonably expected to occur at the site), the maximum concentration of a contaminant in a medium can be compared to the RGO, instead of using the concentration term (i.e., the 95th percent upper confidence limit), which is used to estimate the RME. To assess point source contaminants, a more conservative approach is followed. This maximum value is usually compared to the RGO because, in most situations, assuming long-term contact with the maximum contaminant concentration is most conservative.

Conclusions of the human health risk assessment indicate that the cumulative future baseline cancer risks associated with groundwater were not within the USEPA's acceptable risk range of 1×10^{-4} to 1×10^{-6}, primarily because of the presence of VOCs. A comparison between the maximum detected concentrations of these COCs and the chemical-specific ARARs is shown in Table 2-5.

2.3.3.2 Uncertainty Analysis

Applying NCWQS and Federal MCLs as RGOs may be overly conservative. The groundwater contamination at OU No. 16 has been found to be limited to the upper 40 to 45 feet of the aquifer. At this depth, the geology consists of fine sand with some silt, clay and trace shells. In most of the borings obtained during the RI, this layer is identified by a significant decrease in moisture content and a color change from greenish-gray to olive. In some areas, this layer appears to act as a retarding layer, which can limit the amount of contaminant migration. As depth increases to approximately 50 feet bgs, the moisture content increases again. This layer continues to 70 feet bgs. At this depth, another layer is encountered which exhibits a slight decrease in moisture content. The screens of the deep wells installed during the RI are screened above the layer.

2.3.4 Summary of RLs and Final COCs

RLs associated with the COCs at OU No. 16 are presented on Table 2-6. This list was based on a comparison of chemical-specific standards identified throughout Section 2.3.2. If a COC had a state and Federal standard, the most limiting (or conservative) standard was selected as the RL for that contaminant. The basis for each of the RLs is also presented on Table 2-6.

In order to determine the final set of COCs, the maximum contaminant concentrations detected in the medium of concern were compared to the RLs presented in Table 2-6. The contaminants that exceeded of the RLs were retained as COCs. The contaminants that did not exceed the RLs were no longer considered to be COCs with respect to this FS. Based on this comparison, all of the COCs exceeded a RL and were retained as COCs for OU No. 16; cis-1,2-dichloroethene, trans-1,2-dichloroethene, total-1,2-dichloroethene, trichloroethene, tetrachloroethene, and vinyl chloride. Therefore, the final set of COCs and the associated RLs are presented on Table 2-6.

2.4 Remedial Action Objectives

Remedial action objectives are medium-specific or operable unit-specific goals established for protecting human health and the environment. At OU No. 16, the specific media to be addressed by the remedial action is contaminated groundwater. At Site 89, shallow groundwater has been impacted in the area of the DRMO facility. The contaminant plume has migrated south and slightly east of the DRMO. Groundwater at the intermediate depth has also been impacted. VOCs have migrated east of the DRMO facility across White Street Extension into the wooded area. The contaminant plume at the intermediate depth extends approximately 1,500 feet east of the source area. The shallow and intermediate groundwater areas of concern are shown in Figures 2-1 and 2-2 for Sites 89 and 93.

The areal extent of groundwater volatile contamination at Site 93 is relatively local to the original source area. The contamination is primarily located in the shallow aquifer at low concentrations. The shallow groundwater area of concern for Site 93 is shown in Figure 2-1.

Objectives developed for groundwater at OU No. 16 include:

- Mitigate the potential for direct exposure to the contaminated groundwater in the surficial aquifer.
- Minimize or prevent the horizontal and vertical migration of contaminated groundwater in the surficial aquifer.
- Restore the surficial and intermediate aquifers to the RLs established for the groundwater COCs.
- Maintain the quality of the deeper, Castle Hayne aquifer.

2.5 References

Baker. 1997. Remedial Investigation Report, Operable Unit No. 16, Sites 89 and 93. Marine Corps Base, Camp Lejeune, North Carolina.

North Carolina Administrative Code, Title 15A, Department of Environment, Health, and Natural Resources, Division of Environmental Management, Subchapter 2L, Sections .0200 through .0300, Classifications and Water Quality Standards Applicable to the Groundwater of North Carolina.

USEPA, 1996. United States Environmental Protection Agency. Drinking Water Regulations and Health Advisories. Office of Water. U.S. Environmental Protection Agency. Washington, D.C. EPA 822-R-96-001. February 1996.

SECTION 2.0 TABLES

TABLE 2-1

CONTAMINANTS OF CONCERN FOR THE FS OPERABLE UNIT NO. 16 (SITES 89 AND 93) MCB CAMP LEJEUNE, NORTH CAROLINA FEASIBILITY STUDY, CTO-0356

Media	Contaminants of Concern[1]
Groundwater	cis-1,2-Dichloroethene trans-1,2-Dichloroethene 1,2-Dichloroethene (total) Trichloroethene Tetrachloroethene Vinyl Chloride

Notes:

[1] This list includes contaminants of potential concern evaluated in the the RI (Baker, 1997).

TABLE 2-2

POTENTIAL CHEMICAL-SPECIFIC ARARs AND TBCs FOR GROUNDWATER COCs
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Contaminant of Concern	Federal MCL (µg/L)	NCWQS (µg/L)
cis-1,2-Dichloroethene	70	70
trans-1,2-Dichloroethene	100	70
1,2-Dichloroethene (total)	70	NE
Trichloroethene	5	2.8
Tetrachloroethene	6	0.7
Vinyl Chloride	2	0.015

Notes:

NCWQS = North Carolina Water Quality Standards for Groundwater
MCL = Safe Drinking Water Act Maximum Contaminant Level
NE = No Criteria Established
μg/L = micrograms per liter

TABLE 2-3

EVALUATION OF POTENTIAL LOCATION-SPECIFIC ARARs
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Potential Location-Specific ARAR	General Citation	ARAR Evaluation
National Historic Preservation Act of 1966 - requires action to take into account effects on properties included in or eligible for the National Register of Historic Places and to minimize harm to National Historic Landmarks.	16 USC 470, 40 CFR 6.301(b), and 36 CFR 800	No known historic properties are within or near OU No. 16, therefore, this act will not be considered an ARAR.
Archeological and Historic Preservation Act - establishes procedures to provide for preservation of historical and archeological data which might be destroyed through alteration of terrain.	16 USC 469, and 40 CFR 6.301(c)	No known historical or archeological data is known to be present at the sites, therefore, this act will not be considered an ARAR.
Historic Sites, Buildings and Antiquities Act - requires action to avoid undesirable impacts on landmarks on the National Registry of Natural Landmarks.	16 USC 461467, and 40 CFR 6.301(a)	No known historic sites, buildings or antiquities are within or near OU No. 16, therefore, this act will not be considered as an ARAR.
Fish and Wildlife Coordination Act - requires action to protect fish and wildlife from actions modifying streams or areas affecting streams.	16 USC 661-666	Edwards Creek is located near and within the operable unit boundaries. If remedial actions are implemented that modify this creek, this will be an applicable ARAR.
Federal Endangered Species Act - requires action to avoid jeopardizing the continued existence of listed endangered species or modification of their habitat.	16 USC 1531, 50 CFR 200, and 50 CFR 402	Many protected species have been sited near and on MCB Camp Lejeune such as the American alligator, the Bachmans sparrow, the Black skimmer, the Green turtle, the Loggerhead turtle, the piping plover, the Red-cockaded woodpecker, and the rough-leaf loosestrife (LeBlond, 1991),(Fussell, 1991),(Walters, 1991). Therefore, this will be considered an ARAR.

TABLE 2-3 (Continued)

EVALUATION OF POTENTIAL LOCATION-SPECIFIC ARARs
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Potential Location-Specific ARAR	General Citation	ARAR Evaluation
North Carolina Endangered Species Act - per the North Carolina Wildlife Resources Commission. Similar to the Federal Endangered Species Act, but also includes State special concern species, State significantly rate species, and the State watch list.	GS 113-331 to 113-337	Since the American alligator has been sighted within MCB Camp Lejeune, this will be considered an ARAR.
Rivers and Harbors Act of 1899 (Section 10 Permit) - requires permit for structures or work in or affecting navigable waters.	33 USC 403	No remedial actions will affect the navigable waters of the New River. Therefore, this act will not be considered an ARAR.
Executive Order 11990 on Protection of Wetlands - establishes special requirements for federal agencies to avoid the adverse impacts associated with the destruction or loss of wetlands and to avoid support of new construction in wetlands if a practicable alternative exists.	Executive Order Number 11990, and 40 CFR 6	Based on a review of Wetland Inventory Maps, Edwards Creek has areas of wetlands. Therefore, this will be an applicable ARAR.
Executive Order 11988 on Floodplain Management - establishes special requirements for federal agencies to evaluate the adverse impacts associated with direct and indirect development of a floodplain.	Executive Order Number 11988, and 40 CFR 6	Based on the Federal Emergency Management Agency's Flood Insurance Rate Map for Onslow County, OU No. 16 is primarily within a minimal flooding zone (outside the 500-year floodplain). However, the immediate areas around Edwards Creek are within the 100-year floodplain (FEMA, 1987). Therefore, this may be an ARAR for the operable unit.
Wilderness Act - requires that federally owned wilderness area are not impacted. Establishes nondegradation, maximum restoration, and protection of wilderness areas as primary management principles.	16 USC 1131, and 50 CFR 35.	No known Federally-owned wilderness areas are located near the operable unit, therefore, this act will not be considered an ARAR.
National Wildlife Refuge System - restricts activities within a National Wildlife Refuge.	16 USC 668, and 50 CFR 27	No known National Wildlife Refuge areas are located near the operable unit, therefore, this will not be considered an ARAR.
Scenic Rivers Act - requires action to avoid adverse effects on designated wild or scenic rivers.	16 USC 1271, and 40 CFR 6.302(e)	No known wild or scenic rivers are located near the operable unit, therefore, this act will not be considered an ARAR.

TABLE 2-3 (Continued)

EVALUATION OF POTENTIAL LOCATION-SPECIFIC ARARs
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Potential Location-Specific ARAR	General Citation	ARAR Evaluation
Coastal Zone Management Act - requires activities affecting land or water uses in a coastal zone to certify noninterference with coastal zone management.	16 USC 1451	No activities at the site will affect land or water uses in a coastal zone, therefore, this act will not be considered an ARAR.
Clean Water Act (Section 404) - prohibits discharge of dredged or fill material into wetland without a permit.	33 USC 404	No actions to discharge dredged or fill material into wetlands will be considered for the operable unit, therefore, this act will not be considered an ARAR.
RCRA Location Requirements - limitations on where on-site storage, treatment, or disposal of RCRA hazardous waste may occur.	40 CFR 264.18	These requirements may be applicable if the remedial actions for the operable unit include the on-site storage, treatment, or disposal of RCRA hazardous waste. Therefore, these requirements may be an applicable ARAR for the operable unit.

Notes:

LeBlond, Richard. 1991. "Critical Species List. Camp Lejeune. Endangered Species and Special-Interest Communities Survey." Principal Investigator.

TABLE 2-4

POTENTIAL ACTION-SPECIFIC ARARs
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Standard (1)	Action	General Citation
RCRA	Capping	40 CFR 264
	Closure	40 CFR 264, 244
	Container Storage	40 CFR 264, 268
	New Landfill	40 CFR 264
	New Surface Impoundment	40 CFR 264
	Dike Stabilization	40 CFR 264
	Excavation, Groundwater Diversion	40 CFR 264, 268
	Incineration	40 CFR 264, 761
	Land Treatment	40 CFR 264
	Land Disposal	40 CFR 264, 268
	Slurry Wall	40 CFR 264, 268
	Tank Storage	40 CFR 264, 268
	Treatment	40 CFR 264, 265, 268; 42 USC 6924; 51 FR 40641; 52 FR 25760
	Waste Pile	40 CFR 264, 268
CWA	Discharge to Water of United States	40 CFR 122, 125, 136
	Direct Discharge to Ocean	40 CFR 125
	Discharge to POTW	40 CFR 403, 270
	Dredge/Fill	40 CFR 264; 33 CFR 320-330; 33 USC 403
CAA (NAAQS)	Discharge to Air	40 CFR 50
SDWA	Underground Injection Control	40 CFR 144, 146, 147, 268
TSCA	PCB Regulations	40 CFR 761
DOT	DOT Rules for Transportation	49 CFR 107

Notes:

(1) RCRA = Resource Conservation Recovery Act
CWA = Clean Water Act
CAA = Clean Air Act
NAAQS = National Ambient Air Quality Standards
SDWA = Safe Drinking Water Act
DOT = Department of Transportation

TABLE 2-5

COMPARISON OF MAXIMUM GROUNDWATER COC CONCENTRATIONS TO ARARs
FUTURE RESIDENTS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Contaminant	Maximum Groundwater Concentration		NCWQS[1] (μg/L)	Federal MCL[2] (μg/L)
	Site 89 (μg/L)	Site 93 (μg/L)		
cis-1,2-Dichloroethene	818	175	70	70
trans-1,2-Dichloroethene	451	57	70	100
1,2-Dichloroethene	880	92	NE	70
Trichloroethene	744	39	2.8	5
Tetrachloroethene	43	65	0.7	6
Vinyl Chloride	130	ND	0.015	2

Notes:

(1) NCWQS = North Carolina Water Quality Standards for Groundwater
(2) MCL = Safe Drinking Water Act Maximum Contaminant Level
NE = No Criteria Established
ND = Not Detected
μg/L = micrograms per liter

TABLE 2-6

REMEDIATION LEVELS FOR COCs
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Contaminant of Concern	Remediation Levels		Basis of Goal[1]
	Site 89 (µg/L)	Site 93 (µg/L)	
cis-1,2-Dichloroethene	70	70	NCWQS
trans-1,2-Dichloroethene	70	70	NCWQS
1,2-Dichloroethene	70	70	MCL
Trichloroethene	2.8	2.8	NCWQS
Tetrachloroethene	0.7	0.7	NCWQS
Vinyl Chloride	0.015	NA	NCWQS

Notes:

(1) NCWQS = North Carolina Water Quality Standards for Groundwater
MCL = Maximum Contaminant Level
NA = Not Applicable

SECTION 2.0 FIGURES

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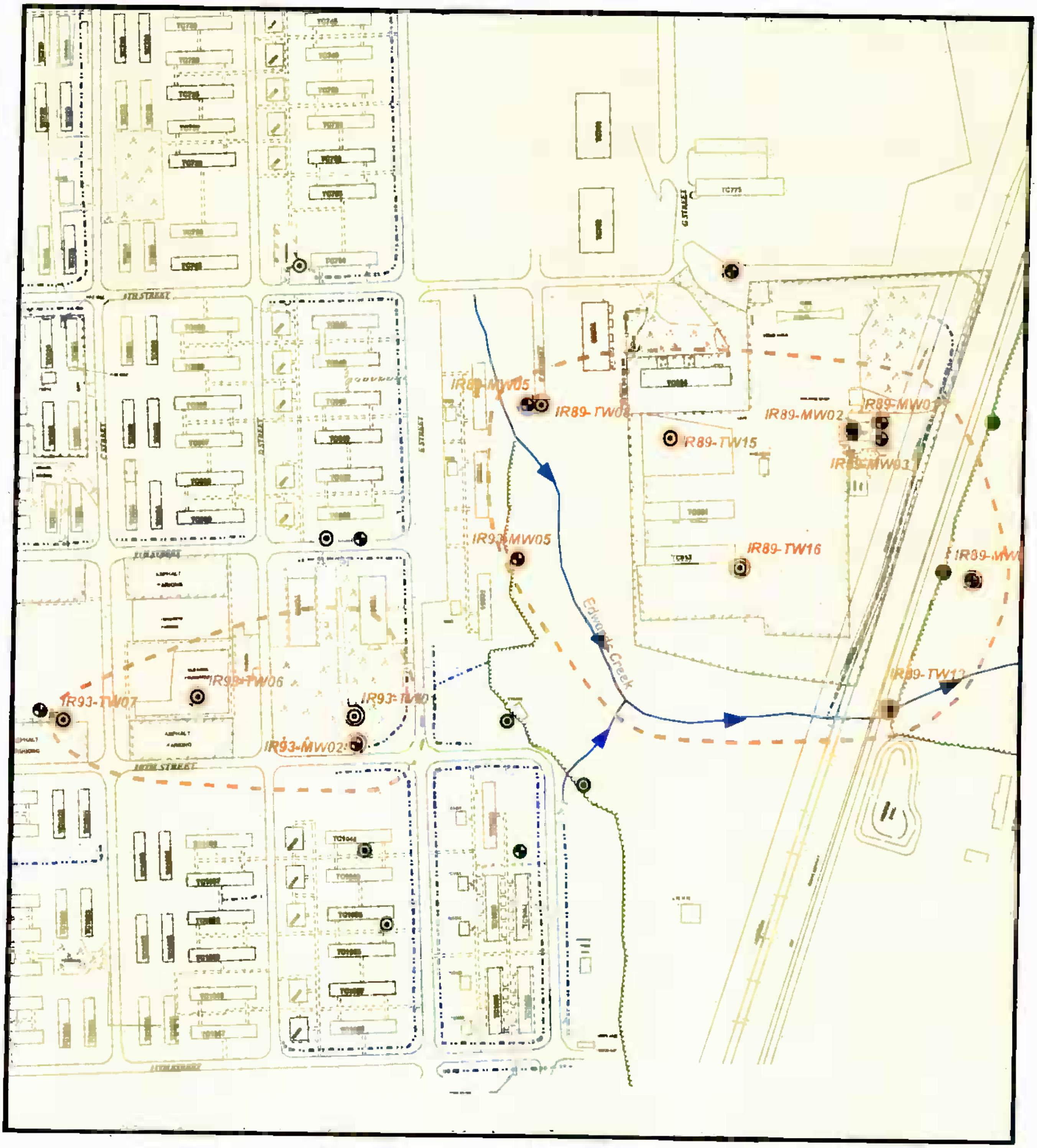

LEGEND

- ● Permanent Monitoring Well Location
- ⊙ Temporary Monitoring Well Location
- MW01 Monitoring Well Location and Well ID with concentrations exceeding NCWQS/MCLS
- / \ / Estimated Boundary of Groundwater Contamination above Applicable Standards

Scale

200 0 200 400 600 Feet

N W E S

MARINE CORPS BASE, CAMP LEJEUNE NORTH CAROLINA

SHALLOW GROUNDWATER AREA OF CONCERN OPERABLE UNIT NO. 16 FEASIBILITY STUDY CTO 0356

Baker

FIGURE 2 - 1

LEGEND

● Permanent Monitoring Well Location

⊙ Temporary Monitoring Well Location

TW21IW Well Location and Well ID with concentrations exceeding NCWQS/MCLS

Estimated Boundary of Groundwater Contamination above Applicable Standards

Scale

300 0 300 600 900 Feet

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

INTERMEDIATE GROUNDWATER
AREA OF CONCERN
OPERABLE UNIT NO. 16
FEASIBILITY STUDY
CTO 0356

Baker

FIGURE 2 - 2

3.0 IDENTIFICATION AND PRELIMINARY SCREENING OF REMEDIAL ACTION TECHNOLOGIES

Section 3.0 includes the identification and preliminary screening of remedial action technology types and process options that may be applicable to the remediation of groundwater at both Sites 89 and 93. More specifically, Section 3.1 identifies a set of general response actions, Section 3.2 identifies remedial action technology types and process options for each general response action, and Section 3.3 presents the preliminary screening of the remedial action technology types and process options. After the preliminary screening, the remaining technology types/process options undergo a process option evaluation in Section 3.4. The final set of remedial action technology types and a brief description of the options that pass the process option evaluation is presented in Section 3.5. Where specific information relates to an individual site alone (i.e., Site 89), the appropriate site reference will be highlighted. If however, a specific site reference is not noted within the following subsections, the above information presented generally relates to both sites.

3.1 General Response Actions

General response actions are broad-based, medium-specific categories of actions that can be identified to satisfy the remedial action objectives of an FS. Due to the similar nature of groundwater contamination at Sites 89 and 93, five general response actions have been identified for these sites. The general response actions applicable to both Site 89 and Site 93 include: no action, institutional controls, containment/collection actions, treatment actions, and discharge actions. A brief description of these general response actions follows.

3.1.1 No Action

The NCP requires the evaluation of the no action response as part of the FS process. A no action response provides a baseline assessment for comparisons involving other remedial alternatives that offer a greater level of response. A no action alternative may be considered appropriate when there are no adverse or unacceptable risks to human health or the environment, or when a response action may cause a greater environmental or health danger than the no action alternative.

3.1.2 Institutional Controls

Institutional controls are various "institutional" actions that can be implemented as part of a complete remedial action alternative (RAA). Institutional controls are designed to minimize exposure to potential site specific hazards. With respect to groundwater, institutional controls may include monitoring programs, access restrictions, and/or aquifer use restrictions. With respect to surface water, institutional controls may include monitoring.

3.1.3 Containment/Collection Actions

This general response action combines both containment and collection actions. Containment actions include technologies which contain and/or isolate contaminants by covering, sealing, chemically stabilizing, or providing an effective barrier against specific areas of concern. These actions also provide isolation and prevent direct exposure with or migration of the contaminated media. Collection actions include technologies that collect contaminants via withdrawal techniques such as extraction or subsurface drains.

3.1.4 Treatment Actions

Treatment actions for contaminated groundwater include biological, physical/chemical, and thermal treatments; engineered wetlands; and off-site and in situ treatment systems. Treatment actions are usually followed by discharge actions.

3.1.5 Discharge Actions

Discharge actions involve the on-site and/or off-site destinations where groundwater may be discharged. Discharge actions are usually employed following groundwater treatment.

3.2 Identification of Remedial Action Technologies and Process Options

In this step, an extensive set of potentially applicable technologies and process options have been identified for each general response action. The term "technology type" refers to general categories of technologies such as biological treatment, physical/chemical treatment, thermal treatment, engineered wetlands, or off-site and in situ treatment. The term "process option" refers to specific processes, or technologies within each generalized technology type. For example, air stripping, carbon adsorption, and reverse osmosis are process options that fall under the technology type identified as physical/chemical treatment. Several technology types may be identified for each general response action, and numerous process options may exist within each generalized technology type.

With respect to their corresponding general response action, the remedial action technology types and the associated process options that are potentially applicable at Site 89 or at Site 93 are identified on Table 3-1.

3.3 Preliminary Screening of Remedial Action Technologies and Process Options

During the preliminary screening, the set of remedial action technology types and process options identified on Table 3-1 have been screened (or reduced) by evaluating the technology types with respect to contaminant-specific and site-specific factors. This screening step was accomplished by using readily available information from the RI (with respect to contaminant types, contaminant concentrations, and on-site characteristics) to screen out technology types and process options that cannot be effectively implemented at the site (USEPA, 1988). In general, all technology types and process options which appear to be applicable to the site contaminants and site conditions has been retained for further evaluation. The preliminary screenings for Sites 89 and 93 are presented on Tables 3-2 and 3-3, respectively.

As noted on Tables 3-2 and 3-3, several technology types and/or process options were eliminated from further evaluation because they were determined to be inappropriate for the site-specific characteristics and/or contaminant-specific characteristics that were identified for Sites 89 and 93.

The groundwater technology types/ process options that passed the preliminary screening and were retained for further evaluation are identical for Sites 89 and 93. This similar preliminary screening outcome was expected, based upon the close proximity of these sites, their similar land-use characteristics, and the very similar nature of the groundwater contamination. Therefore, Table 3-4 presents the process options that passed the individual, preliminary screening conducted for Sites 89 and 93.

3.4 Process Option Evaluation

The objective of the process option evaluation is to select the most appropriate process option for each applicable remedial technology type in order to simplify the subsequent development and evaluation of alternatives without limiting flexibility during remedial design. More than one process option may be selected for a technology type if the processes are sufficiently different in their performance that one would not adequately represent the other. The representative process provides a basis for developing performance specifications during preliminary design. However, the specific process option used to implement the remedial action may not be selected until the remedial design phase.

During the process option evaluation, the process options listed on Table 3-4 were evaluated based on three criteria: effectiveness, implementability, and relative cost. The evaluation of effectiveness focused on: the potential effectiveness of a process option in meeting the remedial action objectives; the potential impacts to human health and the environment during the construction and implementation phase; and how reliable the process is with respect to the COCs. The evaluation of implementability focused on the administrative feasibility of implementing a technology (e.g., obtaining permits), since the technical implementability was previously considered in the preliminary screening. The evaluation of relative cost played a limited role in this screening. Only relative capital and operating and maintenance (O&M) costs were used instead of detailed estimates. As per USEPA guidance, the relative cost analysis was made on the basis of engineering judgement.

A summary of the process option evaluation is presented on Table 3-5. It is important to note that the elimination of a process option does not mean that the process option can never be reconsidered for the site. As previously stated, the purpose of this process option evaluation is to simplify the development and evaluation of the most appropriate potential alternatives. In addition, it should be noted that although Table 3-5 incorporates the evaluation of both Site 89 and Site 93, specifics were incorporated for each site individually. Therefore, the appropriate application of a particular process option to a particular site is spelled out on Table 3-5. The statements of applicability and the screening results will note any exceptions that may apply to either of the two sites. If there is no mention of an exception, then the evaluation results are slated for both Sites 89 and 93.

3.5 Final Set of Remedial Action Technologies/Process Options

Table 3-6 identifies the final set of feasible technology types and process options that were used to develop remedial action alternatives for Sites 89 and 93. A brief description of each technology type/process option is presented below.

3.5.1 No Action

The no action response provides a baseline for comparison with other response actions. Under the no action response, groundwater at Site 89 and Site 93 will be left in place, allowing the effects of natural, passive remediation to occur. Passive remediation involves natural attenuation processes, such as biodegradation, volatilization, leaching, adsorption, and chemical reactions between subsurface materials. Under the no action response; however, no actions will be undertaken to monitor or track remedial success or progress.

3.5.2 Groundwater, Surface Water, and Sediment Monitoring

A long-term groundwater, surface water, and sediment monitoring program could be implemented at Sites 89 and 93 as an institutional control. This program would provide continual information regarding groundwater contaminant concentrations and migration over time.

3.5.3 Restrictions in Base Master Plan

Aquifer-use restrictions could be instituted via the Base Master Plan to restrict the use of the surficial aquifer at Sites 89 and 93. These restrictions would help reduce the risk to human populations from ingestion and direct contact with the contaminants within the aquifer.

3.5.4 Extraction Wells

The extent and migration of a contaminated groundwater plume may be contained or collected via pumping techniques. Existing wells or additional extraction wells, strategically located according to the hydrogeologic characteristics of the surficial aquifer and the chemical characteristics of the contaminants of concern, can be used. The extraction wells are pumped at specific rates such that the capture radius from the well system intercepts the contaminant plume. Groundwater pumping may be combined with additional treatment technology types. Pumping via extraction wells is a proven technique for the containment of groundwater contamination, but may not be appropriate for complete aquifer restoration.

3.5.5 Interceptor Trenches

Interceptor trenches generally consist of a series or network of perforated pipes that are installed within trenches that are then backfilled with porous media. The groundwater that tends to collect within this porous media is transferred (via pumping or gravity) to a collection point and/or above ground treatment facility. Due to the nature of trench construction, interceptor trenches are generally only considered for contaminated groundwater located at shallow depths (similar to the surficial groundwater contamination identified at Site 89).

3.5.6 Volatilization (Air/Steam Stripping)

Air/steam stripping is a physical/chemical treatment process in which water and air/steam are brought into contact with each other for the purpose of transferring volatile substances from solution in a liquid to a solution in a gas. As compared to steam stripping, air stripping has been most cost-effectively used for the treatment of low concentrations of VOCs or as a pretreatment step prior to an activated carbon treatment technology. The off-gas generated during the treatment process may require collection and subsequent treatment.

3.5.7 Carbon Adsorption

Carbon adsorption is a physical/chemical treatment process that binds organic molecules to the surface of the activated carbon particles. The adsorption process involves contacting a waste stream with carbon, usually by flow through a series of packed-bed reactors. Once the micropore surfaces of the carbon are saturated with organics, the carbon is "spent" and must be replaced or regenerated. The time to reach breakthrough is the most critical operating parameter of this type of treatment system (Rich, 1987).

3.5.8 Neutralization

Neutralization is the interaction of an acid with a base, or vice versa, to yield a final pH of approximately 7.0. This process option is one of the most common types of chemical treatments used by industrial wastewater treatment facilities. Pretreatment of the waste stream may be needed for large amounts of suspended solids, oils, or grease. The major limitation of neutralization is that it is subject to the influence of temperature (USEPA, 1990).

3.5.9 Precipitation

Precipitation is a process in which materials in solution are transferred into a solid phase for removal. Removal of heavy metals is the most common precipitation application in wastewater treatment. Generally, lime or sodium sulfide is added to the wastewater in a rapid mixing tank. Flocculating agents such as alum, ferric chloride, and ferric sulfate may be added to enhance the agglomeration of precipitate particles. The insoluble precipitate is then removed for recovery or disposal using solids separation technologies such as sedimentation or filtration.

3.5.10 Filtration

Filtration is a physical process used to remove suspended solids and biological floc from wastewater. The separation is accomplished by passing water through a physically restrictive medium, resulting in the entrapment of suspended particulate matter. The media typically used for filtration includes sand, coal, garnet, and diatomaceous earth. Filtration is generally preceded by chemical precipitation and neutralization.

3.5.11 Flocculation

Flocculation is a process in which chemical coagulants cause colloidal particles to agglomerate into larger particles. Similar to precipitation, the removal of heavy metals is the most common flocculation application in wastewater treatment. Alum, ferric chloride and ferric sulfate are added to the wastewater to agglomerate the flocculated particles.

3.5.12 Sedimentation

Sedimentation is a physical process in which colloidal particles are allowed to settle out of an aqueous waste stream via gravity separation.

3.5.13 In Situ Volatilization (Air Sparging, In-Well Aeration)

Air sparging offers a commercially proven technology, while in-well aeration is a somewhat new and innovative technology. In-well aeration, also referred to as "vacuum vapor extraction", is a variation of air sparging. Where as air sparging can be thought of as in situ air stripping, in-well aeration can be thought of as in-well air stripping. Air sparging incorporates the injection of air into the water saturated zone for the purpose of removing organic contaminants via volatilization. Once volatilized, the sparged contaminants are generally collected. Soil vapor extraction may be used to collect the volatilized contaminants and convey them to an off-gas treatment system. The process of in-well aeration involves injecting air that is not intended to enter the aquifer into a well (although the air may enter the aquifer in a dissolved form). The resulting in-well airlift pump effect causes water to flow into the well from the deeper screened portion of the well and out of the well from the shallower screened portion (Hinchee, 1994). Volatiles are stripped from the groundwater within the well, rise to the top of the well with the injection air, and are collected and treated at an above ground treatment facility. Under the air sparging or in-well aeration system, groundwater is treated without being extracted from the ground. In addition to treating contaminants via volatilization, both technologies may provide enhanced bioremediation within the aquifer and vades zone.

3.5.14 Passive Treatment Wall

An innovative technology, passive treatment walls are in situ permeable walls made of reactive material that reduce the groundwater contaminants as they naturally flow (with the groundwater) through the wall. An example includes the permeable reactive wall which is made of a metals formulation zero-valent iron filings that degrades chlorinated compounds into innocuous products. Appendix A provides additional background information on permeable reactive walls.

3.5.15 Natural Attenuation

The remedial actions associated with natural attenuation include long-term groundwater/surface water monitoring, and groundwater modeling to demonstrate the remedial success of natural attenuation. Factors that influence these natural processes include: water content in soil, soil porosity/permeability, clay content, adsorption, soil density, pH, oxidation/reduction potential, temperature, wind, evaporation, precipitation, microbial community, chemical composition and concentration, soil management, and availability of nutrients. Under this response action, many of these natural attenuation parameters would be monitored, as well as, monitoring the TCL VOCs within the groundwater and surface water/sediments of Edwards Creek.

3.5.16 On-Site Surface Water Discharge

Treated groundwater from Sites 89 or 93 could be discharged into Edwards Creek. The capacity of Edwards Creek, as well as any required discharge permits, must be considered if it is to be used as a discharge location following groundwater treatment.

3.6 References

Hinchee, 1994. Air Sparging for Site Remediation. Lewis Publishers, Columbus, Ohio.

Rich, Gerald and Kenneth Cherry. 1987. Hazardous Waste Treatment Technologies. Third Printing. Pudvan Publishing Company, Northbrook, Illinois.

USEPA, 1988. United States Environmental Protection Agency. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Office of Emergency and Remedial Response. Washington, D.C. EPA/540/G-89/004.

USEPA, 1990. United States Environmental Protection Agency. National Oil and Hazardous Substances Pollution Contingency Plan. 55FR8665. Office of Emergency and Remedial Response. Washington, D.C. March 1990.

SECTION 3.0 TABLES

TABLE 3-1

POTENTIAL SET OF REMEDIAL ACTION TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Media	General Response Action	Remedial Action Technology Type	Process Option
Groundwater	No Action	No Action	Not Applicable
	Institutional Controls	Monitoring	Groundwater/Surface Water Monitoring
		Access Restrictions	Deed Restrictions
			Fencing
		Aquifer Use Restrictions	Restrictions in Base Master Plan
	Containment/Collection Actions	Capping	Clay/Soil Cap
			Asphalt/Concrete Cap
			Soil Cover
			Multilayered Cap
		Vertical Barriers	Grout Curtain
			Slurry Wall
			Sheet Piling
			Rock Grouting
		Horizontal Barriers	Grout Injection
			Block Displacement
		Extraction	Extraction Wells
			Extraction/Injection Wells
			Hydrofracturing
		Subsurface Drains	Interceptor Trenches
	Treatment Actions	Biological Treatment	Aerobic ● Aerated Lagoon ● Activated Sludge ● Powdered Activated Carbon Treatment ● Trickling Filter ● Rotating Biological Contactor
			Anaerobic
		Physical/Chemical Treatment	Volatilization (Air Stripping/ Steam Stripping)
			Carbon Adsorption
			Hydrolysis
			Chemical Dechlorination
			Ultraviolet (UV) Oxidation

TABLE 3-1 (Continued)

POTENTIAL SET OF REMEDIAL ACTION TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Media	General Response Action	Remedial Action Technology Type	Process Option
Groundwater (Continued)	Treatment Actions (Continued)	Physical/Chemical Treatment (Continued)	Chemical Oxidation ● Hydrogen Peroxide ● Chlorine ● Potassium Permanganate ● Ozonation
			Chemical Reduction
			Reverse Osmosis
			Ion Exchange
			Electrolysis
			Electrodialysis
			Electrochemical Ion Generation
			Distillation
			Neutralization
			Precipitation
			Filtration
			Flocculation
			Sedimentation
			Oil/Water Separation
		Thermal Treatment	Liquid Injection Incineration
			Molten Glass
			Plasma Arc Torch
			Pyrolysis
			Wet Air Oxidation
			Supercritical Oxidation
		Engineered Wetland Treatment	Constructed Wetlands
		Off-site Treatment	RCRA Facility
			Site 82 Treatment System
			Sewage Treatment Plant
		In Situ Treatment	Biodegradation
			In Situ Volatilization/Air Sparging/In-Well Aeration
			Dual Phase Extraction
			Passive Treatment Wall
			Natural Attenuation

TABLE 3-1 (Continued)

POTENTIAL SET OF REMEDIAL ACTION TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Media	General Response Action	Remedial Action Technology Type	Process Option
Groundwater (Continued)	Discharge Actions	On-site Discharge	Surface Water
			Reinjection ● Injection Wells ● Infiltration Galleries
		Off-site Discharge	Sewage Treatment Plant

TABLE 3-2

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 89)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
No Action	No Action	Not Applicable	No Action - Contaminated groundwater remains as is.	Potentially applicable; required by the NCP.	Retained
Institutional Controls	Monitoring	Groundwater/Surface Water Monitoring	Ongoing monitoring of existing and/or newly installed wells and Edwards Creek.	Potentially applicable.	Retained
	Access Restrictions	Deed Restrictions	Limit the future use of land including placement of wells.	Deed restrictions are not applicable to military installation not on closure list.	Eliminated
		Fencing	Limit access by installing a fence around contamination area.	A fence alone will not prevent contaminant migration.	Eliminated
	Aquifer Use Restrictions	Restrictions in Base Master Plan	Prohibit use of the contaminated aquifer as a potable water source.	Potentially applicable.	Retained
Containment/Collection Actions	Capping	Clay/Soil Cap Asphalt/Concrete Cap Soil Cover Multilayered Cap	Capping material placed over areas of contamination.	This process option would not be feasible due to the extent of groundwater contamination within an industrialized/developed area, as well as, a densely wooded area.	Eliminated
	Vertical Barriers	Grout Curtain	Pressure injection of grout in a regular pattern of drilled holes to contain contamination.	This process option would be impractical due to the extent of groundwater contamination and the depth of the first semi-confining unit (~50 bgs).	Eliminated
		Slurry Wall	Trench around areas of contamination. The trench is filled with a soil bentonite slurry to limit migration of contaminants.	This process option would be impractical due to the extent of groundwater contamination and the depth of the first semi-confining unit (~50 bgs).	Eliminated
		Sheet Piling	Interlocking sheet pilings installed via drop hammer around areas of contamination.	This process option would be impractical due to the extent of groundwater contamination and the depth of the first semi-confining unit (~50 bgs).	Eliminated
		Rock Grouting	Specialty operation for sealing fractures, fissures, solution cavities, or other voids in rock to control flow of groundwater.	The depth to bedrock limits the practicality of this process option.	Eliminated

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 89)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Containment/Collection Actions (Continued)	Horizontal Barriers	Grout Injection	Pressure injection of grout to form a bottom seal across a site at a specific depth.	Technique is in the experimental stage. Grout injection alone will not prevent contaminant migration.	Eliminated
		Block Displacement	Continued pumping of grout into specially notched holes causing displacement of a block of contaminated earth.	Technique is in the experimental stage.	Eliminated
	Extraction	Extraction Wells	Series of wells used to extract contaminated groundwater. Well screen must be placed within the identified plume for maximum contaminant collection.	Potentially applicable.	Retained
		Extraction/Injection Wells	Injection wells inject uncontaminated groundwater to enhance collection of contaminated groundwater via the extraction wells. Injection wells can also inject material into an aquifer to remediate groundwater.	Injection liquid may mound in the subsurface formations rather than flowing through.	Eliminated
		Hydrofracturing	Pressurized water is injected to create fractures in the formation, thus improving permeability. Can be used to enhance pump and treat systems.	The fractures may open new passageways through which contaminants can spread vertically and/or horizontally.	Eliminated
	Subsurface Drains	Interceptor Trenches	Perforated pipe installed in trenches backfilled with porous media to collect contaminated groundwater. Generally limited to shallow depths.	Potentially applicable for the noted shallow contamination (surficial aquifer).	Retained
Treatment Actions	Biological Treatment	Aerobic ● Aerated Lagoon ● Activated Sludge ● Powdered Activated Carbon Treatment ● Trickling Filter ● Rotating Biological Contractor	Degradation of organics using microorganisms in an aerobic environment.	Not highly effective for chlorinated VOCs.	Eliminated

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 89)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Biological Treatment (Continued)	Anaerobic	Degradation of organics using microorganisms in an anaerobic environment.	Potentially applicable to chlorinated VOCs such as TCE.	Retained
	Physical/Chemical Treatment	Volatilization (Air Stripping/Steam Stripping)	Mixing large volumes of air/steam with water in a packed column to promote transfer of VOCs to air. Effective for VOCs and some SVOCs.	Potentially applicable to VOCs.	Retained
		Carbon Adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column. Effective for wide range of organics.	Potentially applicable to VOCs.	Retained
		Hydrolysis	By adding chemicals or irradiation, molecular bonds are broken making contaminants water-soluble. Used primarily to treat aqueous wastes containing refractory organics.	Primary COCs (PCE, TCE, 1,2-DCE) are not very water-soluble.	Eliminated
		Chemical Dechlorination	Process which uses specially synthesized chemical reagents to destroy hazardous chlorinated molecules or to detoxify them to form other less harmful compounds. Effective for PCBs, chlorinated hydrocarbons and dioxins.	Groundwater may require extensive dewatering prior to the application of this technology. Based upon the suspected volume of groundwater to be treated, this process option would be impractical.	Eliminated
		Ultraviolet (UV) Oxidation	UV radiation is used to destroy organic contaminants as water flows into a treatment tank; an ozone destruction unit treats off-gases from treatment tank.	Potentially applicable to VOCs.	Retained

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 89)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Physical/Chemical Treatment (Continued)	Chemical Oxidation • Hydrogen Peroxide • Chlorine • Potassium Permanganate • Ozonation	Addition of an oxidizing agent to raise the oxidation state of a substance. Effective for organics (primarily phenols, pesticides, and sulfur containing wastes), and some metals (primarily iron and manganese).	Not applicable to chlorinated VOCs.	Eliminated
		Chemical Reduction	Addition of a reducing agent to lower the oxidation state of a substance to reduce toxicity/solubility. Effective for chromium, mercury and lead.	Not applicable to chlorinated VOCs.	Eliminated
		Reverse Osmosis	Using high pressure to force water through a RO membrane leaving contaminants behind. Effective for dissolved solids (organic and inorganic).	Not applicable as dissolved solids are not anticipated to be primary treatment concern.	Eliminated
		Ion Exchange	Contaminated water is passed through a resin bed where ions are exchanged between resin and water. Effective for inorganics, but not iron and manganese.	Inorganics are not primary treatment concerns.	Eliminated
		Electrolysis	Metal ions are removed when an electric current drives contaminated water through ion exchangers in membrane form. Effective for recoverable metals or cyanide.	Inorganics are not primary treatment concerns.	Eliminated
		Electrodialysis	Metal ions are removed when an electric current drives contaminated water through ion exchangers in membrane form.	Inorganics are not primary treatment concerns.	Eliminated
		Electrochemical Ion Generation	Electrical currents are used to put ferrous and hydroxyl ions into solution for subsequent removal via precipitation. Effective for metals removal.	Inorganics are not primary treatment concerns.	Eliminated

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 89)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Physical/Chemical Treatment (Continued)	Distillation	Contaminated water is heated so it evaporates leaving contaminants behind. The water vapor is then cooled resulting in condensate of purified water. Highly energy intensive.	This process option would be impractical based upon its highly energy intensive nature and the suspected volume of contaminated groundwater to be treated.	Eliminated
		Neutralization	Addition of an acid or base to a waste in order to adjust its pH. Applicable to acidic or basic waste streams.	Potentially applicable as pretreatment for a VOC removal technology.	Retained
		Precipitation	Materials in solution are transferred into a solid phase for removal. Effective for suspended solids and metals.	Generally applicable as pretreatment for a VOC removal technology.	Retained
		Filtration	Removal of suspended solids from solution by forcing the liquid through a porous medium. Effective for suspended solids and inorganics.	Generally applicable as pretreatment for a VOC removal technology.	Retained
		Flocculation	Small, unsettleable particles suspended in a liquid medium are made to agglomerate into large particles by the addition of flocculating agents. Effective for suspended solids and inorganics.	Generally applicable as pretreatment for a VOC removal technology.	Retained
		Sedimentation	Removal of suspended solids in an aqueous waste stream via gravity separation. Effective for suspended solids.	Generally applicable as pretreatment for a VOC removal technology.	Retained
		Oil/Water Separation	Materials in solution are transferred into separate phases for removal. Applicable to petroleum hydrocarbons.	Not applicable to the primary COCs.	Eliminated

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 89)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Thermal Treatment	Liquid Injection Incineration	Combustion of waste at high temperatures. Effective for pumpable organic wastes.	Incineration is relatively expensive when there are generally low contaminant concentrations in groundwater.	Eliminated
		Molten Glass	Advanced incineration; waste contacts hot molten salt to undergo catalytic destruction. Effective for hazardous liquids, low ash, high chlorine wastes.	Incineration is relatively expensive when there are generally low contaminant concentrations in groundwater.	Eliminated
		Plasma Arc Torch	Advanced incineration; pyrolyzing wastes into combustible gases in contact with a gas which has been energized to its plasma state by an electrical discharge. Effective for liquid organic waste.	Incineration is relatively expensive when there are low contaminant concentrations in groundwater.	Eliminated
		Pyrolysis	Advanced incineration; thermal conversion of organic material into solid, liquid, and gaseous components; takes place in an oxygen-deficient atmosphere. Effective for organics and inorganics.	Incineration is relatively expensive when there are generally low contaminant concentrations in groundwater.	Eliminated
		Wet Air Oxidation	Advanced incineration; aqueous phase oxidation of dissolved or suspended organic substances at elevated temperatures and pressures. Effective for organics with high COD, high strength wastes, and for oxidizable inorganics.	Incineration is relatively expensive when there are generally low contaminant concentrations in groundwater.	Eliminated
		Supercritical Oxidation	An enhanced wet-air oxidation process with reaction conditions in supercritical range of water.	Incineration is relatively expensive when there are generally low contaminant concentrations in groundwater.	Eliminated

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 89)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Engineered Wetland Treatment	Constructed Wetlands	An engineered complex of plants, substrates, water, and microbial populations. Contaminants are removed via plant uptake, biodegradation (organics only), precipitation, and sorption processes.	Wetlands are better suited for removal of metals within soils and sediments. Implementation of this technology may present challenging construction obstacles and would offer little to prevent contaminant migration.	Eliminated
	Off-site Treatment	RCRA Facility	Extracted groundwater transported to licensed RCRA facility for treatment and/or disposal.	Potentially applicable; however, the distance to the nearest RCRA facility coupled with the suspected volume of contaminated groundwater render this process option impractical.	Eliminated
		Site 82 Treatment System	Extracted groundwater discharged to treatment system constructed at Site 82.	The distance and ground-use patterns between Sites 89 and the treatment system at Site 82, along with the suspected volume of contaminated groundwater render this process option impractical.	Eliminated
		Sewage Treatment Plant	Extracted groundwater discharged to sewage treatment plant for treatment.	Not implementable as STP will not accept untreated groundwater.	Eliminated
	In Situ Treatment	Biodegradation	System of introducing nutrients and oxygen to waste for the stimulation or augmentation of microbial activity to degrade contamination. Effective for a wide range of organic compounds.	Potentially applicable to VOCs.	Retained
		In Situ Volatilization (Air Sparging, In-Well Aeration)	"In Situ Air Stripping" uses the injection of air under pressure to remove VOCs via volatilization. May be used in conjunction with soil vapor extraction to collect volatilized contaminants in the vadose zone. "In-Well Aeration" is a process of inducing air into a well by applying a vacuum that serves to strip volatiles from groundwater inside the well.	Potentially applicable to VOCs.	Retained

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 89)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	In Situ Treatment (Continued)	Dual Phase Extraction	A high vacuum placed in a well removes liquid and gas. Effective for VOCs in low permeability or heterogeneous formations.	The maximum suction lift is approximately 30 ft. bgs. The plume at Site 89 is located at approximately 40 to 50 ft. bgs.	Eliminated
		Passive Treatment Wall	A permeable wall is installed across the flow path of a contaminant plume, treating the plume as it passively moves through the wall.	Potentially applicable to VOCs.	Retained
		Natural Attenuation	Natural subsurface processes, including dilution, volatilization, biodegradation, adsorption, and chemical reactions. Process option includes groundwater monitoring combined with modeling to demonstrate on-going contaminant degradation via natural attenuation.	Potentially applicable.	Retained
Discharge Actions	On-site Discharge	Surface Water	Treated water discharged to Edwards Creek.	Potentially applicable.	Retained
		Reinjection ● Injection Wells ● Infiltration Galleries	Treated water reinjection into the site aquifer via use of shallow infiltration galleries (trenches) or via injection wells.	Injected liquid may mound in the subsurface formations.	Eliminated
	Off-site Discharge	Treated water discharged to sewage treatment plant	Treated water discharged to sewage treatment plant.	The closest, on-base sewage treatment plant (Camp Geiger) is scheduled to be decommissioned.	Eliminated

TABLE 3-3

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
No Action	No Action	Not Applicable	No Action - Contaminated groundwater remains as is.	Potentially applicable; required by the NCP.	Retained
Institutional Controls	Monitoring	Groundwater/Surface Water Monitoring	Ongoing monitoring of existing and/or newly installed wells and Edwards Creek.	Potentially applicable.	Retained
	Access Restrictions	Deed Restrictions	Limit the future use of land including placement of wells.	Deed restrictions are not applicable to military installation not on closure list.	Eliminated
		Fencing	Limit access by installing a fence around contamination area.	A fence alone will not prevent contaminant migration.	Eliminated
	Aquifer Use Restrictions	Restrictions in Base Master Plan	Prohibit use of the contaminated aquifer as a potable water source.	Potentially applicable.	Retained
Containment/Collection Actions	Capping	Clay/Soil Cap Asphalt/Concrete Cap Soil Cover Multilayered Cap	Capping material placed over areas of contamination.	This process option would not be feasible due to the location of the groundwater contamination and the amount of industrialized/developed area.	Eliminated
	Vertical Barriers	Grout Curtain	Pressure injection of grout in a regular pattern of drilled holes to contain contamination.	This process option will not vertically contain the shallow groundwater contamination.	Eliminated
		Slurry Wall	Trench around areas of contamination. The trench is filled with a soil bentonite slurry to limit migration of contaminants.	This process option will not vertically contain the shallow groundwater contamination.	Eliminated
		Sheet Piling	Interlocking sheet pilings installed via drop hammer around areas of contamination.	This process option will not vertically contain the shallow groundwater contamination.	Eliminated
		Rock Grouting	Specialty operation for sealing fractures, fissures, solution cavities, or other voids in rock to control flow of groundwater.	The depth to bedrock limits the practicality of this process option.	Eliminated

TABLE 3-3 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Containment/Collection Actions (Continued)	Horizontal Barriers	Grout Injection	Pressure injection of grout to form a bottom seal across a site at a specific depth.	Technique is in the experimental stage. Grout injection alone will not prevent contaminant migration.	Eliminated
		Block Displacement	Continued pumping of grout into specially notched holes causing displacement of a block of contaminated earth.	Technique is in the experimental stage; in addition, displacement may damage existing structures and utilities.	Eliminated
	Extraction	Extraction Wells	Series of wells used to extract contaminated groundwater. Well screen must be placed within the identified plume for maximum contaminant collection.	Potentially applicable.	Retained
		Extraction/Injection Wells	Injection wells inject uncontaminated groundwater to enhance collection of contaminated groundwater via the extraction wells. Injection wells can also inject material into an aquifer to remediate groundwater.	Injection liquid may mound in the subsurface formations rather than flowing through.	Eliminated
		Hydrofracturing	Pressurized water is injected to create fractures in the formation, thus improving permeability. Can be used to enhance pump and treat systems.	The fractures may open new passageways through which contaminants can spread vertically and/or horizontally.	Eliminated
	Subsurface Drains	Interceptor Trenches	Perforated pipe installed in trenches backfilled with porous media to collect contaminated groundwater. Generally limited to shallow depths.	Potentially applicable.	Retained
Treatment Actions	Biological Treatment	Aerobic ● Aerated Lagoon ● Activated Sludge ● Powdered Activated Carbon Treatment ● Trickling Filter ● Rotating Biological Contractor	Degradation of organics using microorganisms in an aerobic environment.	Not highly effective for chlorinated VOCs.	Eliminated

TABLE 3-3 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Biological Treatment (Continued)	Anaerobic	Degradation of organics using microorganisms in an anaerobic environment.	Potentially applicable to chlorinated VOCs such as TCE.	Retained
	Physical/Chemical Treatment	Volatilization (Air Stripping/Steam Stripping)	Mixing large volumes of air/steam with water in a packed column to promote transfer of VOCs to air. Effective for VOCs and some SVOCs.	Potentially applicable to VOCs.	Retained
		Carbon Adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column. Effective for wide range of organics.	Potentially applicable to VOCs.	Retained
		Hydrolysis	By adding chemicals or irradiation, molecular bonds are broken making contaminants water-soluble. Used primarily to treat aqueous wastes containing refractory organics.	Primary COCs (PCE, TCE, 1,2-DCE) are not very water-soluble.	Eliminated
		Chemical Dechlorination	Process which uses specially synthesized chemical reagents to destroy hazardous chlorinated molecules or to detoxify them to form other less harmful compounds. Effective for PCBs, chlorinated hydrocarbons and dioxins.	Groundwater may require extensive dewatering prior to the application of this technology. Not highly effective for primary COCs.	Eliminated
		Ultraviolet (UV) Oxidation	UV radiation is used to destroy organic contaminants as water flows into a treatment tank; an ozone destruction unit treats off-gases from treatment tank.	Potentially applicable to VOCs.	Retained

TABLE 3-3 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Physical/Chemical Treatment (Continued)	Chemical Oxidation ● Hydrogen Peroxide ● Chlorine ● Potassium Permanganate ● Ozonation	Addition of an oxidizing agent to raise the oxidation state of a substance. Effective for organics (primarily phenols, pesticides, and sulfur containing wastes), and some metals (primarily iron and manganese).	Not applicable to chlorinated VOCs.	Eliminated
		Chemical Reduction	Addition of a reducing agent to lower the oxidation state of a substance to reduce toxicity/solubility. Effective for chromium, mercury and lead.	Not applicable to chlorinated VOCs.	Eliminated
		Reverse Osmosis	Using high pressure to force water through a RO membrane leaving contaminants behind. Effective for dissolved solids (organic and inorganic).	Not applicable as dissolved solids are not anticipated to be primary treatment concern.	Eliminated
		Ion Exchange	Contaminated water is passed through a resin bed where ions are exchanged between resin and water. Effective for inorganics, but not iron and manganese.	Inorganics are not primary treatment concerns.	Eliminated
		Electrolysis	Metal ions are removed when an electric current drives contaminated water through ion exchangers in membrane form. Effective for recoverable metals or cyanide.	Inorganics are not primary treatment concerns.	Eliminated
		Electrodialysis	Metal ions are removed when an electric current drives contaminated water through ion exchangers in membrane form.	Inorganics are not primary treatment concerns.	Eliminated
		Electrochemical Ion Generation	Electrical currents are used to put ferrous and hydroxyl ions into solution for subsequent removal via precipitation. Effective for metals removal.	Inorganics are not primary treatment concerns.	Eliminated

TABLE 3-3 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Physical/Chemical Treatment (Continued)	Distillation	Contaminated water is heated so it evaporates leaving contaminants behind. The water vapor is then cooled resulting in condensate of purified water. Highly energy intensive.	This process option is highly energy intensive and not effective for treating groundwater with relatively low contaminant concentrations.	Eliminated
		Neutralization	Addition of an acid or base to a waste in order to adjust its pH. Applicable to acidic or basic waste streams.	Potentially applicable as pretreatment for a VOC removal technology.	Retained
		Precipitation	Materials in solution are transferred into a solid phase for removal. Effective for suspended solids and metals.	Generally applicable as pretreatment for a VOC removal technology.	Retained
		Filtration	Removal of suspended solids from solution by forcing the liquid through a porous medium. Effective for suspended solids and inorganics.	Generally applicable as pretreatment for a VOC removal technology.	Retained
		Flocculation	Small, unsettleable particles suspended in a liquid medium are made to agglomerate into large particles by the addition of flocculating agents. Effective for suspended solids and inorganics.	Generally applicable as pretreatment for a VOC removal technology.	Retained
		Sedimentation	Removal of suspended solids in an aqueous waste stream via gravity separation. Effective for suspended solids.	Generally applicable as pretreatment for a VOC removal technology.	Retained
		Oil/Water Separation	Materials in solution are transferred into separate phases for removal. Applicable to petroleum hydrocarbons.	Not applicable to the primary COCs.	Eliminated

TABLE 3-3 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Thermal Treatment	Liquid Injection Incineration	Combustion of waste at high temperatures. Effective for pumpable organic wastes.	Incineration is relatively expensive when there are generally low contaminant concentrations in groundwater.	Eliminated
		Molten Glass	Advanced incineration; waste contacts hot molten salt to undergo catalytic destruction. Effective for hazardous liquids, low ash, high chlorine wastes.	Incineration is relatively expensive when there are generally low contaminant concentrations in groundwater.	Eliminated
		Plasma Arc Torch	Advanced incineration; pyrolyzing wastes into combustible gases in contact with a gas which has been energized to its plasma state by an electrical discharge. Effective for liquid organic waste.	Incineration is relatively expensive when there are low contaminant concentrations in groundwater.	Eliminated
		Pyrolysis	Advanced incineration; thermal conversion of organic material into solid, liquid, and gaseous components; takes place in an oxygen-deficient atmosphere. Effective for organics and inorganics.	Incineration is relatively expensive when there are generally low contaminant concentrations in groundwater.	Eliminated
		Wet Air Oxidation	Advanced incineration; aqueous phase oxidation of dissolved or suspended organic substances at elevated temperatures and pressures. Effective for organics with high COD, high strength wastes, and for oxidizable inorganics.	Incineration is relatively expensive when there are generally low contaminant concentrations in groundwater.	Eliminated
		Supercritical Oxidation	An enhanced wet-air oxidation process with reaction conditions in supercritical range of water.	Incineration is relatively expensive when there are generally low contaminant concentrations in groundwater.	Eliminated

TABLE 3-3 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Engineered Wetland Treatment	Constructed Wetlands	An engineered complex of plants, substrates, water, and microbial populations. Contaminants are removed via plant uptake, biodegradation (organics only), precipitation, and sorption processes.	Wetlands are better suited for removal of metals within soils and sediments. Implementation of this technology may present challenging construction obstacles and would offer little to prevent contaminant migration.	Eliminated
	Off-site Treatment	RCRA Facility	Extracted groundwater transported to licensed RCRA facility for treatment and/or disposal.	The distance to the nearest RCRA facility eliminates the practicality of this process option.	Eliminated
		Site 82 Treatment System	Extracted groundwater discharged to treatment system constructed at Site 82.	The distance and ground-use patterns between Site 93 and the treatment system at Site 82 render this process option impractical.	Eliminated
		Sewage Treatment Plant	Extracted groundwater discharged to sewage treatnent plant for treatment.	Not implementable as sewage treatment plant will not accept untreated groundwater.	Eliminated
	In Situ Treatment	Biodegradation	System of introducing nutrients and oxygen to waste for the stimulation or augmentation of microbial activity to degrade contamination. Effective for a wide range of organic compounds.	Potentially applicable to VOCs.	Retained
		In Situ Volatilization (Air Sparging, In-Well Aeration)	"In Situ Air Stripping" uses the injection of air under pressure to remove VOCs via volatilization. May be used in conjunction with soil vapor extraction to collect volatilized contaminants in the vadose zone. "In-Well Aeration" is a process of inducing air into a well by applying a vacuum that serves to strip volatiles from groundwater inside the well.	Potentially applicable to VOCs.	Retained

TABLE 3-3 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITE 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	In Situ Treatment (Continued)	Dual Phase Extraction	A high vacuum placed in a well removes liquid and gas. Effective for VOCs in low permeability or heterogeneous formations.	Not applicable to Site 93.	Eliminated
		Passive Treatment Wall	A permeable wall is installed across the flow path of a contaminant plume, treating the plume as it passively moves through the wall.	Potentially applicable to VOCs.	Retained
		Natural Attenuation	Natural subsurface processes, including dilution, volatilization, biodegradation, adsorption, and chemical reactions. Process option includes groundwater monitoring combined with modeling to demonstrate on-going contaminant degradation via natural attenuation.	Potentially applicable.	Retained
Discharge Actions	On-site Discharge	Surface Water	Treated water discharged to Edwards Creek.	Potentially applicable.	Retained
		Reinjection ● Injection Wells ● Infiltration Galleries	Treated water reinjection into the site aquifer via use of shallow infiltration galleries (trenches) or via injection wells.	Injected liquid may mound in the subsurface formations; therefore, interrupting/damaging existing structures and/or utilities.	Eliminated
	Off-site Discharge	Sewage Treatment Plant	Treated water discharged to sewage treatment plant.	The closest, on-base sewage treatment plant (Camp Geiger) is scheduled to be decommissioned.	Eliminated

TABLE 3-4

POTENTIAL SET OF REMEDIAL ACTION TECHNOLOGIES AND PROCESS OPTIONS THAT PASSED THE PRELIMINARY SCREENING
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Media	General Response Action	Remedial Action Technology Type	Process Option
Groundwater	No Action	No Action	Not Applicable
	Institutional Controls	Monitoring	Groundwater/Surface Water Monitoring
		Aquifer Use Restrictions	Restrictions in Base Master Plan
	Containment/Collection Actions	Extraction	Extraction Wells
		Subsurface Drains	Interceptor Trenches
	Treatment Actions	Biological Treatment	Anaerobic
		Physical/Chemical Treatment	Volatilization (Air/Steam Stripping)
			Carbon Adsorption
			Ultraviolet (UV) Oxidation
			Neutralization
			Precipitation
			Filtration
			Flocculation
			Sedimentation
		In Situ Treatment	Biodegradation
			In Situ Volatilization (Air Sparging/In-Well Aeration)
			Passive Treatment Wall
			Natural Attenuation
	Discharge Actions	On-site Discharge	Surface Water

TABLE 3-5

SUMMARY OF THE PROCESS OPTION EVALUATION
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Evaluation			Evaluation Results
			Effectiveness	Implementability	Relative Cost	
No Action	No Action	Not Applicable	● Effectiveness depends on contaminant concentrations, risks associated with the contaminants, and the effects of natural attenuation	● Easily implemented ● No means to monitor site conditions	● No cost	Retained as per the requirements of the NCP
Institutional Controls	Monitoring	Groundwater/Surface Water Monitoring	● Effectively detects contaminant trends so that exposure can be avoided	● Easily implemented	● Low capital ● Low O&M	Retained because of its effectiveness, implementability, and low cost
	Aquifer Use Restrictions	Restrictions in Base Master Plan	● Effective at preventing future exposure to contaminated groundwater ● Effectiveness dependent on continual implementation	● Easily implemented	● Negligible cost	Retained because of its effectiveness, implementability, and negligible cost
Containment/ Collection Actions	Extraction	Extraction Wells	● Conventional, widely demonstrated technology ● Effective for collecting and/or containing a contaminated groundwater plume ● Inorganics may precipitate and clog well screens, necessitating frequent maintenance and equipment replacement	● Easily implemented ● Potential exposures during implementation ● Equipment readily available	● Moderate capital ● Low O&M	Retained because it is a conventional technology that is easy to implement.
	Subsurface Drains	Interceptor Trenches	● Effective for collecting and/or containing a contaminated groundwater plume ● More effective for shallow aquifers ● Slower recovery than extraction wells ● Potential exposures during installation	● Requires an experienced specialty contractor ● Requires extensive excavation/trenching ● Requires more surface area than extraction wells ● Equipment readily available ● May require state discharge and/or wetland permits for work within/adjacent to Edwards Creek.	● Moderate to high capital ● Low to moderate O&M	Although interceptor trenches require more surface area than extraction wells, this process option is retained for consideration within the northern drainage swale (Site 89).

TABLE 3-5 (Continued)

SUMMARY OF THE PROCESS OPTION EVALUATION
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Evaluation			Evaluation Results
			Effectiveness	Implementability	Relative Cost	
Treatment Actions	Biological Treatment	Anaerobic	• Technology is still under development so it is not widely demonstrated • Elevated VOCs may be toxic to organisms • Very slow process • Effectiveness is susceptible to variation in waste stream characteristics and environmental parameters	• Mobile units available • Methane gas is produced and must be utilized or disposed • Low contaminant concentrations may make operation difficult	• Moderate capital • Moderate O&M	Eliminated because it has not been widely demonstrated; its effectiveness is also susceptible to variations noted within the estimated extent of groundwater contamination (Site 89).
	Physical/Chemical Treatment	Volatilization (Air/Steam Stripping)	• Pretreatment and frequent column cleaning may be required to avoid inorganic and biological fouling • Commercially proven technology • Contaminant transfer rather than destruction technology • Lower efficiency in cold weather (steam stripping)	• Off-gas and/or tower scale treatment may be required • May require air emissions permit • Mobile units available • Equipment and vendors readily available • Steam stripping is not as common as air stripping	• Moderate capital • Low to moderate O&M	Retained because of its effectiveness for contaminants that are highly volatile with low water solubility (i.e. chlorinated COCs), its commercial availability, performance record, and its relatively low cost
		Carbon Adsorption	• Inorganics can foul the system • Commercially proven and widely used technology • Contaminant transfer rather than destruction technology • Can be used as a polishing step following air stripping	• Spent carbon must be regenerated or properly disposed • Pretreatment may be required to reduce or remove suspended solids, oil and grease and unstable chemical compounds • Equipment readily available and conventional	• Moderate capital • Moderate to high O&M (dependent on loading rates and carbon life)	Retained because of its commercial availability, performance record, and its relatively moderate cost
		UV Oxidation	• Commercially proven technology • Inorganics such as chromium, iron, and manganese may limit effectiveness • High turbidity limits the transmission of UV light • Contaminant destruction rather than transfer technology • Off-gas treatment will be required	• Energy-intensive • Handling and storage of oxidizers requires special safety precautions • System is easily automated • System is easy to transport and set up	• Moderate to high capital • High O&M	Eliminated because it is energy-intensive and has a relatively high cost

TABLE 3-5 (Continued)

SUMMARY OF THE PROCESS OPTION EVALUATION
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Evaluation			Evaluation Results
			Effectiveness	Implementability	Relative Cost	
Treatment Actions (Continued)	Physical/Chemical Treatment (Continued)	Neutralization	• Can be used in a treatment train for pH adjustment	• Widely used and well-demonstrated • Simple and readily available equipment/materials	• Low capital • Low to moderate O&M	Retained for consideration as a pretreatment for air stripping and/or carbon adsorption
		Precipitation	• Effective, reliable, permanent, and conventional technology • Typically used for removal of heavy metals • Followed by solids-separation method • Generates sludge which can be voluminous, difficult to dewater, and may require treatment	• Equipment is basic and easily designed • Compact, single units can be delivered to the site	• Low capital • Moderate O&M	Retained for consideration as a pretreatment for air stripping and/or carbon adsorption
		Filtration	• Conventional, proven method of removing suspended solids from wastewater • Does not remove contaminants other than suspended solids • Generates a sludge which requires proper handling	• Equipment is relatively simple to install and no chemicals are required • Package units available	• Low capital • Low O&M	Retained for consideration as a pretreatment for air stripping and/or carbon adsorption
		Flocculation	• Conventional, proven technology • Applicable to aqueous waste stream where particles must be agglomerated into larger more settleable particles prior to other types of treatment • Performance depends on the variability of the composition of the waste being treated	• Equipment is readily available and easy to operate • Can be easily integrated into more complex treatment systems	• Low capital • Moderate O&M	Retained for consideration as a pretreatment for air stripping and/or carbon adsorption

TABLE 3-5 (Continued)

SUMMARY OF THE PROCESS OPTION EVALUATION
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Evaluation			Evaluation Results
			Effectiveness	Implementability	Relative Cost	
Treatment Actions (Continued)	Physical/Chemical Treatment (Continued)	Sedimentation	• Conventional, proven technology • Effective for removing suspended solids and precipitated materials from wastewater • Performance depends on density and particle size of the solids, effective charge on the suspended particles, types of chemicals used in pretreatment, surface loading, upflow rate, and rejection time • Feasible for large volumes of water to be treated	• Effluent streams include the effluent water, scum, and settled solids	• Moderate capital • Moderate O&M	Retained for consideration as a pretreatment for air stripping and/or carbon adsorption
	In Situ Treatment	Biodegradation	• Technology is still under development so it is not widely demonstrated • Very slow process • Injection of substrate and nutrients into groundwater may mobilize contaminants • Most effective for a site that has both soil and groundwater contamination, rather than just groundwater contamination	• Injection of substrate and nutrients into groundwater may require permits • Equipment readily available	• Moderate to high capital • Low to moderate O&M	Eliminated because there is limited soil contamination associated with the groundwater contamination at Sites 89 and 93.
		In Situ Volatilization (Air Sparging, In-Well Aeration)	• Groundwater does not need to be lifted above ground surface in order to be treated • Contaminant transfer rather than destruction technology • More effective for larger vadose zones • Fouling of the system may occur by oxidized constituents in the groundwater • Commercially proven technology (Air Sparging)	• Secondary treatment of off-gas may be required • May require air emissions permit	• Moderate to high capital • Low to moderate O&M	Retained due to effectiveness

TABLE 3-5 (Continued)

SUMMARY OF THE PROCESS OPTION EVALUATION
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Evaluation			Evaluation Results
			Effectiveness	Implementability	Relative Cost	
Treatment Actions (Continued)	In Situ Treatment (Continued)	In Situ Volatilization (Air Sparging, In-Well Aeration) (Continued)	• Contamination of the vadose zone may occur as contaminated groundwater passes through it (Air Sparging) • Soil vapor extraction may be necessary to collect volatilized contaminants (Air Sparging) • Limited commercial track record (In-Well Aeration) • Provides a closed loop system for air circulation; volatiles are less likely to escape because they will be collected within the aeration wells (In-Well Aeration)			
		Passive Treatment Wall	• Not widely demonstrated • Groundwater may mound around the wall rather than flowing through it • More effective if used in conjunction with vertical barriers acting as funnel gates • More effective if used in conjunction with extraction wells to increase groundwater velocity through the wall • Inorganics precipitation may occur resulting in a reduction of permeability through the wall • Groundwater constituents exiting the wall may require further treatment	• Treatment does not create contaminated residue, sludge, or other materials requiring disposal • No external energy source is required for the treatment process • Deep confining layers make implementation more difficult	• Moderate to high capital • Low O&M	Retained for consideration at Site 89 - "leading plume edge" containment

TABLE 3-5 (Continued)

SUMMARY OF THE PROCESS OPTION EVALUATION
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

General Response Action	Remedial Action Technology Type	Process Option	Evaluation			Evaluation Results
			Effectiveness	Implementability	Relative Cost	
Treatment Actions (Continued)	In Situ Treatment (Continued)	Natural Attenuation	● Effectively detects contaminant increases and decreases so that exposure can be avoided ● The existence of PCE, TCE, DCE, and VC at Sites 89 and 93 suggests that natural attenuation is occurring ● Natural attenuation processes have demonstrated effective reduction of various chlorinated solvents over time	● Easily implemented ● Minimal mechanical equipment required ● Requires long-term monitoring of groundwater and surface water (Edwards Creek)	● Low to moderate capital ● Moderate O&M	Retained because of its effectiveness and implementability
Discharge Actions	On-Site Discharge	Surface Water	● Effective and reliable discharge method ● Post-treatment action; therefore, minimal risks during construction and operation	● Based on the low pumping rates expected, Edwards Creek should have the capacity to handle discharge from an extraction and treatment system	● Low capital ● Low O&M	Retained due to implementability and low cost

TABLE 3-6

FINAL SET OF REMEDIAL ACTION TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB, CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Media	General Response Action	Remedial Action Technology Type	Process Option
Groundwater	No Action	No Action	Not Applicable
	Institutional Controls	Monitoring	Groundwater/Surface Water Monitoring
		Aquifer Use Restrictions	Restrictions in Base Master Plan
	Containment/Collection Actions	Extraction	Extraction Wells
		Surface Drains	Interceptor Trenches (Site 89)
	Treatment Actions	Physical/Chemical Treatment	Volatilization (Air/Steam Stripping)
			Carbon Adsorption
			Neutralization
			Precipitation
			Filtration
			Flocculation
			Sedimentation
		In Situ Treatment	In Situ Volatilization (Air Sparging, In-Well Aeration)
			Passive Treatment Wall
			Natural Attenuation
	Discharge Actions	On-Site Discharge	Surface Water

4.0 DEVELOPMENT AND SCREENING OF REMEDIAL ACTION ALTERNATIVES

In this section, remedial action technologies and process options chosen for Sites 89 and 93 were combined to form RAAs. The development process associated with each of these RAAs is presented in Section 4.1. Section 4.2 presents the evaluation of each RAA against the short-term and long-term aspects of three criteria: effectiveness, implementability, and cost. The RAAs with the most favorable evaluation will be retained for further consideration during the detailed analysis presented in Section 5.0. The screening evaluation of the most favorable RAAs is optional, and will only be conducted if too many RAAs are initially developed.

As noted in Section 3.4 of this FS, Sites 89 and 93 have numerous similarities. Several of these similarities include their virtual side-by-side location within Camp Geiger, geology and hydrogeology, proximity to Edwards Creek, industrialized/developed nature of their central site locations, and most importantly, the type of identified groundwater contamination. These noted similarities were the overriding influence for the decision to complete the remainder of this FS considering Sites 89 and 93 collectively. Therefore, RAAs developed and evaluated throughout this FS will incorporate the necessary components associated with the remedial actions required for both Sites 89 and 93. As with any remedial action, modifications to any part of an alternative may be necessary and appropriate following collection of new, more definitive information.

4.1 Development of Remedial Action Alternatives

RAAs were developed by combining the general response actions, remedial action technologies, and process options identified on Table 3-6. Five RAAs were developed to address the volatile groundwater contamination detected at Sites 89 and 93; they include:

- RAA 1: No Action
- RAA 2: Institutional Controls and Natural Attenuation
- RAA 3: Extraction and On-Site Treatment
- RAA 4: In-Situ Volatization (Air Sparging)
- RAA 5: Passive Treatment Wall

The following subsections describe these RAAs.

4.1.1 RAA 1: No Action

Under the no action RAA, no physical remedial actions will be performed to reduce the toxicity, mobility, or volume of contaminants identified in groundwater at Sites 89 and 93. The no action alternative is required by the NCP to provide a baseline for comparison with other RAAs that provide a greater level of response.

Although this RAA does not involve physical remediation, remediation of the groundwater is expected to occur via natural attenuation of contaminants. These processes include naturally occurring biodegradation, volatilization, dilution, leaching, adsorption, and chemical reactions between subsurface materials. Under the No Action RAA; however, no means are provided to monitor or confirm the natural remediation process.

Since contaminants will remain at Sites 89 and 93 under this RAA, the NCP [40 CFR 300.430(f)(4)] requires the lead agency to review the effects of this alternative no less often than once every five years.

4.1.2 RAA 2: Institutional Controls and Natural Attenuation

Under RAA 2, a long-term groundwater, surface water, and sediment monitoring program, along with aquifer use restrictions, will be implemented as institutional controls. In addition, remedial actions associated with the in-situ, naturally occurring biodegradation, dispersion, dilution, adsorption, volatilization, and chemical or biological stabilization/destruction of the VOCs in groundwater are expected in the form of natural attenuation. "Natural attenuation" refers to the "naturally occurring processes in soil and groundwater environments that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in these media" (Weidemeier, 1995).

The purpose of the groundwater, surface water, and sediment monitoring program is to track the groundwater contaminated plume's migration over time, to evaluate any fluctuations in COC levels in the groundwater, and to identify the amount of contaminant reduction that has occurred throughout each of these media. For cost estimating purposes, 5 years of quarterly sampling, followed by 25 years of semiannual sampling will be assumed. In turn, the cost estimate for RAA 2 also incorporates the reduction of analytical costs by 50 percent starting in the sixth year of the program.

The monitoring wells selected for RAA 2 are identified on Figure 4-1. As shown, 25 wells will be monitored under this program: eight existing shallow wells, eight existing intermediate wells, and four existing deep wells. A total of five new wells will be installed, including two new wells in the shallow aquifer, two new wells in the intermediate aquifer and one new deep well. The shallow and intermediate wells will monitor COC levels in the upper and lower portions of the surficial aquifer and the deep wells will monitor the upper portion of the Castle Hayne aquifer to ensure that COCs have not migrated vertically. Samples collected from these wells will be analyzed for TCL VOCs.

For purposes of evaluating the effectiveness of natural attenuation, groundwater samples will also include laboratory analyses of the following parameters: nitrate, sulfate, methane, ethane, ethene, and chloride. Field analyses will be conducted on groundwater samples to determine the levels of oxygen, iron II, alkalinity, oxidation-reduction potential (ORP), pH, temperature, conductivity, major cations, and hydrogen. Select soil samples will be collected for laboratory analysis of TOC. The natural attenuation parameters (both the laboratory and field parameters) are identified and described in more detail on Table 4-1. Over time, the results will be used to predict the kind and amount of contaminant reduction that has occurred, as well as, the amount of contaminant reduction that is expected.

Additional monitoring wells may be added to the program, if necessary. Likewise, if the analytical results indicate that the groundwater quality has improved, the monitoring program may be refined to include fewer sampling locations or less frequent sampling events.

As part of the monitoring program, surface water, and sediment samples will be collected from five existing and two new locations along Edwards Creek (Figure 4-1). The surface water and sediment samples will be collected and analyzed for TCL VOCs at the same frequency as note for groundwater monitoring.

Biodegradation may occur as an aerobic, anaerobic, or cometabolic process. Aerobic processes involve oxidation-reduction reactions in which oxygen is the electron receptor. Anaerobic processes involve iron-reducing, denitrifying, and sulfate-reducing reactions. Cometabolic processes involve carbon dioxide-reducing reactions and result in the accumulation of methane as a final product. Technical literature indicates that chlorinated solvent contamination can undergo natural attenuation through one or a combination of these biodegradation processes. At Sites 89 and 93, the following evidence suggests that natural attenuation processes are successfully degrading the chlorinated solvent contamination in the surficial and intermediate aquifers:

- PCE, TCE, and DCE have all been detected within the estimated boundary of contaminated groundwater at Sites 89 and 93. In addition, the detection of vinyl chloride (VC) at Site 89 further documents the degradation process.

- The locations and concentrations of the chlorinated compounds within each site are positioned as to suggest that the daughter products detected are the direct result of the VOC degradation. Appendix B contains both plan and cross-section views of the various chlorinated VOCs; PCE, TCE, 1,2-DCE, and VC. These figures were generated via a modeling program that estimates the 3-dimensional extent of groundwater contamination based on the RI results collected from Sites 89 and 93. Based upon this information, the natural attenuation alternative appears to be a justifiable remedial option for the chlorinated solvent contamination detected in the surficial and intermediate aquifers.

In an effort to provide additional evidence that natural attenuation is occurring, RAA 2 incorporates the option of performing a contaminant fate and transport model. The cost estimate accounts for annual modeling, as new results become available.

In addition, the Base Master Plan will be modified to include aquifer use restrictions. These restrictions will prohibit future use of the surficial aquifer as a potable water source.

Until RLs are met, the NCP [40 CFR 300.430(f)(4)] requires the lead agency to review the effects of this alternative no less often than once every five years.

4.1.3 RAA 3: Extraction and On-Site Treatment

Extraction and on-site treatment, selected as RAA 3, is a conventional extraction alternative in which groundwater will be collected via extraction wells and an interceptor trench, and then transported to an on-site treatment plant for VOC removal. Once treated, the groundwater will then be discharged to Edwards Creek which flows westerly to the New River.

Since pump tests have never been conducted at either Site 89 or Site 93, there is no conclusive way to determine the pumping rate and capture radius for an extraction well. In lieu of a pump test, the pumping rate and capture radius were estimated based on slug test data, site geology, site hydrogeology, and engineering judgement. A pumping rate per extraction well was estimated to be 5 gallons per minute (gpm) and the radius of influence was estimated to be 100 feet. This information was used to develop the conceptual system layout and cost estimate for the FS. These estimations are not intended to be used as design parameters. If RAA 3 is selected as the preferred RAA, a pump test should be conducted to more accurately determine the pumping rate and capture radius that can be expected. Data from the pump test will then be utilized to perform a groundwater flow and transport model (three-dimensional) to further evaluate the number and placement of extraction wells. The cost associated with a pump test and modeling effort has been included in the RAA 3 cost estimate.

Figure 4-2 identifies the conceptual system layout that will be used for RAA 3. This conceptual layout is subject to change during the design phase based on new and/or more accurate information that may become available. The conceptual layout was based on information available to date and was adequate for developing the FS cost estimate. Therefore, the conceptual layout is not intended to be the final design layout should this RAA be selected.

As shown on Figure 4-2, seven shallow extraction wells, four intermediate extraction wells, and a 400 linear foot shallow interceptor trench will be installed to collect groundwater from both the surficial and intermediate aquifers. The extraction wells will be positioned so that their combined zones of influence intercept the contaminated plume. Each extraction well will be screened in accordance with the depth of detected contamination (i.e., shallow ~ 10 to 20 feet bgs and intermediate ~ 40 to 50 feet bgs). The interceptor trench is estimated to be constructed from existing ground to a depth of 15 feet bgs.

After being extracted, the groundwater will be transported by pipeline to the on-site treatment plant. At the treatment plant, the groundwater will undergo suspended solids and metals removal via neutralization, precipitation, flocculation, sedimentation, and filtration units, and VOC treatment via a low profile air stripper. In addition, vapor phase and liquid phase carbon adsorption will provide secondary treatment of the VOC emissions from the air stripper and of the treated groundwater. After receiving treatment, groundwater will be discharged to Edwards Creek which flows to the New River. Edwards Creek is expected to have the capacity to accept the estimated 60 gpm discharge.

In addition to groundwater extraction, treatment, and discharge, RAA 3 incorporates a long-term groundwater, surface water, and sediment monitoring program to measure the effects of this RAA over time. The monitoring wells and surface water/sediment sampling locations included under this program are those identified under RAA 2. The wells include:

- Existing Site 89 Shallow Wells (IR 89-): MW03, MW04, MW05, and MW42B
- Existing Site 93 Shallow Wells (IR 93-): MW02, MW03, MW04, and MW05
- New Shallow Monitoring Wells: IR89-MWA and IR93-MWA
- Existing Site 89 Intermediate Wells (IR 89-): MW03IW, MW04IW, MW05IW, MW06IW, MW07IW, and MW08IW
- Existing Site 93 Intermediate Wells (IR 93-): MW02IW and MW05IW
- New Intermediate Wells (IR 89-): MWAIW and MWBIW
- Existing Site 89 Deep Wells (IR 89-): MW03DW, MW04DW, MW06DW, and MW08DW
- New Site 89 Deep Well: IR89-MWBDW

Surface water and sediment samples will be collected from existing locations SW01, SW02, SW04, SW08, and SW11. Two new surface water/sediment sampling locations are included under RAA 3; they are SWA and SWB. These locations are identified on Figure 4-2. Monitoring for all three media will be conducted semiannually and samples will be analyzed for TCL VOCs. Additional monitoring wells may be added to this monitoring program if necessary. Likewise, if the analytical results indicate that the groundwater quality has improved, the monitoring program may be refined to include fewer sampling locations or less frequent sampling events.

Aquifer use restrictions prohibiting the use of the surficial aquifer as a potable water source will be implemented via the Base Master Plan.

Until RLs are met, the NCP [40 CFR 300.430(f)(4)] requires the lead agency to review the effects of this alternative no less often than once every five years.

4.1.4 RAA 4: Air Sparging and Soil Vapor Extraction

RAA 4 includes in-situ air sparging (IAS) and soil vapor extraction (SVE) technologies for treating the VOC-contaminated groundwater. IAS is a technique in which air is injected into water saturated zones for the purpose of removing organic contaminants primarily via volatilization and secondarily via aerobic biodegradation. IAS systems introduce contaminant-free air into an impacted aquifer near the base of the zone of contamination, forcing contaminants to transfer from the groundwater into sparged air bubbles. The air bubbles are then transported into soil pore spaces in the unsaturated zone where they are typically collected via SVE and conveyed to an on-site, off-gas treatment system.

An IAS system typically is comprised of the following components: 1) air injection wells; 2) an air compressor; 3) air extraction wells; 4) a vacuum pump; 5) associated piping and valving for air conveyance; and 6) an off-gas treatment system (e.g., activated carbon, combustion, or oxidation). Under RAA 4, a line of air sparging wells will be installed along the leading edge of the contaminated groundwater plume identified in the shallow aquifer of Site 93. In addition, a series of air sparging wells will be located within the DRMO facility; adjacent to the confluence of Edwards Creek and the northern drainage swale; and along the east side of White Street Extension. The proposed layout associated with the IAS and SVE wells for Sites 89 and 93 is shown on Figure 4-3. Based on empirical data from similar sites, the radius of influence of an air sparging well ranges from five to almost 200 feet, but is typically on the order of 25 feet (EPA, 1992). A typical well detail and process flow diagram for the IAS system proposed under RAA 4 is depicted in Figure 4-4. In order to minimize disturbance of the existing developed area, the IAS/SVE wells and the proposed off-gas treatment system (consisting primarily of vapor phase activated carbon units) will be located in the southeast corner of the DRMO as shown on Figure 4-3. The air emissions from the off-gas treatment system will be sampled monthly to ensure that all applicable air emissions standards are being met.

Air sparging systems are most effective in sandy soils, but can be adversely impacted by high levels of inorganic compounds in the groundwater which oxidize and precipitate when contacted by the sparged air. These inorganics can form a heavy scale on well screens and clog the well space of the sand pack surrounding the well screen resulting in a reduction in permeability. A field pilot test is recommended to determine specific design parameters including: the loss of efficiency due to oxidation, the radius of influence of the wells under various heads of injection air pressure, and the rate of off-gas organic contaminant removal via carbon adsorption and carbon breakthrough.

RAA 4 assumes that the Base Master Plan will be modified to include restrictions on the use of the surficial aquifer in the vicinity of Sites 89 and 93. In addition to aquifer-use restrictions, long-term groundwater, surface water, and sediment monitoring is to be included under this RAA to measure the effects of this RAA over time. Long-term groundwater monitoring includes the semiannual collection and analysis (TCL VOCs) of groundwater samples collected from a total of 25 monitoring wells, the development of a semi-annual monitoring report, and the replacement of a monitoring well every five years. Surface water and sediment samples will be collected from five existing and two proposed surface water locations along Edwards Creek. The surface water/sediment samples will be analyzed semiannually for TCLVOCs. Results of the surface water/sediment monitoring will be included within the semiannual monitoring report. As with other remedial alternatives, additional monitoring wells and/or surface water/sediment locations may be added to/or subtracted from this program to better meet the overall monitoring objective.

Until RLs are met, the NCP [40 CFR 300.515(e)(iii)] requires the lead agency to review the effects of this alternative at least once every five years.

4.1.5 RAA 5: Passive Treatment Wall

Under RAA 5, groundwater will be treated in situ via a passive wall unit. This RAA also includes institutional controls such as monitoring and aquifer-use restrictions. A passive treatment wall is a permeable underground wall installed across the flow path of a contaminated plume. As groundwater naturally migrates through the wall, contaminants are either degraded or retained in a concentrated form by the wall material which can consist of chelators, sorbents, microbes, or other agents.

Figure 4-5 identifies the conceptual system layout that will be used for RAA 5. This conceptual layout is subject to change during the design phase of the project based on new and/or more accurate information that may become available. The conceptual layout was based on information available to date and was adequate for developing the associated FS cost estimate.

As shown on Figure 4-5, each passive wall system proposed will be excavated and installed within locations of the highest VOC detections, as well as, along the most prominent discharge locations detected along Edwards Creek. The trenches will be located so as to minimize disturbance of the surrounding functional areas of Sites 89 and 93. In general, two shallow walls (20 foot approximate depths) and two deeper walls (50 foot approximate depths) are proposed for treatment of the contamination detected in the shallow and intermediate aquifers, respectively. The thickness of the treatment walls are expected to range between 3 to 5 feet. The shallow and deeper treatment walls will consist of the following:

Shallow Wall Systems

- For Site 89, approximately 150 linear feet of wall adjoined with two 25 linear feet impermeable funnel gates (sheet pilings).

- For Site 93, approximately 200 linear feet of wall adjoined by one (southern) impermeable funnel gate.

Deeper Wall Systems (Site 89 only)

- Both walls are estimated to be approximately 300 linear feet long. These walls will be located to channel groundwater within, the suspected source area of the DRMO and along Edwards Creek. Funnel gates are expected to extend at least 50 feet on either side of both gates.

The impermeable pilings will direct the groundwater into the treatment wall. Without the pilings creating this funnel effect, groundwater would be more likely to travel along the lateral edge of the treatment wall rather than through it. Depending on aquifer characteristics and the lengths of the final wall sections, the funnel effect may also increase the groundwater velocity through the wall.

Passive treatment wall technology is a relatively new and innovative technology. As such bench-scale and/or pilot-scale testing will be necessary prior to initiating the full-scale system.

In addition to in situ treatment, RAA 5 includes a long-term groundwater, surface water, and sediment monitoring program to measure the effects of this RAA over time. The monitoring wells, surface water, and sediment sampling locations included under this program are those initially identified under RAA 2. These locations are identified on Figure 4-5. Analysis and frequency of the monitoring program previously discussed for RAA 3 will be implemented under RAA 5.

Aquifer-use restrictions prohibiting the use of the surficial aquifer as a potable water source will be implemented under this RAA. These restrictions will be spelled out in the Base Master Plan.

Until RLs are met, the NCP [40 CFR 300.430(f)(4)] requires the lead agency to review the effects of this alternative no less often than once every five years.

4.2 Screening of Alternatives

Typically, this section of the FS presents the initial screening of the potential RAAs. The objective of this screening is to make comparisons between similar alternatives so that only the most promising ones are carried forward for further evaluation (USEPA, 1988). This screening is an optional step in the FS process, and is usually conducted if there are too many RAAs to perform the detailed evaluation on. For Sites 89 and 93, the decision was made to eliminate this preliminary RAA screening step. Therefore, all of the developed RAAs will undergo the detailed evaluation presented in Section 5.0.

4.3 References

USEPA, 1992. United States Environmental Protection Agency. A Technology Assessment of Soil Vapor Extraction and Air Sparging. Risk Reduction Engineering Laboratory. Office of Research and Development. Cincinnati, Ohio. EPA/600/R-92/173.

USEPA, 1988. United States Environmental Protection Agency. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Office of Emergency and Remedial Response. Washington, D.C. EPA/540/G-89/004.

Wiedemeier, T.H.; Swanson, M.A.; Montoux, D.E.; Gordon, E.K.; Wilson, J.T.; Wilson, B.H.; Kampbell, D.H.; Hansen, J.E.; Haas, P.; Chapelle, F.H. 1996. Technical Protocol for Evaluating

Natural Attenuation of Chlorinated Solvents in Groundwater. Parsons Engineering, Inc., USEPA, AFCEE Technology Transfer Division, and USGS, 1996.

SECTION 4.0 TABLE

TABLE 4-1

NATURAL ATTENUATION PARAMETERS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB, CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Matrix	Analysis	Method/Reference	Data Use	Field or Fixed-Base Laboratory
Soil	Total organic carbon (TOC)	SW9060 modified for soil samples	The rate of migration of petroleum contaminants in groundwater is dependent upon the amount of TOC in the aquifer matrix.	Fixed-Base Laboratory
Water	VOCs	Contract Laboratory Protocol	Method of analysis includes benzene, toluene, ethylbenzene, and xylenes (BTEX) and chlorinated solvents/ byproducts, which are the primary target analytes for monitoring natural attenuation.	Fixed-Base Laboratory
Water	Oxygen	Dissolved oxygen meter	Concentrations less than 1 mg/L generally indicate an anaerobic pathway.	Field
Water	Nitrate	IC Method E300	Substrate for microbial respiration if oxygen is depleted.	Fixed-Base Laboratory
Water	Iron (II) (Fe^{2+})	Colorimetric Hach Method #8146	May indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese.	Field
Water	Sulfate (SO_4^{2-})	IC Method E300	Substrate for anaerobic microbial respiration.	Fixed-Base Laboratory
Water	Methane (CH_4), ethane, and ethene	Kampbell et al., 1989 or SW3810 Modified	The presence of CH_4 suggests BTEX degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing biological transformation.	Fixed-Base Laboratory

TABLE 4-1 (Continued)

NATURAL ATTENUATION PARAMETERS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB, CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Matrix	Analysis	Method/Reference	Data Use	Field or Fixed-Base Laboratory
Water	Alkalinity	Hach alkalinity test kit model AL AP MG-L	General water quality parameter used (1) to measure the buffering capacity of groundwater, and (2) as a marker to verify that all site samples are obtained from the same groundwater system.	Field
Water	Oxidation-reduction potential (ORP)	A2580B	The ORP of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the ORP of groundwater may range from more than 800 mV to less than -400 mV.	Field
Water	pH	Field probe with direct reading meter	Aerobic and anaerobic processes are pH-sensitive.	Field
Water	Temperature	Field probe with direct reading meter	Well development.	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Field
Water	Major cations	SW6010	Can be used to evaluate other remedial actions.	Field
Water	Chloride	IC Method E300	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system. Final product of chlorinated solvent reduction.	Fixed-Base Laboratory

TABLE 4-1 (Continued)

NATURAL ATTENUATION PARAMETERS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB, CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Matrix	Analysis	Method/Reference	Data Use	Field or Fixed-Base Laboratory
Water	Total Organic Carbon	SW9060	Used to classify plume and to determine if cometabolism is possible in the absence of anthropogenic carbon.	Fixed-Base Laboratory
Water	Hydrogen (H_2)	Equilibration with gas in the field. Determined with a reducing gas detector.	Determine terminal electron accepting process. Predicts the possibility for reductive dechlorination.	Field

Reference: Wiedemeier, Todd, et al. 1996. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater. Air Force Center for Environmental Excellence, Technology Transfer Division. Brooks Air Force Base, San Antonio, Texas.

SECTION 4.0 FIGURES

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LEGEND

- ◒ Monitoring Well
- ⊙ Temporary Well
- ☒ Surface Water/Sediment Sample
- ☒ Surface Water Sample
- ● New Monitoring Well
- ☒ New Surface Water/Sediment Sample
- ○ Sampling Location Included Under the Monitoring Plan
- Fence Line DRMO
- Edwards Creek Waterways

N
W E
S

Scale

200 0 200 400 600 800 1000 Feet

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

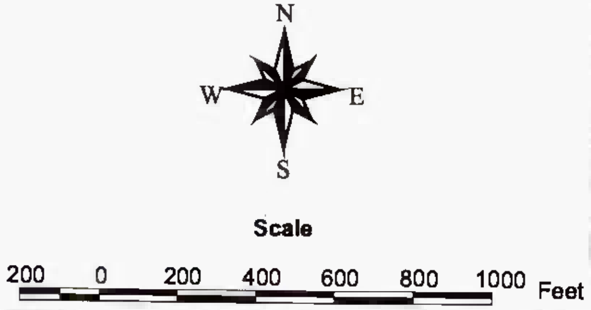
RAA 2: INSTITUTIONAL CONTROLS
AND NATURAL ATTENUATION
OPERABLE UNIT NO. 16 (SITES 89 & 93)
FEASIBILITY STUDY, CTO 0356

Baker

FIGURE 4 - 1

LEGEND

Ⓢ Shallow Extraction Wells
Ⓘ Intermediate Extraction Wells
— Extraction Trench
◕ Monitoring Well
◉ Temporary Well
☒ Surface Water/Sediment Sample
☒ Surface Water Sample
● New Monitoring Well
☒ New Surface Water/Sediment Sample
○ Sampling Location Included Under the Monitoring Plan
/\/ Fence Line DRMO
/\/ Edwards Creek Waterways



MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

RAA 3: EXTRACTION AND ON-SITE
TREATMENT
OPERABLE UNIT NO. 16 (SITES 89 & 93)
FEASIBILITY STUDY, CTO 0356

Baker

FIGURE 4 - 2

LEGEND

- In Situ Air Sparging (IAS) Wells and Associated Piping
- Soil Vapor Extraction (SVE) Wells and Associated Piping
- Monitoring Well
- ⊙ Temporary Well
- ☒ Surface Water/Sediment Sample
- Surface Water Sample
- ● New Monitoring Well
- ☒ New Surface Water/Sediment Sample
- Sampling Location Included Under the Monitoring Plan
- Fence Line DRMO
- Edwards Creek Waterways

N
W E
S

Scale

200 0 200 400 600 800 1000 Feet

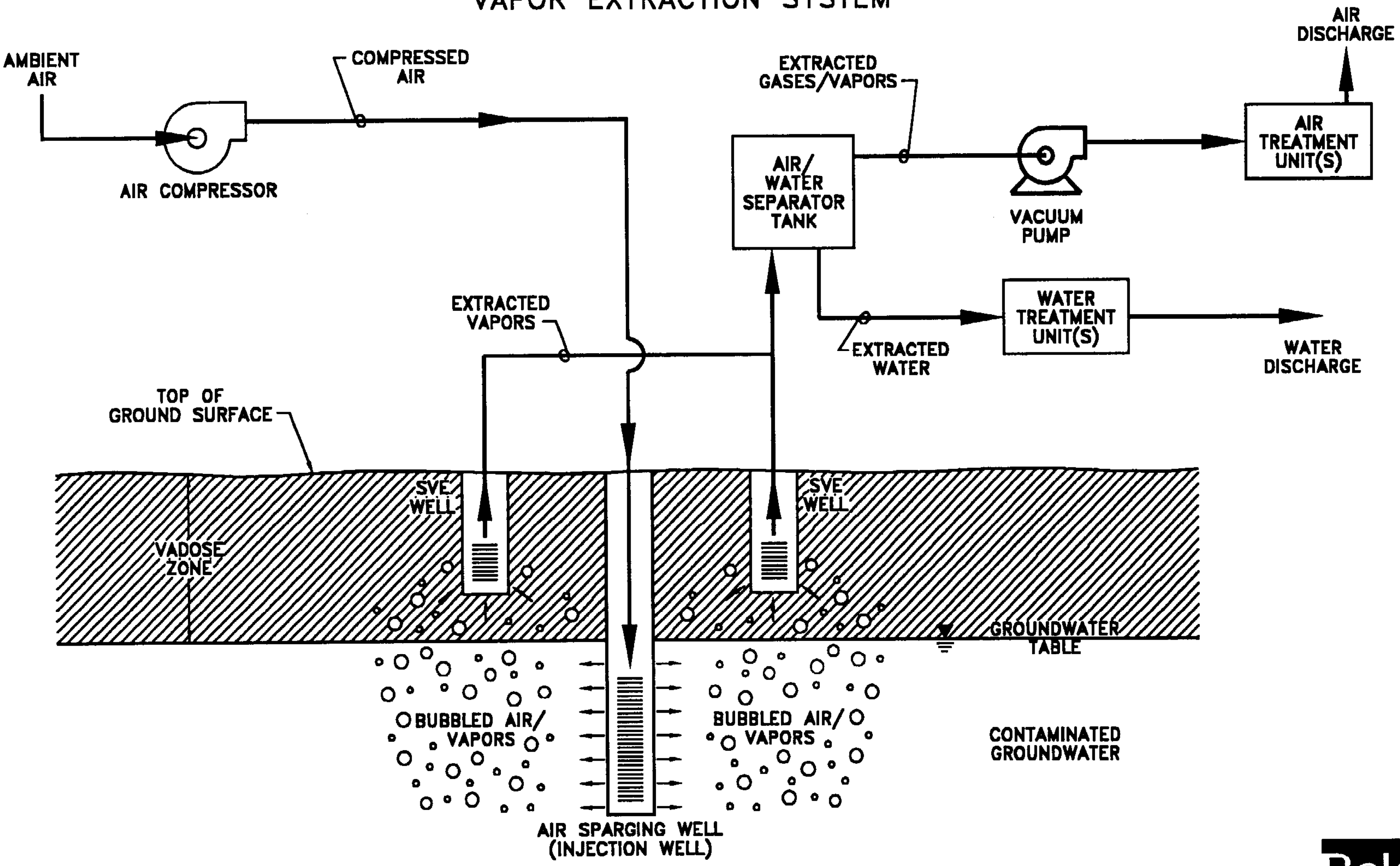
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

RAA 4: AIR SPARGING
AND SOIL VAPOR EXTRACTION
OPERABLE UNIT NO. 16 (SITES 89 & 93)
FEASIBILITY STUDY, CTO 0356

Baker

FIGURE 4 - 3

TYPICAL AIR SPARGING AND SOIL – VAPOR EXTRACTION SYSTEM



Baker
Baker Environmental, Inc.

FIGURE 4-4
AIR SPARGING AND SOIL
VAPOR EXTRACTION CROSS SECTION
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
FEASIBILITY STUDY, CTO-0356
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

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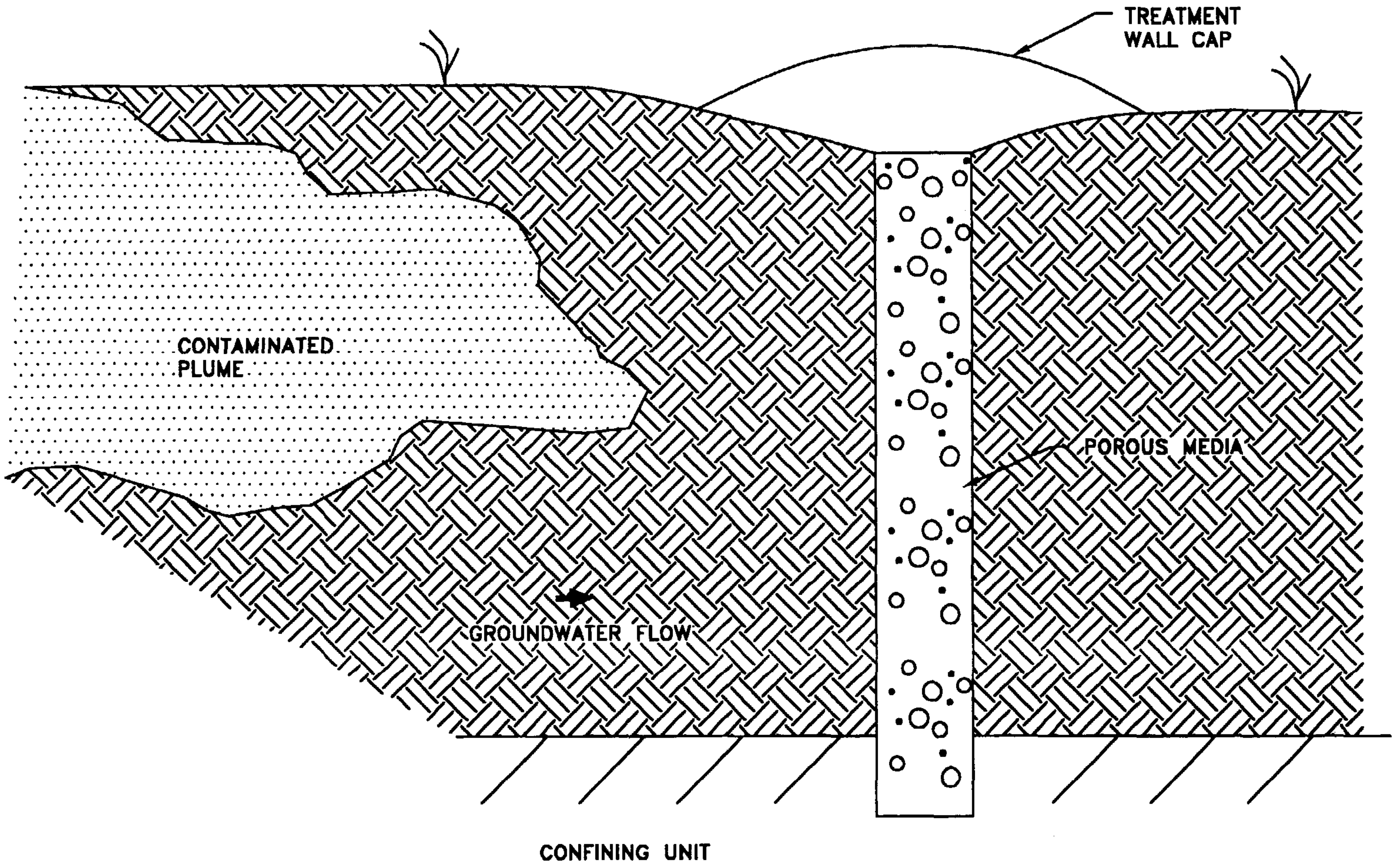
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

RAA 5: PASSIVE TREATMENT WALL
OPERABLE UNIT NO. 16 (SITES 89 & 93)
FEASIBILITY STUDY, CTO 0356

Baker

FIGURE 4 - 5



NOT TO SCALE

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FIGURE 4-6
TYPICAL PASSIVE TREATMENT WALL

OPERABLE UNIT NO. 16 (SITES 89 AND 93)
FEASIBILITY STUDY, CTO-0356
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

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5.0 DETAILED ANALYSIS OF REMEDIAL ACTION ALTERNATIVES

This section presents the detailed analysis of the remedial action alternatives that were developed in Section 4.0. Section 5.1 presents an overview of evaluation criteria that will be used in the detailed analysis. Sections 5.2 and 5.3 present two parts of the detailed analysis: the individual analyses of remedial action alternatives, and the comparative analysis of remedial action alternatives, respectively.

This detailed analysis has been conducted to provide sufficient information to adequately compare the alternatives, select an appropriate remedy for the site, and demonstrate satisfaction of the CERCLA remedy selection requirements in the Record of Decision (ROD). The extent to which alternatives are assessed during the detailed analysis is influenced by the available data, the number and types of alternatives being analyzed, and the degree to which alternatives were previously analyzed during their development and screening (USEPA, 1988).

The detailed analysis of alternatives was conducted in accordance with the "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA" (USEPA, 1988) and the NCP, including the February 1990 revisions. In conformance with the NCP, seven of the following nine criteria were used for the detailed analysis:

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

State acceptance and community acceptance will be evaluated in the ROD by addressing comments received after the Technical Review Committee (TRC) has reviewed the FS and Proposed Remedial Action Plan (PRAP). The TRC includes participants from the NC DENR, USEPA Region IV, and the public.

5.1 Overview of Evaluation Criteria

The following paragraphs describe the evaluation criteria that are used in the detailed analysis.

Overall Protection of Human Health and the Environment: Overall protection of human health and the environment is the primary criteria that a remedial action must meet. A remedy is considered protective if it adequately eliminates, reduces, or controls all current and potential site risks posed through each exposure pathway at the site. A site where hazardous substances remain without engineering or institutional controls allows for unlimited exposure for human and environmental receptors. Adequate engineering controls, institutional controls, or some combination of the two, can be implemented to control exposure and thereby ensure reliable protection over time. In addition, implementation of a remedy cannot result in unacceptable short-term risks or cross-media impacts on human health and the environment.

Compliance with Applicable or Relevant and Appropriate Requirements (ARARs): Compliance with ARARs is one of the statutory requirements for remedy selection. Alternatives are developed and refined throughout the FS process to ensure that they will meet all ARARs or that there is a sound rationale for waiving an ARAR. During the detailed analysis, the alternatives will be analyzed based on the Federal and state contaminant-specific ARARs, the action-specific ARARs, and the location-specific ARARs that were presented in Section 2.0 of this FS.

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

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

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

Short-Term Effectiveness: This criterion examines the short-term impacts associated with implementing the alternative. Implementation may impact the neighboring community, workers, or the surrounding environment. Short-term effectiveness also includes potential threats to human health and the environment associated with the excavation, treatment, and transportation of hazardous substances, the potential cross-media impacts of the remedy, and the time required to achieve protection of human health and the environment.

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

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

In accordance with USEPA guidance (USEPA, 1988), the cost estimates will have an accuracy of -30 to +50 percent. The exact accuracy of each cost estimate depends upon the assumptions made and the availability of costing information. The present worth costs were calculated assuming a five percent discount factor and a zero percent inflation rate.

For this FS, it has been assumed that groundwater, surface water, and sediment monitoring will be conducted for thirty years. This assumption has been made for costing purposes only.

State Acceptance: This criterion, which is an ongoing concern throughout the remedial process, reflects the statutory requirement to provide for substantial and meaningful state involvement. State comments will be addressed during the development of the FS, the PRAP, and the ROD, as appropriate.

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

5.2 Individual Analysis of Alternatives

The following subsections present the detailed analysis of RAAs on an individual basis. This individual analysis includes a brief description of each RAA and an assessment of how well the RAA performs against the evaluation criteria. Table 5-1 summarizes the individual, detailed analysis of the alternatives proposed for Sites 89 and 93.

5.2.1 RAA 1: No Action

Description

Under the no action alternative, groundwater at Sites 89 and 93 will remain as is. No physical remedial actions will be implemented.

Assessment

Overall Protection of Human Health and the Environment: Under RAA 1, no physical remedial actions will be implemented. As a result, there will be no measurable reduction in potential human health or environmental risks.

Compliance With ARARs: Under RAA 1, no active effort will be made to reduce contaminant levels to below Federal and state chemical-specific ARARs. Over an indefinite period of time, however, passive remediation, in the form of natural attenuation processes, may reduce VOC levels to below ARARs.

No action-specific or location-specific ARARs apply to this no action alternative.

Long-Term Effectiveness and Permanence: Residual risk will remain at the site under the no action alternative as humans could potentially come in contact with the contaminated groundwater. Of the human health risk evaluations conducted, risks were due to groundwater ingestion under the future adult child residential scenarios (Sites 89 and 93). All other risk evaluations concluded that the human health risks were within (future adult and child residents - Site 89 surface water/sediment exposure), or below (current adult and child residents - Site 89 surface water/sediment exposure; and future construction worker - Sites 89 and 93 groundwater and subsurface soil exposure) acceptable risk levels. However, it is highly unlikely that this scenario will occur because the on-site groundwater is not used as a potable source. Similarly, based on the mixed industrial uses in the vicinity of Sites 89 and 93, it is unlikely that these areas would be developed for future residents. Residual risks associated with leaving contaminants untreated within the surface water and sediments of Edwards Creek will be minimal.

Under the no action alternative, any long-term or permanent effect on contaminant levels will depend on the effectiveness of natural attenuation. The extent to which natural attenuation may reduce contaminant levels and the time it will take, are difficult to predict. In addition, there is no way to monitor the effects of this no action alternative.

Because the contaminants will remain on site at levels exceeding ARARs, RAA 1 will require 5-year reviews to ensure that adequate protection of human health and the environment is maintained.

Reduction of Toxicity, Mobility, or Volume Through Treatment: The no action alternative does not provide physical treatment processes for toxicity, mobility, or volume reduction of contaminated groundwater. Although passive treatment processes (i.e., natural attenuation) may eventually provide toxicity and volume reduction of the contaminated groundwater, the extent to which natural attenuation may reduce contaminant toxicity and volume is difficult to predict. Because there is no physical treatment process, there will be no treatment residuals. Although RAA 1 provides no means of measurement, this alternative may in time satisfy the statutory preference for treatment through natural attenuation.

Short-Term Effectiveness: There are no physical remedial action activities associated with RAA 1. As a result, short-term potential risks to the community due to extraction, treatment, or ex-situ transport of contaminated groundwater will not be increased. There will be no risks to workers, and there will be no additional environmental impacts. The exact time until the action is complete (i.e., the time required for natural attenuation to remediate the shallow and intermediate aquifers) is unknown.

Implementability: The no action alternative is implementable since no additional construction or operation activities will be conducted. In terms of administrative feasibility, RAA 1 should not require additional coordination with other agencies, although a waiver of the state ARARs may be required since VOC levels exceeding these ARARs will be left on-site indefinitely. The availability of services, materials, and/or technologies is not applicable to this alternative.

If site-specific data identifies that the groundwater quality appears to be deteriorating, remedial actions could easily be implemented under RAA 1.

Cost: There are no capital costs or O&M costs associated with this alternative. Therefore, the net present worth (NPW) is $0.

5.2.2 RAA 2: Institutional Controls and Natural Attenuation

Description

Under RAA 2, no physical remedial actions will be implemented to extract or treat the surficial and intermediate groundwater contamination. Instead, treatment via natural attenuation processes will be relied upon to reduce contaminant levels. The main component of RAA 2 includes a long-term groundwater, surface water, and sediment monitoring program. Groundwater samples will be analyzed for TCL VOCs and various natural attenuation parameters. These parameters will indicate the type of natural biodegradation that is occurring in both the shallow and intermediate aquifers, and the amount of contaminant reduction that has occurred over time. Evaluation of the VOC results and the natural attenuation parameters will also be used to estimate the amount of contaminant reduction that can be expected. Surface water and sediment samples will be analyzed for TCL VOCs. RAA 2 includes aquifer use restrictions to prohibit future use of the surficial aquifer as potable water source. To further support the occurrence of natural attenuation, RAA 2 includes the option to complete annual fate and transport groundwater modeling.

Assessment

Overall Protection of Human Health and the Environment: Under RAA 2, contaminants in the surficial and intermediate aquifers will remain. Contaminant migration from the surficial aquifer to Edwards Creek is expected to continue. Although the results of the human health risk assessment indicate that the chlorinated solvent contaminants within the groundwater may pose potential risks to future residents via the ingestion of groundwater; institutional controls should eliminate/restrict the use of the groundwater. In addition, the current uses associated with Sites 89 and 93 make them unlikely candidates for future residential development.

Current technical literature indicates that chlorinated solvents are capable of naturally attenuating, provided the appropriate conditions are present at the site. The groundwater contamination at Sites 89 and 93 appear to be naturally attenuating as PCE, TCE, DCE, and VC have been detected. Thus, the contamination in the groundwater is expected to naturally attenuate over time.

Based on this information, additional physical groundwater treatment is not necessary to provide a justifiable solution for the groundwater contamination detected at Sites 89 and 93. RAA 2 ensures the protection of human health and the environment through the combination of natural attenuation, monitoring, and aquifer use restrictions. Thus, RAA 2 will mitigate the potential for direct exposure and provide overall protection of human health and the environment.

Compliance With ARARs: Under RAA 2, no physical effort will be made to enhance or reduce contaminant concentrations to levels below chemical-specific ARARs. Natural attenuation processes; however, are expected to eventually achieve these ARARs. Thus, RAA 2 offers the potential to remediate the groundwater over an extended period of time. No action-specific or location-specific ARARs apply to this alternative.

Long-Term Effectiveness and Permanence: Allowing the groundwater to naturally attenuate is a justifiable solution because the potential human health and ecological risks appear to be insignificant at present and minimal in the future; and the data collected to date documents that chlorinated solvent contamination appears to be naturally attenuating. Through monitoring and aquifer use restrictions, RAA 2 provides a means for monitoring contaminant concentrations over time, prohibiting future potable use of the surficial and intermediate aquifers, and proving that natural attenuation is indeed occurring. As a result, RAA 2 will ensure the safety of potential receptors over time and will provide long-term effectiveness and permanence.

Under RAA 2, 5-year reviews by the lead agency will be required to ensure that adequate protection of human health and the environment is maintained.

***Reduction of Toxicity, Mobility, or Volume Through Treatment*:** RAA 2 does not provide additional physical treatment processes; however, some reduction in toxicity, mobility, and volume through natural attenuation is anticipated. Thus, RAA 2 satisfies the statutory preference for treatment.

***Short-Term Effectiveness*:** Under RAA 2, the only activities that may increase risks to the community and to workers include monitoring well installation and periodic groundwater, surface water, and sediment sampling. However, proper material handling procedures and appropriate personal protective equipment should sufficiently protect the community and workers against these risks. RAA 2 will not create any additional environmental impacts. The time required for the action to be complete is unknown, but 30 years of monitoring was assumed for cost estimating purposes.

***Implementability*:** RAA 2 is a technically implementable alternative since monitoring well installation; groundwater, surface water, and sediment monitoring; and ordinance (restrictions in the Base Master Plan) procurement have been easily implemented in the past. If water quality appears to be deteriorating, additional remedial actions could easily be implemented or incorporated under RAA 2.
In terms of administrative feasibility, this alternative will not require additional coordination with other agencies. However, semiannual reports must be submitted to document sampling procedures. All required services, materials, and/or technologies should be readily available.

Cost: The estimated capital cost associated with RAA 2 is $110,000. The projected annual O&M costs are approximately $307,000 for quarterly sampling in years 1-5, and $167,000 for semiannual sampling in years 6-30. Assuming an annual percentage rate of 5 percent, the NPW of this alternative is $2,680,000. Table 5-2 presents the cost estimate for RAA 2.

5.2.3 RAA 3: Extraction and On-Site Treatment

Description

Prior to initiating the system design, a site-specific pump test and three-dimensional groundwater flow/transport models will be performed. For alternative development; however, RAA 3 involves the installation of seven shallow extraction wells, four intermediate extraction wells, and a 400 linear foot shallow interceptor trench. These extraction devices will intercept the contaminated plume as it moves in the direction of groundwater flow within the shallow and intermediate aquifers. Each extraction well will have an estimated capacity of 5 gpm. Once the groundwater is extracted, it will undergo VOC treatment at an on-site treatment plant. The treatment will consist of suspended solids/metals removal, air stripping, and vapor phase carbon adsorption of the VOC air stripper emissions. Likewise, the groundwater will receive secondary treatment via liquid phase carbon adsorption prior to being discharged to Edwards Creek. In addition, RAA 3 includes a long-term groundwater, surface water, and sediment monitoring program, and aquifer use restrictions as institutional controls.

Assessment

Overall Protection of Human Health and the Environment: Because RAA 3 provides institutional controls and active groundwater remediation, this RAA will reduce potential risks to human health. The long-term monitoring program will indicate any increase in and/or migration of VOC concentrations so that appropriate action can be taken. Thus, the monitoring program mitigates the potential for human exposure. Aquifer use restrictions also mitigate the potential for human exposure by prohibiting the use of the surficial aquifer. The extraction/treatment system mitigates human health risks by decreasing the VOC concentrations. Under RAA 3, there will be a reduction in potential ecological risks via active treatment and institutional controls. Overall; however, ecological risks were determined to be minimal.

Compliance With ARARs: Under RAA 3, the groundwater quality will be improved through the use of an active remediation system, groundwater extraction and treatment. Over time, contaminant concentrations may meet Federal and state chemical-specific ARARs via active remediation.

In addition, RAA 3 can be designed to meet the location-specific and action-specific ARARs that apply.

Long-Term Effectiveness and Permanence: RAA 3 will reduce residual risk that remains at the site because: (1) the aquifer use restriction will prohibit groundwater from being used as a potable water source in the future, (2) the monitoring program will detect any improvement or deterioration in groundwater/surface water quality, and (3) groundwater extraction and treatment will reduce VOC levels. As a result, RAA 3 is expected to provide long-term effectiveness and performance.

Groundwater extraction/treatment methods are both adequate and reliable controls. However, technologies for completely extracting contaminants from groundwater are not proven. Contaminants may sorb to solid particles or escape into subsurface pore spaces or fissures where they become difficult to extract. Also, contaminants may continue to leach from solid particles below the vades zone. Due to this partitioning of contaminants, extraction technologies may not be reliable for completely remediating the aquifer. The potential for inorganic precipitation to clog well screens also limits the reliability of extraction wells. As with most remediation equipment, there is a potential for replacement and/or repairs. However, all of the treatment technologies associated with RAA 3 (for example, air stripping) have demonstrated their adequacy and reliability.

RAA 3 includes adequate and reliable institutional controls that will help monitor contaminant levels remaining in the groundwater. The proposed monitoring program will be an adequate and reliable control for assessing the effectiveness of the RAA. Aquifer use restrictions will be adequate and reliable controls for preventing the future use of the aquifer at Sites 89 and 93. These restrictions, however, must be enforced over time to ensure their adequacy and reliability.

RAA 3 will require 5-year reviews by the lead agency.

Reduction of Toxicity, Mobility, or Volume Through Treatment: The treatment processes associated with RAA 3 include neutralization, precipitation, flocculation, sedimentation, and filtration for suspended solids/metals removal, air stripping for VOC removal, and secondary treatment of VOC emissions from the air stripper and the treated groundwater (carbon adsorption). These treatment processes will be effective at pretreating inorganics, but more importantly, primarily treating VOCs in the groundwater.

The treatment processes associated with RAA 3 will reduce the toxicity and volume of contaminated groundwater; while the pumping effect associated with the extraction wells and interceptor trench will reduce the mobility of the contaminated groundwater plume. In addition, the treatment processes are expected to have irreversible effects.

Residuals remaining after treatment may include metals sludge, spent carbon, and treated groundwater. The sludge is expected to be non-hazardous, but will require proper disposal. The spent carbon will require regeneration or proper disposal. Treated groundwater is expected to be within acceptable discharge limits; therefore, discharge to Edwards Creek is anticipated.

RAA 3 satisfies the statutory preference for treatment.

Short-Term Effectiveness: Proper site controls may be necessary to minimize dust production during the underground piping and extraction well installation. In addition, workers may require protection during the installation and operation of the extraction/treatment system. In terms of environmental impacts, RAA 3 may cause localized aquifer drawdown during groundwater extraction. Similarly, due to the close proximity of the contaminated groundwater plume and Edwards Creek, there is a possibility that the extraction wells may draw in creek water. The overall environmental impact due to extraction can be reassessed during future 3-dimensional modeling; however, is considered negligible.

With respect to the time required to complete the remedial action, the groundwater extraction/treatment system is expected to be operated for many years prior to achieving complete groundwater restoration. The exact amount of time is unknown; however, 30 years of operation have been assumed for costing purposes.

Implementability: RAA 3 is technically implementable. Based on past experience and case studies, no major technical difficulties are anticipated during the construction and operation of the extraction/treatment system. All of the associated technologies/process options are conventional and have proven to be implementable.

There is a potential for high dissolved metals to precipitate out of solution and clog the well screens. This would require frequent well maintenance and replacement. There is also a potential for equipment replacement at the treatment plant. Releases of VOCs from the air stripper may also be a concern; however, measures to control atmospheric emissions have been included.

Another disadvantage for system operation is the fact that groundwater must be lifted from below the ground surface. This requires more power, more extensive treatment processes, and the need to discharge the treated groundwater.

If the long-term monitoring program associated with this alternative indicates that groundwater quality is deteriorating, additional remedial actions could easily be implemented under RAA 3.

In terms of administrative feasibility, RAA 3 requires extensive coordination with the Base Public Works/Planning Department. Also, the substantive requirements of air and water discharge permits will have to be met. However, all required services, materials, and/or technologies should be readily available.

Cost: Table 5-3 presents a cost estimate for RAA 3. As shown, the estimated capital cost is approximately $813,500, including the $27,000 cost associated with the pump test and three-dimensional groundwater modeling. O&M costs of approximately $135,500 are projected for treatment plant O&M and groundwater, surface water, and sediment monitoring over 30 years. Assuming a discount rate of 5 percent, the NPW of this alternative is $2,900,000.

5.2.4 RAA 4: Air Sparging and Soil Vapor Extraction

Description

IAS is a technique in which air is injected into the groundwater for the purpose of removing organic contaminants primarily via volatilization and secondarily via aerobic biodegradation. The IAS system forces air bubbles into soil pore spaces in the unsaturated zone where they can be collected via SVE and conveyed to an on-site, off-gas treatment system.

For the purpose of this FS, the IAS/SVE layout that is recommended for Sites 89 and 93 includes 40 air sparging and 47 SVE wells. The proposed off-gas treatment system (vapor-phase activated carbon) will be located south of the DRMO, where it appears that there is adequate space available. The air emissions from the off-gas treatment system will be sampled monthly to insure that all applicable air emissions standards are being met.

A field pilot test has been included to determine the loss of efficiency over time as a result of inorganics precipitation and oxidation, the radius of influence experienced by the wells which are under various heads of injection air pressure, and the rate of off-gas organic contaminant removal via carbon adsorption and carbon breakthrough.

RAA 4 assumes that the Base Master Plan will be modified to include restrictions on the use of the surficial aquifer.

In addition to aquifer use restrictions, long-term groundwater, surface water, and sediment monitoring is to be included under this RAA. Long-term groundwater monitoring includes the semiannual collection and analysis (VOCs) of groundwater samples from 25 monitoring wells, the development of a semiannual monitoring report, and the assumed replacement of a monitoring well once every five years.

Assessment

Overall Protection of Human Health and the Environment: This RAA will provide for the overall protection of human health and the environment by the application of an in situ treatment technology to reduce the level of organic contaminants in the surficial and intermediate aquifers. Contaminant reduction due to this system will be limited primarily to the radius of influence of the air sparging wells (estimated at approximately 25 feet).

Aquifer use restrictions will serve to provide additional protection against direct exposure to contaminated surficial and intermediate groundwater at Sites 89 and 93.

Compliance With ARARs: Under RAA 4 substantial reductions of the levels of organic contaminants in the groundwater can be expected within the radius of influence of the IAS system. Further downgradient, some additional reduction is expected from natural attenuation processes because contaminants are dispersed throughout Sites 89 and 93, beyond the locations of the proposed IAS/SVE system. Therefore, over time, contaminant concentrations may meet Federal and state chemical-specific ARARs via active remediation.

In addition, RAA 4 can be designed to meet the applicable location-specific and action-specific ARARs.

Long-Term Effectiveness and Permanence: This RAA involves in situ treatment technology designed to permanently remove organic contaminants from the surficial and intermediate aquifers. RAA 4 will reduce residual risks as: (1) aquifer use restrictions will prohibit groundwater from being used as a potable water source; (2) monitoring will detect improvements or deterioration in groundwater quality; and (3) treatment will reduce VOC levels.

Air sparging has a significant track record of commercial use and should be able to be controlled adequately and reliably for an indefinite period. High dissolved metals could be precipitated out of solution by the system and cause clogging, which would necessitate frequent maintenance and equipment replacement.

Since contaminants will remain at the site, the effects of this alternative must be reviewed no less often than once every five years.

Reduction of Toxicity, Mobility, or Volume: This RAA involves the application of in situ air sparging technology which, by design, is intended to reduce the volume of VOCs in the surficial and intermediate aquifers. The technology, in essence, works like an in-situ air stripper by injecting air below the groundwater table and, in turn extracting air, presumably laden with volatile organics, from the vades zone. The contaminants are collected and, in this case, transferred to activated carbon for ultimate disposal. Reductions of contaminants will be limited primarily to the zone defined by the radius of influence of the air sparging wells. However, natural attenuation is expected to reduce contaminant levels further over time.

System installation will result in drill cuttings (soil) for which proper disposal will be required. The on-site air treatment will produce residual wastes including spent activated carbon, and a moderate volume of contaminated water (i.e., condensed vapor collected in a knock-out tank).

RAA 4 satisfies the statutory preference for treatment alternatives.

Short-Term Effectiveness: The primary activity in constructing an IAS system is installing the air injection and soil vapor extraction wells. This involves standard environmental drilling techniques which, when executed by experienced professionals, should involve minimal risk of exposure to workers. The potential exists for the release of toxic vapors to the atmosphere if the vapor extraction portion of the IAS system is not as efficient as the air sparging portion. This concern increases when IAS systems are installed in areas where the groundwater surface is within a few feet of the ground surface as is the case at Sites 89 and 93. The release of toxic vapors to the atmosphere during operation of the IAS system could increase the risk of exposure to the surrounding area.

Relative to required treatment time, the IAS system is expected to operate many years prior to achieving complete groundwater remediation. The exact treatment time is unknown; however, 30 years was estimated for the IAS system.

Implementability: IAS technology is widely used and commercially available. Nevertheless, a field pilot-scale study to ensure its effectiveness at Sites 89 and 93 would help to more accurately determine critical design parameters. As with any in situ system where oxygen is injected, a concern is the effect on the system operation of metals precipitation and oxidation. At high enough levels the metals can clog the well screens, prompting frequent maintenance or even well replacement.

The implementation of this technology will require the installation of multiple air sparging and soil vapor extraction wells. Access for construction equipment to certain portions of the proposed system locations is limited and will require the cooperation of Base personnel. Construction schedules will need to be coordinated so as not to interfere with on-going military uses. Also, the requirements related to air emissions will have to be met.

The proposed groundwater, surface water, and sediment monitoring program, coupled with regular ambient air monitoring, should be sufficient to provide notice of a system failure so that adjustments can be made before a significant contaminant release would occur.

Cost: The project cost of RAA 4 is presented in Table 5-4. As shown, the estimated capital cost is approximately $1,235,000 , while O&M costs are anticipated to be approximately $137,000. Assuming a 5 percent discount rate, the NPW of RAA 4 is $3,340,000.

If the long-term monitoring program indicates that groundwater quality is deteriorating, additional remedial actions could easily be implemented under RAA 4.

5.2.5 RAA 5: Passive Treatment Wall

Description

RAA 5 involves the treatment of contaminated groundwater via funneling the groundwater through an in situ passive treatment wall. In addition, RAA 5 includes a similar long-term groundwater, surface water, and sediment monitoring program and aquifer- use restriction as identified for RAA 2.

Assessment

Overall Protection of Human Health and the Environment: Because RAA 5 provides institutional controls and active groundwater remediation, this RAA will reduce potential risks to human health. The long-term monitoring program will indicate any increase in and/or migration of COC concentrations so that additional appropriate actions can be taken. Thus, the monitoring program mitigates the potential for human exposure. Aquifer-use restrictions also mitigate the potential for human exposure by prohibiting the use of the surficial aquifer. The passive treatment system mitigates human health risks by decreasing the COC concentrations. Under RAA 5, there will be a reduction in potential ecological risks via active treatment and institutional controls.

Compliance With ARARs: Under RAA 5, the groundwater quality will be improved through the use of a passive in situ groundwater remediation system. Over time, contaminant concentrations may meet Federal and state chemical-specific ARARs via active remediation.

In addition, RAA 5 can be designed to meet the location-specific and action-specific ARARs that apply.

Long-Term Effectiveness and Permanence: The magnitude of residual risk associated with RAA 5 will be reduced since: (1) the aquifer-use restriction will prohibit groundwater from being used as a potable water source in the future, (2) the monitoring program will detect any improvement or deterioration in groundwater or surface water quality, and (3) the passive groundwater treatment system will reduce COC levels. As a result, RAA 5 is expected to provide long-term effectiveness and performance.

The passive treatment wall is a relatively new and innovative technology. Therefore, its effectiveness and reliability have not been proven. In addition, passive treatment walls may lose their reactive capacity which then requires the replacement of the reactive medium. This type of system is sensitive to pH levels, and biological activity may limit the permeability of the treatment wall (USEPA, 1994).

RAA 5 includes adequate and reliable institutional controls that will help monitor contaminant levels remaining in the aquifer. The proposed monitoring program will be an adequate and reliable control for assessing the effectiveness of the RAA. Aquifer-use restrictions will be adequate and reliable controls for preventing the future use of the aquifers at Sites 89 and 93. These restrictions, however, must be enforced over time to ensure their adequacy and reliability.

RAA 5 will require, at a minimum, 5-year reviews by the lead agency.

Reduction of Toxicity, Mobility, or Volume Through Treatment: The treatment processes associated with RAA 5 includes treatment via a passive treatment wall. This treatment process should be effective for treating the organics detected in the groundwater.

The treatment process associated with RAA 5 will reduce the toxicity of contaminated groundwater. In addition, the treatment process is expected to have irreversible effects.

Residuals remaining after treatment may include spent reactive medium from the treatment wall. If the reactive medium needs to be replaced, it will require proper disposal.

RAA 5 satisfies the statutory preference for treatment.

Short-Term Effectiveness: Proper site controls may be necessary to minimize dust production during the treatment wall installation and the installation of the additional monitoring wells. Environmental impacts caused by RAA 5 should be minimal.

With respect to the time required to complete the remedial action, the groundwater treatment system is expected to be operated for many years prior to achieving complete groundwater restoration. The exact amount of time is unknown; however, 30 years of operation have been assumed for costing purposes.

Implementability: RAA 5 is technically implementable, but site conditions may prove to cause construction problems. Since Sites 89 and 93 are located within functional areas of Camp Geiger, the passive treatment walls and monitoring wells would be located in an area that experiences minimal use. Therefore, the walls and monitoring wells would have to be located at the southern portion of the DRMO and/or outside the limits of roadways or existing structures.

At this time, this technology may not be readily available for full-scale use.

If the long-term monitoring program associated with this alternative indicates that groundwater or surface water quality is deteriorating, additional remedial actions could easily be implemented under RAA 5.

In terms of administrative feasibility, semiannual reports must be submitted to document sampling procedures and results. In addition, RAA 5 will require logistic coordination with Base personnel. The availability of all required services, materials, and/or technologies may be limited.

Cost: The cost estimate for RAA 5 is presented in Table 5-5. The estimated capital cost is approximately $30,025,000. O&M costs of approximately $270,000 are projected for treatment wall O&M, groundwater, surface water, and sediment monitoring, and monitoring well replacement over 30 years. Assuming a discount rate of 5 percent, the NPW of this alternative is approximately $34,150,000.

5.3 Comparative Analysis

This section presents a comparative analysis of the five groundwater alternatives presented for Sites 89 and 93. The purpose of the comparative analysis is to identify the relative advantages and disadvantages of each RAA. Thus, seven of the nine previously introduced criteria used for the detailed analysis will be the basis for the following comparative analysis.

5.3.1 Overall Protection of Human Health and the Environment

RAA 1, the no action alternative, does not reduce potential risks to human health nor the environment. On the other hand, RAAs 2, 3, 4, and 5 do reduce potential human health risks because they all involve institutional controls which prevent future exposure to the groundwater. RAAs 3, 4 and 5 also involve active remediation systems (extraction and on-site treatment, IAS/SVE and passive treatment wall) which provide additional protection to human health.

Human health risk values generated for groundwater at Sites 89 and 93 only exceeded acceptable limits under the future residential, groundwater exposure scenarios. However, it is highly unlikely that future residential development will ever occur at these sites. As a result, the future residential, groundwater exposure scenario and the associated risk values generated are overly conservative. Risk values generated under the current land use and future construction worker scenarios at Sites 89 and 93 were within acceptable limits. Similarly, the current and future risk values generated under the child and adult residential scenarios for exposure to surface water/sediments at Site 89 were within acceptable risk values.

Considering the minimal human health risks associated with contaminated groundwater, institutional controls (RAA 2) should be adequate for protecting human health and the environment. Active treatment via groundwater extraction and treatment (RAA 3), air sparging and SVE (RAA 4), or passive treatment wall (RAA 5) will provide additional human health and environmental protection. No action provides no protection. Therefore, RAA 1 may be inferior to the other four alternatives, while RAAs 3, 4 and 5 may overcompensate for the risks that exist at the site.

RAAs 3, 4 and 5 provide for risk reduction to ecological receptors via active treatment and institutional controls. The VOCs detected are not expected to bio concentrate in the aquatic food chain, thus ecological effects are expected to be low.

5.3.2 Compliance with ARARs

Under all of the RAAs, the primary groundwater COCs have the potential to meet Federal and state chemical-specific ARARs, through passive and/or active remedial approaches. Based on the nature of the site contamination and the indications that the VOCs are currently degrading, groundwater contamination may eventually meet ARARs via passive remediation via natural attenuation. The COCs are also expected to eventually meet ARARs via the active remedial approaches introduced under RAAs 3, 4 and 5. However, very few active remedial actions can document that contaminated groundwater have been remediated to drinking water standards.

RAAs 3, 4 and 5 can be designed to meet applicable location- and action-specific ARARs. No location- or action-specific ARARs apply to RAAs 1 or 2.

5.3.3 Long-Term Effectiveness and Permanence

RAAs 3, 4 and 5 appear to provide the greatest degree of long-term effectiveness and permanence. Of all the alternatives evaluated, RAA 1 will allow the most residual risk to remain at the site because it involves taking no action. The other RAAs allow less residual risk to remain at the site because they involve, at a minimum, institutional controls. Compared to RAA 2, however, RAAs 3, 4 and 5 will mitigate residual risk to a greater extent because they involve active groundwater remediation. Regardless, the magnitude of residual risk associated with leaving the VOCs untreated at the site is minimal (Section 5.3.1).

The overall, long-term effectiveness of RAAs 1 and 2 rely on the effectiveness of natural attenuation at reducing groundwater contamination. As previously noted, the extent to which natural attenuation may reduce contaminant levels, and the amount of time it will take, are difficult to predict. However, cleanup times under RAAs 3, 4, and 5 are also very difficult to predict.

Active remediation may be considered a more reliable means of treating contaminants than passive remediation; however, RAAs 3, 4, and 5 will only be adequate and reliable to a certain extent. Technologies for completely remediating contaminants from groundwater are not proven.

Contaminants may sorb to solid particles or escape into subsurface pore spaces or fissures where they become difficult to extract. Also, contaminants may continue to leach from solid particles below the vades zone. As a result, active remediation methods may not be completely reliable for extracting contaminants from the groundwater.

RAAs 2, 3, 4, and 5 all involve long-term groundwater, surface water, and sediment monitoring programs and aquifer use restrictions as institutional controls. These controls have been proven in the past to be adequate and reliable means to manage the hazardous substances remaining on site. RAA 1, however, does not provide adequate and reliable controls. As a result, RAAs 2, 3, 4, and 5 mitigate human health exposure through the use of institutional controls, but RAA 1 does not. Also, the effectiveness of RAAs 2, 3, 4, and 5 can be determined (via monitoring) more often than the effectiveness of RAA 1 (no action). The effectiveness of RAA 1 can only be determined by the lead agency's 5-year reviews.

All of the RAAs require 5-year reviews to ensure that adequate protection of human health and the environment is maintained. This review will no longer be necessary once ARARs are achieved.

5.3.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

RAAs 3, 4, and 5 will reduce the toxicity, mobility, and volume of groundwater contamination through active treatment. The treatment processes associated with these alternatives will reduce toxicity and volume, and the effects that these alternatives have on groundwater flow will reduce contaminant mobility. The treatment processes associated with these alternatives are also expected to have irreversible effects. Unlike RAAs 3, 4, and 5, RAAs 1 and 2 do not involve active treatment processes. However, RAAs 1 and 2 do involve passive treatment processes in the form of natural attenuation. Thus, as previously discussed, groundwater contamination may undergo toxicity and volume reduction under RAAs 1 and 2, but offer little reduction in plume mobility.

The RAAs differ significantly in the kind of residuals they will create after treatment. Structural residuals (monitoring wells) will remain at the site under all five of the RAAs. RAAs 1, 2, and 5; however, create no treatment residuals. RAAs 3 and 4, on the other hand, create treatment residuals. The residuals associated with RAA 3 (sludge, spent carbon, and treated groundwater) are more voluminous than the treatment residuals associated with RAA 4 (condensed vapor and spent carbon).

RAAs 3, 4, and 5 satisfy the statutory preference for treatment via active remediation, while RAAs 1 and 2 satisfy the preference for treatment via natural attenuation.

5.3.5 Short-Term Effectiveness

Implementation of RAAs 1 and 2 does not pose substantial risks to the community or workers. Implementation of RAAs 3, 4, and 5 may pose some risk to community and/or workers because they involve construction and operation of on-site treatment facilities. Trench installation is designed to minimize worker exposure (RAAs 3 and 4); therefore, the risks associated with installation of this alternative are somewhat less than those for installation of extraction wells (RAA 3) and IAS/SVE wells (RAA 4).

The time for natural attenuation to be complete is unknown and difficult to estimate. Likewise, the time for RAAs 3, 4, and 5 to be complete is unknown.

5.3.6 Implementability

RAA 1 is obviously the easiest to implement as this alternative requires no action. RAA 2 is the next most implementable alternative, followed by RAAs 3, 4, and 5. RAAs 3, 4, and 5 are the least implementable because they involve construction of treatment systems (RAAs 3 and 4), well installation (RAAs 3 and 4), trench installation (RAA 3), and passive treatment wall installation (RAA 5).

RAA 1 requires no operation or maintenance; while RAA 2 requires minimal operation and maintenance for the groundwater, surface water, and sediment sampling and periodic well replacement. RAAs 3 and 4 require the most O&M, while once installed RAA 5 should not require significant O&M. Compared to RAA 3, RAAs 4 and 5 require much less system O&M because the groundwater being treated is not lifted above the ground surface.

Under RAAs 3, 4, and 5, there is the potential for inorganic precipitation and oxidation to clog the systems, necessitating frequent maintenance and possibly equipment replacement. Under RAA 4, this potential is greater because metals precipitation and oxidation will be enhanced by the injection of oxygen.

Under all of the RAAs, additional remedial actions could potentially be implemented with relative ease, if necessary.

There are no equipment requirements associated with RAA 1. RAAs 2, 3, and 4 involve conventional equipment and services that should be readily available; while the initial construction of the passive treatment wall (RAA 5) may require speciality contractors experienced with this type of excavation.

RAA 1 may require a waiver since contaminated groundwater will be left on site indefinitely at concentrations that exceed ARARs, RAAs 3, 4, and 5 will require extensive coordination with the Base Public Works/Planning Department. Additionally, RAAs 2, 3, 4, and 5 will require semiannual submission of reports that document sampling results.

5.3.7 Cost

In terms of NPW, the no action alternative (RAA 1) would be the least expensive alternative to implement. The estimated NPW values in increasing order are: $0 (RAA 1), $2,680,000 (RAA 2), $2,900,000 (RAA 3), $3,340,000 (RAA 4), and $34,150,000 (RAA 5).

5.4 Reference

USEPA, 1994. United States Environmental Protection Agency. Remediation Technologies Screening Matrix and Reference Guide. Second Edition. Prepared by the Department of Defense Environmental Technology Transfer Committee. EPA/542/BV-94/013. October 1994.

USEPA, 1988. United States Environmental Protection Agency. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Office of Emergency and Remedial Response. Washington, D.C. EPA/540/G-89/004.

SECTION 5.0 TABLES

TABLE 5-1

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Evaluation Criteria	RAA 1 No Action	RAA 2 Institutional Controls and Natural Attenuation	RAA 3 Extraction and On-Site Treatment	RAA 4 Air Sparging and Soil Vapor Extraction	RAA 5 Passive Treatment Well
OVERALL PROTECTIVENESS					
● Human Health	No reduction in potential human health risks.	Institutional controls and natural attenuation will reduce potential human health risks.	Institutional controls and groundwater extraction/treatment will reduce potential human health risks.	Institutional controls, air sparging and SVE will reduce potential human health risks.	Institutional controls and active groundwater remediation will reduce potential risks to human health.
● Environmental Protection	No reduction in potential risks to ecological receptors.	No reduction in potential risks to ecological receptors; however, natural attenuation will reduce risks posed by organics.	Institutional controls and active groundwater treatment will reduce risks to ecological receptors.	Institutional controls and active groundwater treatment will reduce risks to ecological receptors.	Active treatment and institutional controls will reduce the potential ecological risks.
COMPLIANCE WITH ARARs					
● Chemical-Specific ARARs	Contaminants may eventually meet the Federal and state ARARs through natural attenuation.	Contaminants may eventually meet the Federal and state ARARs through natural attenuation.	Groundwater contamination may eventually meet Federal and state ARARs through extraction and treatment.	Groundwater contamination may eventually meet Federal and state ARARs through active treatment.	Through the use of a passive in situ groundwater remediation system, Federal and state ARARs are expected to be met.
● Location-Specific ARARs	Not applicable.	Not applicable.	Can be designed to meet location-specific ARARs.	Can be designed to meet location-specific ARARs.	Can be designed to meet location-specific ARARs.
● Action-Specific ARARs	Not applicable.	Not applicable.	Can be designed to meet action-specific ARARs.	Can be designed to meet action-specific ARARs.	Can be designed to meet action-specific ARARs.
LONG-TERM EFFECTIVENESS AND PERMANENCE					
● Magnitude of Residual Risk	The residual risk from untreated contaminants will be minimal. However, RAA 1 provides no active means for reducing residual risk.	Although residual risk from untreated contaminants will be minimal, it will remain on site under RAA 2. However, institutional controls should mitigate any residual risks that may exist.	Groundwater extraction/treatment should mitigate residual risk. However, due to the technical limitations associated with groundwater remediation, extraction/treatment is not expected to eliminate residual risk.	Air sparging should mitigate residual risk. However, due to the technical limitations associated with groundwater remediation, air sparging and SVE are not expected to eliminate residual risk.	The residual risk will be reduced with aquifer-use restriction, a monitoring program, and the passive groundwater treatment system.

TABLE 5-1 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Evaluation Criteria	RAA 1 No Action	RAA 2 Institutional Controls and Natural Attenuation	RAA 3 Extraction and On-Site Treatment	RAA 4 Air Sparging and Soil Vapor Extraction	RAA 5 Passive Treatment Well
LONG-TERM EFFECTIVENESS AND PERMANENCE (Continued)					
• Adequacy and Reliability of Controls	There are no controls associated with this alternative.	The monitoring program is adequate and reliable for determining the alternative's effectiveness. If enforced over time, aquifer use restrictions are adequate and reliable for preventing human exposure to groundwater.	Once designed/sized in accordance with site-specific characteristics, extraction and treatment should be both adequate and reliable. The groundwater, surface water, and sediment monitoring program is adequate and reliable for determining the alternative's effectiveness. If enforced over time, aquifer use restrictions are adequate and reliable for preventing human exposure to groundwater.	The adequacy and reliability of air sparging is expected throughout treatment period. The groundwater, surface water, and sediment monitoring program is adequate and reliable for determining the alternative's effectiveness. If enforced over time, aquifer use restrictions can be adequate and reliable for preventing human exposure to groundwater.	Passive treatment wall is new and innovative technology; therefore, its effectiveness and reliability have not been proven. They may lose their reactive capacity and are sensitive to pH levels and biological activity. However, adequate and reliable institutional controls are adequate for assessing effectiveness.
• Need for 5-year Review	Review will be required to ensure adequate protection of human health and the environment.	Review will be required to ensure adequate protection of human health and the environment.	Review will be required to ensure adequate protection of human health and the environment.	Review will be required to ensure adequate protection of human health and the environment.	Review will be required to ensure adequate protection of human health and the environment.
REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT					
• Treatment Process Used	There is no treatment process other than natural attenuation associated with this alternative.	There is no treatment process other than natural attenuation associated with this alternative.	The treatment process includes neutralization, precipitation, flocculation, sedimentation, and filtration as pretreatment for the air stripper; air stripping for VOC removal; and secondary treatment of air emission and treated groundwater via carbon adsorption.	The treatment process includes air sparging, SVE, and off-gas carbon adsorption. This process strips VOCs from the groundwater and removes contaminants from the off-gas via carbon adsorption.	A passive treatment wall should be effective for treating the organics in the groundwater.

TABLE 5-1 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Evaluation Criteria	RAA 1 No Action	RAA 2 Institutional Controls and Natural Attenuation	RAA 3 Extraction and On-Site Treatment	RAA 4 Air Sparging and Soil Vapor Extraction	RAA 5 Passive Treatment Well
REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT (Continued)					
● Amount Destroyed or Treated	No destruction through treatment; however, natural attenuation is expected to reduce contaminant concentrations.	No destruction through treatment; however, natural attenuation is expected to reduce contaminant concentrations.	Due to the technical limitations associated with groundwater remediation, most of the contamination, located in the vicinity of the suspected source areas of Sites 89 and 93, but not all, is expected to be treated.	Due to the technical limitations associated with groundwater remediation, most of the contamination, located in the vicinity of the suspected source areas of Sites 89 and 93, but not all, is expected to be treated.	Eventually, the majority of the contamination, located in the vicinity of the suspected source areas of Sites 89 and 93, is expected to treated by the treatment system.
● Reduction of Toxicity, Mobility, or Volume Through Treatment	No reduction through treatment.	No reduction through treatment.	The groundwater treatment processes are expected to reduce toxicity and volume of contaminants in the groundwater. The extraction wells and interceptor trench will reduce the mobility of the plume.	The air sparging and SVE system is expected to reduce the toxicity, mobility, and volume of the plume.	The treatment process will reduce the toxicity of contaminated groundwater.
● Irreversibility of the Treatment	Not applicable.	Not applicable.	Air stripping will have irreversible results.	In situ air stripping and off-gas carbon adsorption will have irreversible results.	The treatment process is expected to have irreversible effects.
● Residuals Remaining After Treatment	Not applicable.	Not applicable.	Treatment residuals may include sludge, spent carbon, and treated groundwater. The sludge should be non-hazardous, the spent carbon will require disposal or regeneration, and the treated groundwater will be within acceptable groundwater discharge limits.	Treatment residuals will include liquid left in the knockout tanks and spent carbon. The liquid should be non-hazardous, but the spent carbon will contain adsorbed contaminants requiring disposal or regeneration.	Remaining residuals include spent reactive medium from the treatment wall and reactive medium disposal if replacement is required.

TABLE 5-1 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Evaluation Criteria	RAA 1 No Action	RAA 2 Institutional Controls and Natural Attenuation	RAA 3 Extraction and On-Site Treatment	RAA 4 Air Sparging and Soil Vapor Extraction	RAA 5 Passive Treatment Well
REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT (Continued)					
● Statutory Preference for Treatment	Satisfied via natural attenuation.	Satisfied via natural attenuation.	Satisfied.	Satisfied.	Satisfied.
SHORT-TERM EFFECTIVENESS					
● Community Protection	Potential risks to the community will not be increased.	Potential risks to the community will not be increased during implementation.	Potential risks to the community will be increased during installation of the extraction/treatment system and during system operation.	Potential risks to the community will be increased during installation of the in-well aeration system and during system operation.	Potential risks to the community will be increased during the installation of the treatment wall and additional monitoring wells.
● Worker Protection	No risks to workers.	No risks to workers.	Potential risks to workers will be increased; worker protection is required.	Potential risks to workers will be increased; worker protection is required.	Potential risks to workers will be increased; worker protection is required.
● Environmental Impact	No additional environmental impacts.	No additional environmental impacts.	No additional environmental impacts.	No additional environmental impacts.	Environmental impacts should be minimal.
● Time Until Action is Complete	Unknown.	Unknown; 30 years has been assumed for cost estimating purposes.	Unknown; 30 years has been assumed for cost estimating purposes.	Unknown; 30 years has been assumed for cost estimating purposes.	30 years has been assumed for cost estimating purposes.

TABLE 5-1 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Evaluation Criteria	RAA 1 No Action	RAA 2 Institutional Controls and Natural Attenuation	RAA 3 Extraction and On-Site Treatment	RAA 4 Air Sparging and Soil Vapor Extraction	RAA 5 Passive Treatment Well
IMPLEMENTABILITY					
● Ability to Construct and Operate	Not applicable.	Based on past experience, ordinance procurement and groundwater, surface water, and sediment sampling are easily implemented.	Based on past experience, an extraction/treatment system will be easily constructed and operated. Disposal of treatment residuals (i.e., sludge), inorganics precipitation on the well screens, and trench installation may pose operation and/or construction challenges. The fact that groundwater must be lifted above the ground surface also complicates system operation.	The system should be easily constructed and operated. Carbon replacement and inorganics precipitation on the well screens may make system operation more challenging. The fact that groundwater will not be lifted above the ground surface simplifies system operation.	Site conditions (i.e., active use of the sites, wetlands, and existing vegetation) may cause construction obstacles.
● Reliability of Technology	Not applicable.	Monitoring wells and sampling are reliable technologies.	Inorganics may precipitate on the well screens creating the need for well replacement. The lengthy system operation time may necessitate equipment replacement.	Air sparging has been commercially demonstrated so its treatment actions are reliable. Inorganics may precipitate on the well screens necessitating well replacement.	Placement restrictions may not allow for the capture of all contaminated groundwater. Additionally, technology may not currently be readily available for full-scale use.
● Ease of Undertaking Additional Remedial Actions	Additional remedial actions can be easily implemented.	Additional remedial actions can be easily implemented.	Additional remedial actions can be easily implemented.	Additional remedial actions can be easily implemented.	Additional remedial actions can be easily implemented.

TABLE 5-1 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 16 (SITES 89 AND 93)
MCB CAMP LEJEUNE, NORTH CAROLINA
FEASIBILITY STUDY, CTO-0356

Evaluation Criteria	RAA 1 No Action	RAA 2 Institutional Controls and Natural Attenuation	RAA 3 Extraction and On-Site Treatment	RAA 4 Air Sparging and Soil Vapor Extraction	RAA 5 Passive Treatment Well
IMPLEMENTABILITY (Continued)					
• Ability to Monitor Effectiveness	No monitoring plan. Failure to detect contamination could result in human and/or environmental exposure.	Monitoring plan designed to detect contaminants before significant exposure can occur.	Monitoring plan designed to detect contaminants before significant exposure can occur.	Monitoring plan designed to detect contaminants before significant exposure can occur.	Monitoring plan will detect contaminants before significant exposure can occur.
• Availability of Services and Equipment	No services or equipment required.	Services and equipment are readily available.	The majority of services and equipment are readily available.	Services and equipment are available through a number of vendors.	The availability of required services, materials, and/or technologies may be limited.
• Requirements for Agency Coordination	May require a waiver of ARARs since contaminated groundwater will be left on site.	Must submit semiannual reports to document sampling and provide results of groundwater modeling.	Substantive requirements of air and water discharge permits must be met. Must submit semiannual reports to document sampling.	Substantive requirements of air emission permits must be met. Must submit semiannual reports to document sampling.	Coordination with Camp Lejeune personnel would be required. Semiannual reports must be submitted to document sampling procedures and results.
COST (Net Present Worth)	**$0**	**$2,680,000**	**$2,900,000**	**$3,340,000**	**$34,150,000**

TABLE 5-2
ESTIMATED COSTS FOR GROUNDWATER RAA No. 2

GROUNDWATER RAA No. 2: INSTITUTIONAL CONTROLS AND NATURAL ATTENUATION
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-356
MCB, CAMP LEJEUNE, NORTH CAROLINA

NATURAL ATTENUATION
MONITORING 20 EXISTING & 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITAL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
MONITORING WELLS							
Additional Well Installation	LS	1	$12,700	$12,700		Install 2-shallow, 2-intermediate, and 1 deep well	Engineering Estimates - Table A
Total Well Installation Capital Costs					$12,700		
NATURAL ATTENUATION STUDIES							
Initial Field Effort	LS	1	$20,000	$20,000		Collection of soil, soil gas, and groundwater samples	Engineering Estimates
Microcosm Study	LS	1	$20,000	$20,000			Engineering Estimates - Previous Projects
Modeling, Data Evaluation and Analysis	LS	1	$25,000	$25,000			Engineering Estimates - Previous Projects
Work Plan Development	LS	1	$10,000	$10,000			Engineering Estimates - Previous Projects
Reporting	LS	1	$10,000	$10,000			Engineering Estimates - Previous Projects
Contingency	LS	1	$7,905	$7,905		15% of direct capital costs	Engineering Estimates - Previous Projects
Total Natural Attenuation Study Capital Costs					$92,905		
TOTAL DIRECT AND INDIRECT CAPITAL COSTS					$ 105,605		

ANNUAL O&M COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
GROUNDWATER/SURFACE WATER/SEDIMENT MONITORING O&M PER SAMPLING EVENT							
Labor	Hours	400	$32	$12,800		20 days/event, 10 hrs/day/person, 2 people	Engineering Estimate - Table B
Travel	Sample Event	1	$4,050	$4,050		Includes minivan rental and airfare for 2 people	Engineering Estimate - Table B
Per Diem	Sample Event	1	$2,640	$2,640		Includes lodging and meals for 2 people	Engineering Estimate - Table B
Laboratory Analysis & Data Validation							
Intrinsic Remed. Parameters	Sample	45	$632	$28,431		25 gw samples/7 sed/ 7 surface water/5 dups /1 MS/MSD	Basic Ordering Agreement
Equip. & Supplies	Sample Event	1	$1,100	$1,100		Ice, DI water, expendables, pump, etc.	Engineering Estimate - Table B
Shipping	Sample Event	1	$3,750	$3,750		2 coolers per day for 5 days; $83/cooler	Engineering Estimate - Table B
Reporting	Sample Event	1	$10,000	$10,000		Laboratory reports, administration, etc.	Engineering Estimate
Well Redevelopment	Year	1	$7,500	$7,500			
Total Cost of the Data Sampling and Validation Events				$70,271			
Well Replacement	Year	1	$6,250	$6,250		Equal annual cost of replacing 25 wells every 10 years for 30 years	Engineering Estimate
Model Updates & Reporting	Year	1	$20,000	$20,000			
Total Monitoring O&M Costs (1 to 5 years)					$307,332	Quarterly sampling will be performed for the first 5 years	
Total Monitoring O&M Costs (6 to 30 years)					$166,791	Semi-annual sampling will be performed for the remaining 25 yrs	

TABLE 5-2
ESTIMATED COSTS FOR GROUNDWATER RAA No. 2

GROUNDWATER RAA No. 2: INSTITUTIONAL CONTROLS AND NATURAL ATTENUATION
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-356
MCB, CAMP LEJEUNE, NORTH CAROLINA

NATURAL ATTENUATION
MONITORING 20 EXISTING & 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

SUMMARY OF TOTAL CAPITAL AND O&M COSTS

TOTAL DIRECT AND INDIRECT CAPITAL COSTS	$110,000	
TOTAL ANNUAL O&M COSTS (1 - 5 YEARS) TOTAL ANNUAL O&M COSTS (6 - 30 YEARS)	$307,000 $167,000	
PRESENT WORTH VALUE	$2,680,000	Based on a discount rate of 5%

TABLE 5-3
ESTIMATED COSTS FOR GROUNDWATER RAA No. 3

GROUNDWATER RAA No. 3: EXTRACTION AND ON-SITE TREATMENT
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB CAMP LEJEUNE, NC

11 EXTRACTION WELLS
55 GPM TREATMENT FACILITY

MONITORING 20 EXISTING AND 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITAL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
DIRECT CAPITAL COSTS:							
GENERAL							
Preconstruction Submittals	LS	1	$12,000	$12,000		Work Plan, Erosion and Sediment Control Plan, and H & S Plan	Engineering Estimate- Previous Projects
Mobilization/Demobilization	LS	1	$9,000	$9,000		Includes mobilization for all subcontractors	Engineering Estimate- Previous Projects
Decontamination Pad	LS	1	$7,500	$7,500		Includes decon/laydown area	Engineering Estimate- Previous Projects
Contract Administration	LS	1	$9,000	$9,000			Engineering Estimate- Previous Projects
Post-Construction Submittals	LS	1	$5,500	$5,500			Engineering Estimate- Previous Projects
Total General Costs					$43,000		
SITE WORK							
Site Work During System Installation:							
Clearing	Acre	3	$8,000	$24,000		Clear and grub, chip stumps	Means Site 1997, 021-104 & Estimate
Piping Trench for the Collection Line	LF	2835	$4	$11,340		Includes excavation, removal, backfill, and tamping	Means Site 1997, A12.73-110 & Estimate
Piping Trench for the Discharge Line	LF	150	$4	$600		Includes excavation, removal, backfill, and tamping	Means Site 1997, A12.73-110 & Estimate
Excavation for Treatment Area Slab	CY	75	$12	$900		Roughly 30' x 30' x 2'excavation	Means Site 1997, 022-200 & Estimate
Backfill Around Treatment Area Slab	CY	45	$5	$225		Roughly 5' x 2' x 120' around plant	Means Site 1997, 022-226 & Estimate
Gravel Driveway & Road Improvement	LF	900	$15	$13,500		3" Thick Aggregate Road, incl. materials and labor	Engineering Estimate- Previous Projects
Water Connection at Treatment Area	LF	150	$8	$1,200		Includes trenching & laying a 1" copper line	Means Site 1997, 026-662 & 022-258
Overhead Electrical to Treatment Area	LF	150	$25	$3,750		Includes overhead routing and poles	Means Site 1997, 167-100 & Estimate
Erosion Protection at Discharge Point	CY	5	$62	$310		For erosion protection around headwall	Engineering Estimate- Previous Projects
Site Restoration:							
Topsoil Spreading in Cleared Areas	SY	15000	$3	$45,000		Includes revegetation of disturbed site and trench area	Means Site 1997, 022-286 & Estimate
Top Dressing Around Treatment Plant	CY	50	$40	$2,000			Means Site 1997, 022-286 & Estimate
Fine Grading and Seeding for Revegetation	SY	14500	$2	$29,000			Means Site 1997, 022-286 & Estimate
Total Site Work Costs					$131,825		

TABLE 5-3
ESTIMATED COSTS FOR GROUNDWATER RAA No. 3

GROUNDWATER RAA No. 3: EXTRACTION AND ON-SITE TREATMENT
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB CAMP LEJEUNE, NC

11 EXTRACTION WELLS
55 GPM TREATMENT FACILITY

MONITORING 20 EXISTING AND 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITAL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
DIRECT CAPITAL COSTS (CONTINUED):							
CONCRETE/STRUCTURAL							
Metals Pretreatment Bldg.	LS	1	$20,000	$20,000		Prefabricated metal enclosure, installed	Engineering Estimate- Previous Projects
Slab for Treatment Area	EA	1	$4,500	$4,500		25' x 25' on-grade slab	Engineering Estimate- Previous Projects
Headwall for Discharge Point	EA	1	$1,711	$1,711		Includes excavation, backfill, concrete, and forms	Means Site 1997, A12.3-750 & Estimate
Total Concrete/Structural Costs					$6,211		
EXTRACTION WELLS							
Extraction Well Installation	LF	340	$450	$153,000		6" stainless steel	Engineering Estimate- Previous Projects
Well Development	EA	11	$375	$4,125			Engineering Estimate- Previous Projects
Total Extraction Well Costs					$157,125		
EXTRACTION TRENCH							
Excavation	CY	2222	$4	$8,510		trench 400' x 15' deep x 10' wide	Eng Est - Means 1997 022-254-1300
Perforated PVC piping	LF	400	$11	$4,360			Eng Est - Means 1997 026-678-2200
Submersible pump	EA	1	$335	$335			Eng Est - Means 1997 152-480-7180
Geotextile	SY	755	$1	$1,117			Eng Est - Means 1997 027-054-0100
Drainage Material Backfill	CY	444	$21	$9,102			Eng Est - Means 1997 027-054-0300
Backfill Soil	CY	1774	$2	$3,158			Eng Est - Means 1997 022-254-3020
Total Extraction Trench Costs					$26,582		
PIPING SYSTEM							
2" PVC Line for Recovery	LF	2835	$5	$14,175		Includes materials and installation (also includes down-hole line)	Means Site 1997, 026-678 & Estimate
2" PVC Line for Discharge to Creek	LF	150	$5	$750		Includes materials and installation (also includes down-hole line)	Means Site 1997, 026-678 & Estimate
4" PVC Containment Line for Recovery	LF	2835	$8	$22,680		Includes materials and installation (also includes down-hole line)	Means Site 1997, 026-678 & Estimate
Fittings	LS	1	$5,641	$5,641		Assume 15% of Total Piping Cost	Engineering Estimate- Previous Projects
Total Piping System Costs					$43,246		
TREATMENT EQUIPMENT							
Package VOC and Solids Removal System	EA	1	$27,500	$27,500		Includes air stripper, solids filter, electric submersible pumps, all controls, and shipping (system skid mounted & enclosed)	Vendor Quote
Metals Pretreatment System	EA	1	$38,000	$38,000		Includes surge tank, clarifier, filter press, etc.	Engineering Estimate- Previous Projects
Flowmeter	EA	1	$1,500	$1,500			Engineering Estimate- Previous Projects
Installation of Equipment	LS	1	$4,000	$4,000		Incl. unloading crane, pump installation, hookups, and startup	Vendor Estimate
Piping and Fittings	LS	1	$7,250	$7,250		Assume 25% of equipment cost	Engineering Estimate- Previous Projects
Carbon Treatment Unit	EA	2	$1,000	$2,000			Engineering Estimate- Previous Projects
Total Treatment Plant Equipment Costs					$80,250		
MONITORING WELLS							
Additonal Well Installation	LS	1	$12,700	$12,700		Install 2 shallow, 2 intermediate, 1 deep well	Engineering Estimate - Table A
Total Well Installation Cost					$12,700		
TOTAL DIRECT CAPITAL COSTS					$500,939		

TABLE 5-3
ESTIMATED COSTS FOR GROUNDWATER RAA No. 3

GROUNDWATER RAA No. 3: EXTRACTION AND ON-SITE TREATMENT
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB CAMP LEJEUNE, NC

11 EXTRACTION WELLS
55 GPM TREATMENT FACILITY

MONITORING 20 EXISTING AND 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITAL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
INDIRECT CAPITAL COSTS:							
Engineering and Design	LS	1	$60,113	$60,113		12% of Total Direct Cost	Engineering Estimate
Pump Test	EA	1	$15,000	$15,000			Engineering Estimate- Previous Projects
3D Groundwater Modeling	Hours	300	$40	$12,000			Engineering Estimate- Previous Projects
Design and Construction Administration	LS	1	$75,141	$75,141		15% of Total Direct Cost	Engineering Estimate
Contingency Allowance	LS	1	$75,141	$75,141		15% of Total Direct Cost	Engineering Estimate
Start-up Costs	LS	1	$75,141	$75,141		15% of Total Direct Cost	Engineering Estimate
TOTAL INDIRECT CAPITAL COSTS					$312,535		

ANNUAL O&M COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
GROUNDWATER/SURFACE WATER/SEDIMENT MONITORING O&M (Based on semiannual sampling for 30 years)							
Labor	Hours	800	$32	$25,600		2 sample events, 20 days each, 10hrs/day/person, 2 people	Engineering Estimate
Travel	Sample Event	2	$4,050	$8,100		Includes travel-airfare for 2 people and truck rental	Engineering Estimate
Per Diem	Sample Event	2	$2,640	$5,280		20 days/sample event, $80 day/person, 2 people	Engineering Estimate
Laboratory Analysis & Data Validation							
VOCs	Sample	90	$300	$27,000		25 gw/ 7 sed/7 surface water/5dups/ 1MS/MSD / twice yearly	Basic Ordering Agreement
Supplies and Equipment	Sample Event	2	$1,100	$2,200		Ice, DI water, expendables, pump, meters, etc.	Engineering Estimate
Sample Shipping	Sample Event	2	$3,750	$7,500		2 coolers per day for 20 days; $83/cooler	Engineering Estimate
Reporting	Sample Event	2	$10,000	$20,000		Laboratory reports, administration, etc.	Engineering Estimate
Well Replacement	Year	1	$6,250	$6,250		Equal annual cost of replacing 25 wells every 10 years for 30 years	Engineering Estimate
Total Monitoring O&M Costs					$101,930		

TABLE 5-3
ESTIMATED COSTS FOR GROUNDWATER RAA No. 3

GROUNDWATER RAA No. 3: EXTRACTION AND ON-SITE TREATMENT
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB CAMP LEJEUNE, NC

11 EXTRACTION WELLS
55 GPM TREATMENT FACILITY

MONITORING 20 EXISTING AND 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

ANNUAL O&M COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
TREATMENT SYSTEM O&M (Based on 30 years of system operation)							
Labor for Plant O&M	Week	52	$120	$6,240		4 hrs/wk, 52 weeks/yr, at $30/hr	Engineering Estimate
Labor for Sampling	Month	12	$240	$2,880		8 hr/month, 12 months/yr, at $30/hr	Engineering Estimate
Air Sampling - Analysis	Sample	24	$200	$4,800			Engineering Estimate
Effluent Sampling - Analysis	Sample	24	$300	$7,200			Engineering Estimate
Carbon Regeneration/Replacement	EA	2	$1,000	$2,000			Engineering Estimate
Sludge Disposal	Month	12	$300	$3,600		2 drums/month at $150/drum disposal costs	Engineering Estimate
Electricity	Month	12	$150	$1,800		24 hr/day, 365 days/year operation	Engineering Estimate
Administration & Reports	HR	100	$50	$5,000		25 hrs/quarter at $50/hr	Engineering Estimate
Total Treatment System O&M Costs					$33,520		

SUMMARY OF TOTAL CAPITAL AND O&M COSTS

TOTAL DIRECT AND INDIRECT CAPITAL COSTS	$813,474	
TOTAL ANNUAL O&M COSTS	$135,450	Assuming 30 Years of Operation
PRESENT WORTH VALUE	$2,900,000	Based on a discount rate of 5%

TABLE 5-4
ESTIMATED COSTS FOR GROUNDWATER RAA No. 4

GROUNDWATER RAA No. 4: IN SITU VOLATILIZATION (AIR SPARGING)
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB, CAMP LEJEUNE, NORTH CAROLINA

40 AIR SPARGING AND 47 SVE WELLS
MONITORING 20 EXISTING AND 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITOL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS / COMMENTS	SOURCE
DIRECT CAPITAL COST ESTIMATE							
GENERAL							
Preconstruction Submittals	LS	1	$ 12,000	$ 12,000		Work, E&S, NPDES, H&S, and QC Plans; Shop Drawings	Engineering Estimate - Previous Projects
Mobilization/Demobilization	LS	1	$ 9,000	$ 9,000		Includes mobilization for all subcontractors	Engineering Estimate - Previous Projects
Decontamination Pad	LS	1	$ 7,500	$ 7,500		Includes decon/laydown area	Engineering Estimate - Previous Projects
Contract Administration	LS	1	$ 9,000	$ 9,000		Invoicing, project management	Engineering Estimate - Previous Projects
Post-Construction Submittals	LS	1	$ 5,500	$ 5,500		Operation Manuals, Record Drawings, etc.	Engineering Estimate - Previous Projects
Pilot Study	LS	1	$ 75,000	$ 75,000			Engineering Estimate - Previous Projects
Total General Costs					$ 118,000		
SITE WORK							
Site Work During System Installation:							
Piping Trench for the Air Injection Line	LF	1390	$ 4	$ 5,560		Includes excavation, removal, backfill, and tamping	Means Site 1997, A12.73-110 & Estimate
Piping Trench for the Air Extraction Line	LF	1330	$ 4	$ 5,320		Includes excavation, removal, backfill, and tamping	Means Site 1997, A12.73-110 & Estimate
Excavation for Treatment Plant Bldg	LS	1	$ 2,500	$ 2,500			Engineering Estimate
Water Connection at Treatment Plant	LF	100	$ 8	$ 800		Includes trenching & laying copper line	Means Site 1997, 026-662 & 022-258
Overhead Electrical to Treatment Plant	LF	70	$ 25	$ 1,750		Includes overhead routing and poles	Means Site 1997, 167-100 & Estimate
Site Restoration:							
Top Dressing Around Treatment Plant	CY	50	$ 40	$ 2,000		Around 30' x 30' treatment plant slab, 6" thick	Means Site 1997, 022-286 & Estimate
Fine Grading and Seeding for Revegetation	SY	1000	$ 2	$ 2,000		Revegetation at trenched area (2,720 ft x 3 ft) and treatment area	Means Site 1997, 022-286 & Estimate
Total Site Work Costs					$19,930		

TABLE 5-4
ESTIMATED COSTS FOR GROUNDWATER RAA No. 4

GROUNDWATER RAA No. 4: IN SITU VOLATILIZATION (AIR SPARGING)
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB, CAMP LEJEUNE, NORTH CAROLINA

40 AIR SPARGING AND 47 SVE WELLS
MONITORING 20 EXISTING AND 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITOL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS / COMMENTS	SOURCE
BUILDING							
Slab for Treatment Bldg	EA	1	$ 4,500	$ 4,500		30'x30' on-grade slab	Engineering Estimate; Previous Projects
Block Building for Treatment Plant	SF	900	$ 100	$ 90,000		30' x 30' building incl. materials and installation	Engineering Estimate; Previous Projects
Total Building Costs:					$ 94,500		
MONITORING WELLS							
Additional Well Installation	LS	1	$ 12,700	$ 12,700		Install 2 shallow, 2 intermediate, and 1 deep monitoring wells	Engineering Estimate - Table A
Total Well Installation Cost					$ 12,700		
AIR SPARGING & VAPOR EXTRACTION WELLS							
Air Sparging (injection) Wells	LF	1580	$ 72	$ 113,760		14 IAS wells at 20 ft; 26 IAS wells at 50 ft, 1 inch dia. PVC	Engineering Estimate
Soil Vapor Extraction Wells	LF	1870	$ 72	$ 134,640		16 SVE wells at 20 ft; 31 SVE wells at 50 ft., 2 inch dia. PVC	Engineering Estimate
Watertight Vaults for Wells	Each	87	$ 1,500	$ 130,500		Fiberglass, watertight closure/vault (4' deep) for each well	Engineering Estimate
Total Air Sparging and Vapor Extraction Wells Costs:					$ 378,900		
PIPING SYSTEM							
2" Steel Air Injection Line	LF	1390	$ 9	$ 12,510			Means Site 1997, 026-678 & Estimate
2" Steel Vapor Extraction Line	LF	1330	$ 9	$ 11,970			Means Site 1997, 026-678 & Estimate
6" PVC Conduit to Contain 1" & 2" Lines	LF	2720	$ 10	$ 27,200		To provide protection for the 1" and 2" lines	Means Site 1997, 026-678 & Estimate
Miscellaneous Fittings	LS	1	$ 7,752	$ 7,752		Assume 15% of piping costs	Engineering Estimate
Total Piping System Costs:					$ 59,432		
TREATMENT PLANT EQUIPMENT							
Positive Displacement Rotary Lobe Blower	Each	4	$ 5,000	$ 20,000		Assume 100 cfm blowers (1 per 10 wells)	Engineering Estimate
Positive Displacement Rotary Lobe Blower	Each	4	$ 8,000	$ 32,000		Assume 200 cfm blowers (1 per 10 wells)	Engineering Estimate
Vapor Phase Activated Carbon Unit	Each	4	$ 1,000	$ 4,000		Assume 4 units	Engineering Estimate
Air/Water Separator	Each	1	$ 15,000	$ 15,000		Assume 1 separator to treat all extracted material	Engineering Estimate
Water Collection Tank	Each	1	$ 500	$ 500		Assume a capacity of approximately 100 gallons	Engineering Estimate
Instrument Control Panel	Each	1	$ 5,000	$ 5,000		Includes pump controls	Engineering Estimate
Miscellaneous Appurtenances	LS	1	$ 7,650	$ 7,650		Assume 10% of treatment equipment costs	Engineering Estimate
Equipment Installation	LS	1	$ 19,125	$ 19,125		Assume 25% of treatment equipment costs	Engineering Estimate
Total Treatment Plant Equipment Costs:					$ 103,275		
TOTAL DIRECT CAPITOL COSTS					$ 786,737		

TABLE 5-4
ESTIMATED COSTS FOR GROUNDWATER RAA No. 4

GROUNDWATER RAA No. 4: IN SITU VOLATILIZATION (AIR SPARGING)
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB, CAMP LEJEUNE, NORTH CAROLINA

40 AIR SPARGING AND 47 SVE WELLS
MONITORING 20 EXISTING AND 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITOL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS / COMMENTS	SOURCE
INDIRECT CAPITAL COSTS:							
Engineering and Design	LS	1	$ 94,408	$ 94,408		Assume 12% of Total Direct Capital Costs	Engineering Estimate
Construction Administration	LS	1	$ 118,011	$ 118,011		Assume 15% of Total Direct Capital Costs	Engineering Estimate
Contingency Allowance	LS	1	$ 118,011	$ 118,011		Assume 15% of Total Direct Capital Costs	Engineering Estimate
Start-Up Costs	LS	1	$ 118,011	$ 118,011		Assume 15% of Total Direct Capital Costs (6 months operation)	Engineering Estimate
SUBTOTAL INDIRECT CAPITAL COSTS:					$ 448,440		

ANNUAL O&M COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS / COMMENTS	SOURCE
GROUNDWATER/SURFACE WATER/SEDIMENT MONITORING O&M (Based on semiannual sampling for 30 years)							
Labor	Hours	800	$ 32	$ 25,600		2 sample events, 20days, 10 hrs/day/person, 2 people	Engineering Estimate
Travel	Sample Event	2	$ 4,050	$ 8,100		Includes travel-airfare for 2 people and truck rental	Engineering Estimate
Per Diem	Sample Event	2	$ 2,640	$ 5,280		20 days/sample event, $80/day/person, 2 people	Engineering Estimate
Laboratory Analysis & Data Validation							
VOCs	Sample	90	$ 300	$ 27,000		25 gw/7 surface water/7 sed/ 5 dups / 1 MS/MSD / twice yearly	Basic Ordering Agreement
Supplies and Equipment	Sample Event	2	$ 1,100	$ 2,200		Ice, DI water, expendables, pump, meters, etc.	Engineering Estimate
Sample Shipping	Sample Event	2	$ 3,750	$ 7,500		2 coolers per day for 20 days; $83/cooler	Engineering Estimate
Reporting	Sample Event	2	$ 10,000	$ 20,000		Laboratory reports, administration, etc.	Engineering Estimate
Well Replacement	Year	1	$ 6,250	$ 6,250		Equal annual cost of replacing 25 wells every 10 years for 30 years	Engineering Estimate
Total Monitoring O&M Costs					$101,930		

TABLE 5-4
ESTIMATED COSTS FOR GROUNDWATER RAA No. 4

GROUNDWATER RAA No. 4: IN SITU VOLATILIZATION (AIR SPARGING)
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB, CAMP LEJEUNE, NORTH CAROLINA

40 AIR SPARGING AND 47 SVE WELLS
MONITORING 20 EXISTING AND 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITOL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS / COMMENTS	SOURCE
TREATMENT SYSTEM O&M (Assume 30 years of System Operation)							
Labor for Plant O&M	Week	52	$ 240	$ 12,480		Assume 8 hours/week @$30/hr	Engineering Estimate
Labor for Sampling	Week	52	$ 60	$ 3,120		Assume 2 hours/week @$30/hr	Engineering Estimate
Vapor Sampling & Analysis	Months	12	$ 200	$ 2,400		1 sample/month at $ 200/VOC analysis	Engineering Estimate
Carbon Replacement	Each	2	$ 1,000	$ 2,000		Assume 2 unit replacement/year	Engineering Estimate
Knockout Liquids Sampling & Analysis	Sample	6	$ 300	$ 1,800		1 sample bimonthly at $300/analysis	Engineering Estimate
Disposal of Knockout Liquids	Each	6	$ 150	$ 900		0.5 drums/month at $ 150/drum disposal costs	Engineering Estimate
Electricity	Month	12	$ 200	$ 2,400		24 hours/day for 365 days/yr operation	Engineering Estimate
Equipment Maintenance	Year	1	$ 5,000	$ 5,000		Assume $5,000/year	Engineering Estimate
Administration and Records	Hours	100	$ 50	$ 5,000		25 hrs/quarter at $50/hr	Engineering Estimate
Total Treatment O&M Costs:					$ 35,100		

SUMMARY OF TOTAL CAPITAL AND O&M COSTS

TOTAL DIRECT AND INDIRECT CAPITAL COSTS	$ 1,235,177	
TOTAL ANNUAL O&M COSTS	$137,030	Assuming 30 Years of Operation
PRESENT WORTH VALUE	$3,340,000	Based on a discount rate of 5 %

TABLE 5-5
ESTIMATED COSTS FOR GROUNDWATER RAA No. 5

GROUNDWATER RAA No. 5: PASSIVE TREATMENT WALL
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB CAMP LEJEUNE, NC

PASSIVE TREATMENT WALL
WALL 1 - 150'X20'; WALL 2 200'X20'; WALLS 3 AND 4 300'X50'
MONITORING 20 EXISTING WELLS
INSTALLING AND SAMPLING 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITAL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
DIRECT CAPITAL COSTS:							
GENERAL							
Preconstruction Submittals	LS	1	$12,000	$12,000		Work Plan, Erosion and Sediment Control Plan, and H & S Plan	Engineering Estimate- Previous Projects
Mobilization/Demobilization	LS	1	$9,000	$9,000		Includes mobilization for all subcontractors	Engineering Estimate- Previous Projects
Decontamination Pad	LS	1	$7,500	$7,500		Includes decon/laydown area	Engineering Estimate- Previous Projects
Contract Administration	LS	1	$9,000	$9,000		Invoicing, shop drawings, etc.	Engineering Estimate- Previous Projects
Post-Construction Submittals	LS	1	$5,500	$5,500			Engineering Estimate- Previous Projects
Bench-Scale Study	LS	1	$30,000	$30,000			Vendor Estimate - Previous Projects
Pilot-Scale Study	LS	1	$150,000	$150,000			Engineering Estimate
Total General Costs					$223,000		
SITE WORK							
Site Work During System Installation:							
Clearing	Acre	1	$8,000	$8,000		Clear and grub, chip stumps	Means Site 1997, 021-104 & Estimate
Site Restoration:							
Topsoil Spreading in Cleared Areas	SY	1600	$3	$4,800		Includes off-site topsoil and 6" placement; assume 3/4 acre	Engineering Estimate - Previous Projects
Fine Grading and Seeding for Revegetation	SY	1600	$2	$3,200		Area as noted for topsoil spreading	Means Site 1997, 022-286 & Estimate
Total Site Work Costs					$16,000		

TABLE 5-5
ESTIMATED COSTS FOR GROUNDWATER RAA No. 5

GROUNDWATER RAA No. 5: PASSIVE TREATMENT WALL
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB CAMP LEJEUNE, NC

WALL 1 - 150'X20'; WALL 2 200'X20'; WALLS 3 AND 4 300'X50'
MONITORING 20 EXISTING WELLS
INSTALLING AND SAMPLING 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITAL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
DIRECT CAPITAL COSTS (CONTINUED):							
PERMEABLE REACTIVE WALL							
Gate Casions	CF	111000	$125	$13,875,000			Engineering Estimate- Previous Projects
Reactive Media	CF	111000	$45	$4,995,000			Engineering Estimate- Previous Projects
Funnel Walls	SF	1500	$10	$15,000		Assumes slurry wall/Gundwall	Engineering Estimate- Previous Projects
Total Reactive Wall Costs					$18,885,000		
TOTAL DIRECT CAPITAL COSTS					$19,124,000		

TABLE 5-5
ESTIMATED COSTS FOR GROUNDWATER RAA No. 5

GROUNDWATER RAA No. 5: PASSIVE TREATMENT WALL
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB CAMP LEJEUNE, NC

PASSIVE TREATMENT WALL
WALL 1 - 150'X20'; WALL 2 200'X20'; WALLS 3 AND 4 300'X50'
MONITORING 20 EXISTING WELLS
INSTALLING AND SAMPLING 5 NEW WELLS
SAMPLING 7 SURFACE WATER/SEDIMENT STATIONS
Nov-97

DIRECT AND INDIRECT CAPITAL COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
INDIRECT CAPITAL COSTS:							
Engineering and Design	LS	1	$2,294,880	$2,294,880		12% of Total Direct Cost	Engineering Estimate
Design and Construction Administration	LS	1	$2,868,600	$2,868,600		15% of Total Direct Cost	Engineering Estimate
Contingency Allowance	LS	1	$2,868,600	$2,868,600		15% of Total Direct Cost	Engineering Estimate
Start-up Costs	LS	1	$2,868,600	$2,868,600		15% of Total Direct Cost	Engineering Estimate
TOTAL INDIRECT CAPITAL COSTS					$10,900,680		

ANNUAL O&M COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
GROUNDWATER/SURFACE WATER/SEDIMENT MONITORING O&M (Based on semiannual sampling for 3							
Labor	Hours	800	$32	$25,600		2 sample events, 10 days each, 10hrs/day/person, 2 people	Engineering Estimate
Travel	Sample Event	2	$4,050	$8,100		Includes minivan rental and airfare for 2 people	Engineering Estimate
Per Diem	Sample Event	2	$2,640	$5,280		Includes lodging and meals for 2 people	Engineering Estimate
Laboratory Analysis & Data Validation							
VOCs	Sample	90	$300	$27,000		25 gw, 7 sed/ 7 surface water/5 dups/1 MS/MSD/twice yearly	Basic Ordering Agreement
Supplies and Equipment	Sample Event	2	$1,100	$2,200		Ice, DI water, expendables, pump, meters, etc.	Engineering Estimate
Sample Shipping	Sample Event	2	$3,750	$7,500		2 coolers per day for 20 days; $83/cooler	Engineering Estimate
Reporting	Sample Event	2	$10,000	$20,000		Laboratory reports, administration, etc.	Engineering Estimate
Well Replacement	Year	1	$6,250	$6,250		Equal annual cost of replacing 25 wells every 10 years for 30 years	Engineering Estimate
Total Monitoring O&M Costs					$101,930		

TABLE 5-5
ESTIMATED COSTS FOR GROUNDWATER RAA No. 5

GROUNDWATER RAA No. 5: PASSIVE TREATMENT WALL
OU No. 16, SITES 89 AND 93
FEASIBILITY STUDY, CTO-0356
MCB CAMP LEJEUNE, NC

WALL 1 - 150'X20'; WALL 2 200'X20'; WALLS 3 AND 4 300'X50'
MONITORING 20 EXISTING WELLS
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Nov-97

ANNUAL O&M COSTS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
TREATMENT SYSTEM O&M (Based on 30 years of system operation)							
Reactive Media Replacement and Disposal	Year	1	$166,500	$166,500		Equal annual cost of replacing the media once in 30 years	Engineering Estimate
Total Treatment System O&M Costs					$166,500		Engineering Estimate

SUMMARY OF TOTAL CAPITAL AND O&M COSTS

TOTAL DIRECT AND INDIRECT CAPITAL COSTS	$30,024,680	
TOTAL ANNUAL O&M COSTS	$268,430	Assuming 30 Years of Operation
NET PRESENT WORTH	$34,150,000	Based on a discount rate of 5%

APPENDIX A
PASSIVE TREATMENT WALL INFORMATION

Paper Presented at the 1992, 45th Canadian Geotechnical Society Conference, Toronto, Ontario Oct 25-28.

A PERMEABLE REACTION WALL FOR IN SITU DEGRADATION OF HALOGENATED ORGANIC COMPOUNDS

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SYNOPSIS

This paper describes a new remediation technology for removing aqueous-phase halogenated organic compounds from groundwater. A permeable reaction wall is installed across the flow path of a contaminant plume, allowing the plume to passively move through the wall. The halogenated organic compounds are degraded by reactions with a mixture of porous media and a metal catalyst, emerging on the opposite side with the halogenated organic compounds removed. This passive method of remediation could be a cost effective alternative to conventional pump-and-treat systems and the halogenated organic compounds actually degrade rather than simply being transferred to a different medium.

INTRODUCTION

Estimates of the cost to clean up contaminated groundwater in the United States range as high as 1.3 trillion U.S. dollars. While this number may be difficult to defend, it is also true that few would argue for a lower estimate. Considering the global scale of the problem, it is clear that very substantial resources will be required to remediate contaminated groundwater or, in many areas, it is more likely that aquifers will remain contaminated for many decades into the future. The only alternative would appear to be the development of new cost-effective methods of remediation.

The most common method used to remediate contaminated aquifers is some variation of pump-and-treat. Though simple in concept, experience with this approach has been less than encouraging. In particular, the time and cost required to remediate a site has generally far exceeded estimated values. Common reasons for this include geochemical retardation of the contaminants, incomplete removal of the source, geologic heterogeneity and inadequate characterization of the initial contaminant distribution. The unavoidable consequence is much higher capital and operating costs than anticipated.

This paper describes the field testing of a new passive remediation technology for removing aqueous-phase halogenated organic compounds from groundwater. The design involves an *in-situ* permeable wall installed across the path of a contaminant plume (Figure 1). The wall consists of a porous medium containing a metal catalyst. As the water passes through the wall, the contaminants are degraded, preventing further down-stream migration of contaminated water.

This passive method of remediation should be a cost effective alternative to conventional pump-and-treat systems. In addition, the contaminants are degraded instead of being transferred from the water to different media, that would subsequently the well-defined plume and the existence of a detailed monitoring network were all favourable for evaluating the performance of the catalyst in a passive *in situ* treatment wall.

The initial step in the investigation involved laboratory tests to evaluate the effectiveness of the catalyst in the presence of geologic materials from the test site and for the contaminants that were present in the plume. This was followed by the installation and evaluation of a reactive wall.

LABORATORY TESTS

Laboratory batch experiments similar to those reported in Gillham and O'Hannesin (1992), were carried out to determine the rate of degradation of the organic contaminants in contact with the iron catalyst and aquifer material. The aquifer material for these experiments was collected from Canadian Forces Base Borden, near the site of the field test. This aquifer is an unconfined sand aquifer underlain by a thick, silty clay deposit.

The solution used in the batch tests contained; carbon tetrachloride (CT), chloroform (TCM), trichloroethene (TCE) and tetrachloroethene (PCE), with initial concentrations of 4050, 4650, 4080 and 3970 μg/L, respectively. Tests were conducted at 12°C, the approximate temperature of the groundwater at the field site. The batch tests were conducted in 60 mL glass hypovials. Control hypovials contained 60 g of Borden sand and the reactive hypovials contained 60 g of Borden sand along with 10 g of 100 mesh iron filings. The hypovials were filled, leaving no head space, with the aqueous solution containing the organic compounds of interest, then sealed immediately with aluminum crimp caps with Teflon®-lined septa. Six hypovials were sacrificed for each sampling time: three controls and three reactive vials. All organic samples were analyzed using a gas chromatograph, and procedures similar to those described in Reynolds et al. (1990).

The results of the batch tests are plotted in Figure 2 as concentration of the organics in μg/L versus time. The control hypovials, aqueous organic solution and aquifer materials, maintained the initial concentrations for the duration of the experiment, with minor fluctuations but no consistent trends. In contrast, the reactive hypovials, those containing both aquifer material, iron and aqueous organic solution, show an exponential decline in concentration. The CT degraded to concentrations below detection in 21 minutes. The initial increase in the TCM concentration is due to CT degrading to form TCM; however, the TCM subsequently degraded though at a slower rate than CT. TCE could not be detected by 143 hours. PCE degraded, though at a slower rate and thus low concentrations persisted at the conclusion of the experiment (165 hours).

Using a first-order kinetic model, the half-lives obtained from the slopes of the first-order model are 2.2, 850, 1520 and 4000 minutes for CT, TCM, TCE and PCE, respectively. The controls experienced no Eh change, while the reactive vials showed highly reducing conditions, but no significant change in pH.

In addition to the batch tests, laboratory column experiments were conducted in order to determine if the process would occur under dynamic flow conditions. The columns contained a mixture of Borden sand and metal catalyst similar to that proposed for use at the field site and flow rates were similar to the groundwater velocity at the site. Though not presented here, the results were reasonably consistent with the results of the batch tests.

FIELD TEST

The reactive wall was constructed perpendicular to the groundwater flow direction, 5.5 m down gradient from the emplaced source. A plan-view

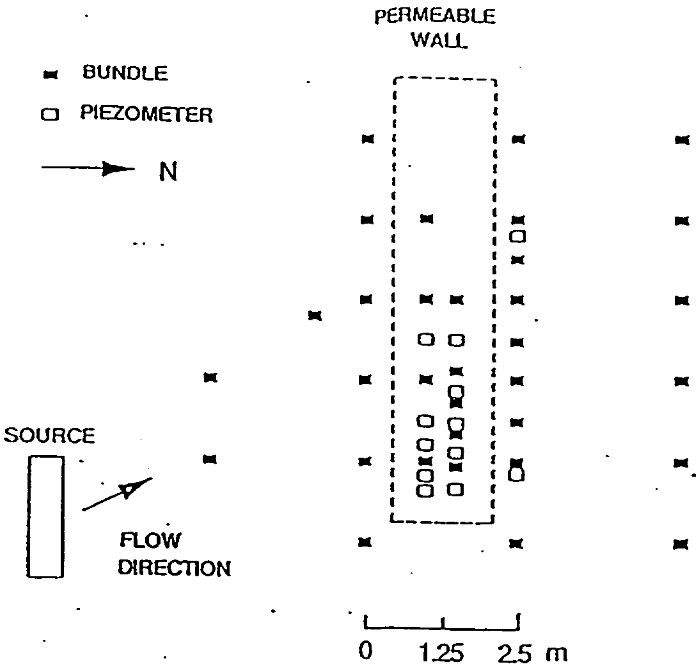

Figure 3: Plan-view of field test site.

of hydrogeochemical environments, the reaction mechanism and formation of toxic breakdown products. Nevertheless, due to the apparent effectiveness and relatively low cost of the reactants, there appears to be significant potential for this technology to be applied to a variety of practical groundwater contamination problems.

REFERENCES

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envirometal
technologies
inc.

the envirometal process

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metal-enhanced abiotic degradation of chlorinated organic compounds

THE COMPANY

envirometal technologies Inc. (ETI) is a Canadian-owned company, committed to providing its clients with cost effective, long-term solutions for the remediation of water contaminated with halogenated organic compounds, through the application of the **envirometal** process developed at the Waterloo Centre for Groundwater Research. The University of Waterloo, as a partner in ETI and through the Waterloo Centre for Groundwater Research, is developing further applications of this patented process.

TECHNOLOGY DESCRIPTION

The **envirometal** process uses a metal formulation to degrade dissolved halogenated organic chemicals from groundwater including common chlorinated compounds such as tetrachloroethene (PCE), trichloroethene (TCE), vinyl chloride (VC) and trichloroethane (TCA). The **envirometal** formulation induces conditions that cause substitution of halogen atoms by hydrogen atoms. The end-products of the process are completely dehalogenated and non-toxic. Examples of end-products of chlorinated VOCs degraded by the **envirometal** process are ethene, ethane, methane and chloride ions.

ADVANTAGES

The **envirometal** process is a mechanically simple, long-term, and cost effective technology for treating groundwater containing VOCs. The simplicity of the process applied in either an *in-situ* or above-ground configuration will greatly reduce operating and maintenance costs such as:

- energy consumption;
- water processing and disposal charges; and
- activated carbon regeneration or disposal.

It is a **destructive** treatment technology and therefore does not simply transfer chemicals from one medium to another as is the case with air stripping and activated carbon systems.

Because the VOCs are degraded, the **envirometal** process is superior to barrier technologies which simply contain these compounds.

In-situ installations require no ongoing energy input because groundwater is treated while migrating in the natural hydrogeologic system (i.e., there is no extraction and discharge of treated groundwater). Installations made up gradient of the property lines will enable maximum concentration limits (MCLs) to be met at the property boundary.

The process will effectively combine with other groundwater remedial and control technologies for full treatment of groundwater contaminants.

It does not produce toxic end-products or sludge.

APPLICATION CONFIGURATIONS

In-Situ envirometal Permeable Treatment Walls

An *in-situ* **envirometal** treatment wall consists of a permeable metal formulation installed across the flow path of a plume of VOC-bearing groundwater (Figure 1). The VOCs are degraded as they migrate slowly through the wall under natural groundwater flow conditions.

By utilizing alternating sections of impermeable sheet pile or slurry wall constructed so as to funnel the VOC-bearing groundwater through permeable treatment sections, large plumes of VOCs can be degraded as groundwater passes through the **envirometal** formulation (Figure 2).

Above-Ground envirometal Treatment Canisters

Above ground **envirometal** treatment units are being designed to replace air strippers and activated carbon canisters in existing groundwater treatment systems. Components that enhance the reaction rate of VOCs with the **envirometal** treatment mixture may allow these canisters to treat significant quantities of extracted groundwater over short periods of time (tens to hundreds of gallons per minute). Data collected during field tests of the **envirometal** canister show that the process may effectively replace air stripping and activated carbon as methods of removing halogenated VOCs from extracted groundwater.

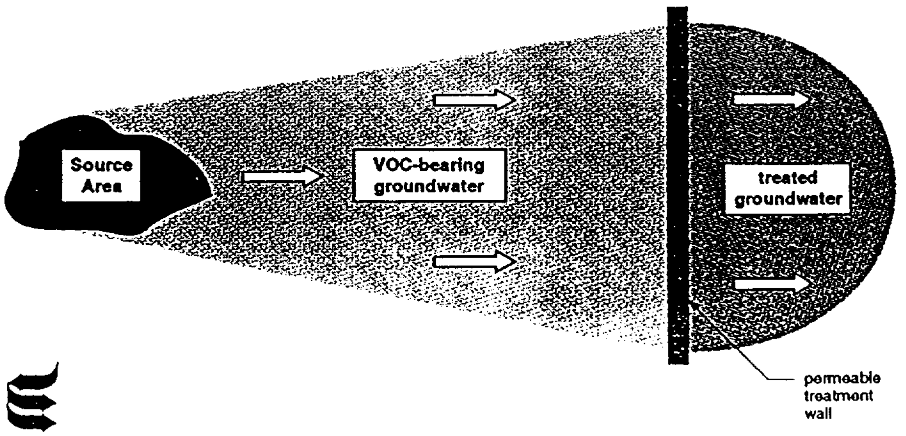


Figure 1: Schematic Plan View of an *In-Situ* Permeable Treatment Wall

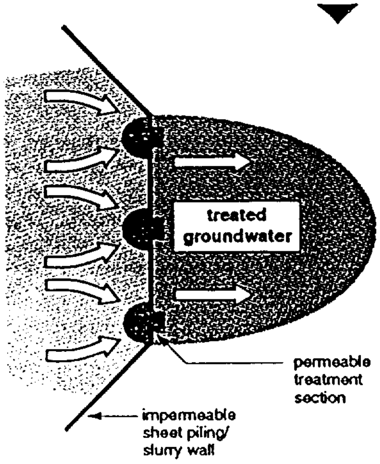


Figure 2: Schematic Plan View of *In-Situ* Permeable Treatment Sections Installed in Conjunction with an Impermeable Barrier

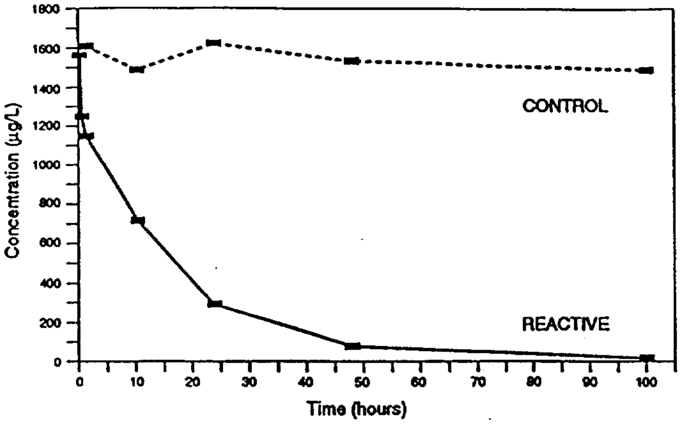


Figure 3: Typical Batch Degradation Curve for TCE

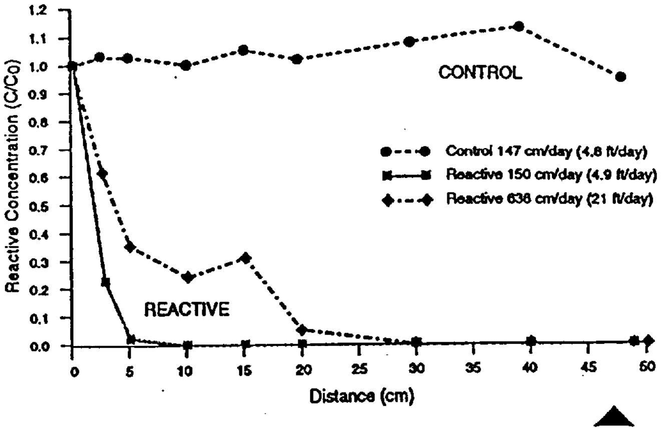


Figure 4: Typical Steady State, Control & Reactive Columns for TCE

IMPLEMENTATION PROCEDURE

The complex nature of the remediation of halogenated organic compounds requires a phased approach to the application of the envirometal process. The phases are described below.

Phase 1 - Preliminary Assessment

The purpose of Phase 1 is to review existing site data to screen the site relative to the current knowledge level of the technology, i.e. conditions that affect the process and its application. On the basis of this review the site will fall into one of two categories.

The first category includes sites that have a physical setting and groundwater chemistry similar to other sites at which the envirometal process is effective. The envirometal process has a high probability of success at these sites.

The second category are sites having unique physical and geochemical properties that may affect the application of the envirometal process. They have in common an unknown probability for the successful application of the technology, due to the presence of untested chemicals, unusual inorganic chemistry or unusual geologic settings.

Data that are necessary to assess a site include:

- groundwater inorganic and organic chemistry;
- VOC characteristics: compounds, concentration and distribution;
- site geology and soils: depth to water table, aquifer and aquitard thickness;
- hydrogeological data, such as hydraulic conductivity and groundwater velocity; and
- current remedial activities.

Phase 2 - Feasibility Evaluation

If the site falls into the first category, a feasibility evaluation is recommended. The purpose of Phase 2 is to evaluate the efficiency of the process under simulated groundwater flow conditions, through laboratory tests using representative groundwater samples taken from the site. Groundwater flow and geochemical models may be used to assist in the feasibility evaluation.

The tests will:

- confirm that the VOCs present are degraded by the process;
- evaluate the rates of VOC degradation; and
- evaluate associated inorganic geochemical reactions.

The Phase 2 report will interpret the laboratory data in light of the site's hydrogeologic characteristics and provide a preliminary design and cost estimate for a pilot scale field test. Examples of typical data from a feasibility evaluation are shown in Figures 3 and 4.

Figure 3 shows a typical laboratory batch test degradation curve for TCE. Figure 4 shows a typical column test result for TCE under steady state conditions and two flow rates. Column tests are performed to assess the process under dynamic conditions representative of groundwater flow through the treatment media. This figure shows that the process is effective even with flow rates of 638 cm/day (21 ft/day).

The feasibility evaluation recommended for second category sites may incorporate additional testing to better evaluate the unique geochemistry of the site in terms of potential technology application.

Phase 3 - Pilot Scale Field Test

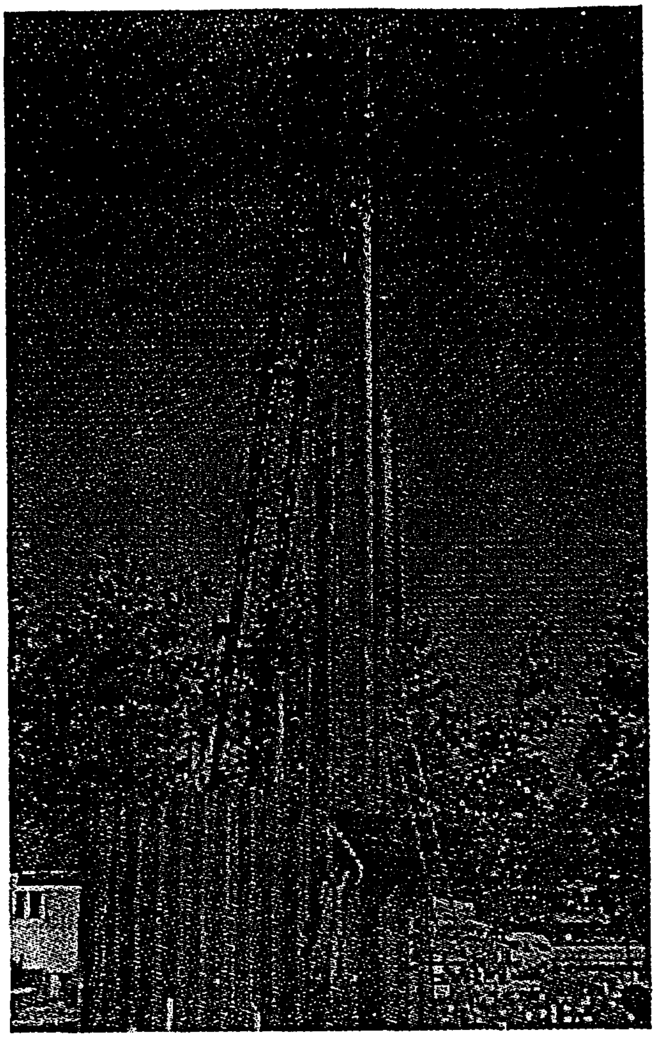
Following successful laboratory tests, a pilot scale field test will collect the data required for a full scale application of the process. Results of Phase 2 tests are used to design the pilot scale system. The system may be installed *in-situ* or above-ground (depending on the potential full scale application and site conditions). This field verification of the envirometal process provides data concerning full scale costs, long term performance and operation, and maintenance requirements. The Phase 3 report will present an evaluation of the field test, and a detailed cost estimate for a full scale system.

Phase 4 - Full Scale Implementation

Phase 4 is the design and installation of a full scale system. The results from Phase 3 provide the basis for full scale design.

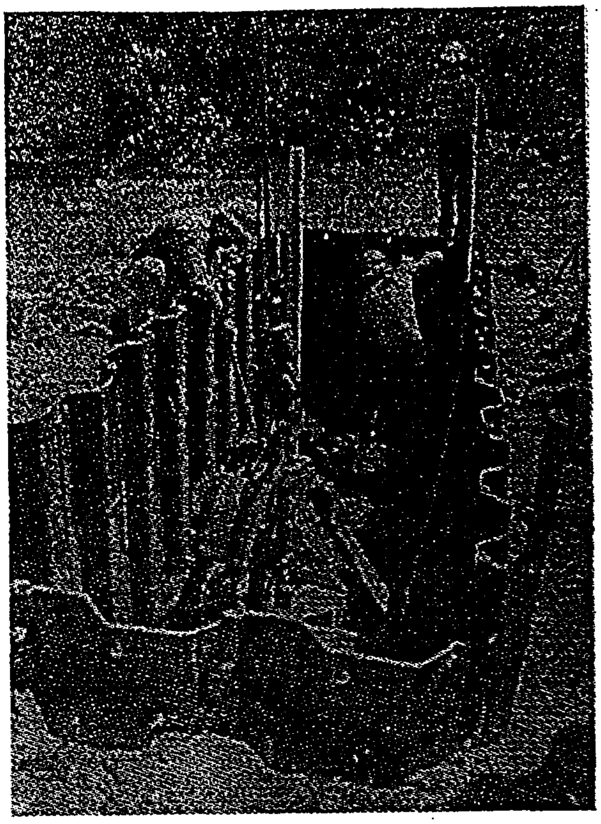
Phase 5 - Long Term Performance Monitoring

Routine performance monitoring and reporting will be undertaken according to regulatory requirements, and will include an ongoing comparison of field results to design criteria.



▲

Sealable sheet piling being used to construct
a permeable treatment wall.



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Installation of permeable treatment sections.
Impermeable sheet piles or slurry walls are used to funnel
groundwater through treatment sections.

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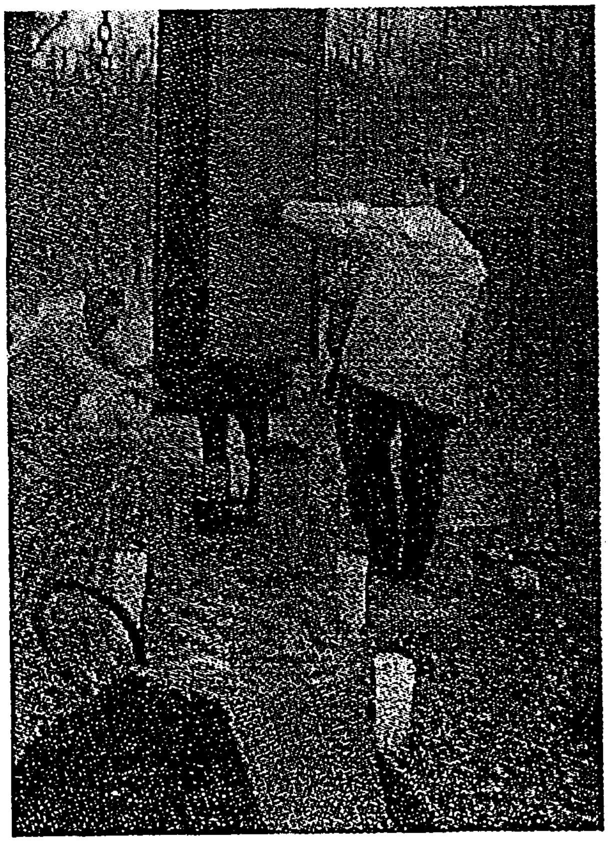

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Enhanced Degradation of Halogenated Aliphatics by Zero-Valent Iron

by Robert W. Gillham and Stephanie F. O'Hannesin[a]

Abstract

Laboratory tests were conducted to examine zero-valent iron as an enhancing agent in the dehalogenation of 14 chlorinated methanes, ethanes, and ethenes. All compounds were tested by batch procedures in which 10 g of 100-mesh electrolytic iron was added to 40 ml hypovials. Aqueous solutions of the respective compounds were added to the hypovials, and the decline in concentration was monitored over time. Substantial rates of degradation were observed for all compounds tested with the exception of dichloromethane. The degradation process appeared to be pseudo first-order with respect to the organic compound, with the rate constant appearing to be directly proportional to the surface area to volume ratio and increasing with increasing degree of chlorination. Column tests showed the process to proceed under flow conditions with degradation rates indpendent of velocity and consistent with those measured in the batch tests. When normalized to 1 m^2/ml, the t_{50} values ranged from 0.013 to 20 hr, and were about 5 to 15 orders of magnitude lower than values reported for natural rates of abiotic degradation. The results indicate abiotic reductive dechlorination, with iron serving as the source of electrons; the mechanism is, however, uncertain. Based on the rapid rates of degradation, both in situ and aboveground applications for remediation of contaminated ground water are proposed.

Introduction

Over the past decade, the development of improved methods for remediation of ground water contaminated by halogenated organic compounds has emerged as a significant environmental priority. Furthermore, with growing awareness of the limitations of pump-and-treat technologies (Mackay and Cherry, 1989, for example), the priority is shifting to in situ methods.

Of the substantial research effort that is now being focused on remediation technologies, a very large proportion concerns biological processes. Research in this area has been directed primarily toward the development of an understanding of biochemical pathways, developing/isolating effective strains of bacteria and the development of methods for stimulating effective populations of indigenous bacteria. In spite of the significant progress that has been made, in situ bioremediation technologies continue to be frustrated by the requirement of intimate mixing between the contaminated ground water and solutions injected into the subsurface for the purpose of stimulating favorable biological activity.

With the exception of granular activated carbon and advanced oxidation processes (ultraviolet irradiation, for example), neither of which is easily adaptable to in situ applications, relatively little attention has been focused on abiotic degradation processes. This is undoubtedly a consequence of the observed persistence of many chlorinated organic compounds in the subsurface environment and the very long half-lives that have been reported for these processes (Vogel et al., 1987 and Jeffers et al., 1989). Electrolytic transformations of carbon tetrachloride and 1,1,1-trichloroethane, as reported by Criddle and McCarty (1991), and the transformation of carbon tetrachloride in the presence of sulfide, biotite, and vermiculite, as reported by Kriegman-King and Reinhard (1992), are notable exceptions. In addition, several studies have examined biochemical transformations through the use of organo-metallic complexes including porphyrins and corrinoids. Gantzer and Wackett (1991), for example, reported half-lives of 0.09, 2.4, and 96 hr for tetrachloroethylene (PCE), trichloroethylene (TCE), and cis 1,2-dichloroethylene (cDCE), respectively, in the presence of vitamin B12 and titanium (III) citrate. In these reactions, the reduced metal of the organo-metallic complex is considered to be the source of electrons for the reductive dechlorination process.

In view of the observed rates of transformation in the presence of reduced metals of organo-metallic complexes, and in view of the significant literature related to metal corrosion by organic liquids and the use of zero-valent metals in the processing of organic liquids (as reviewed in Baciocchi, 1983, for example), it is perhaps surprising that environmental applications of zero-valent metals have not received greater attention. To our knowledge, the first environmental application, for removal of chlorinated organic compounds from aqueous solution, was reported in the patent literature (Sweeny and Fischer, 1972) and later in Sweeny (1981a, 1981b). In this case, catalyzed metallic iron powder was shown to degrade a wide range of halogenated organic contaminants. Though the results were promising, it appears that the work of Sweeny was not published in refereed journals, and has been largely overlooked by the research community.

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Received January 1994, revised May 1994, accepted July 1994.

More recently, in the presence of galvanized metal, Reynolds et al. (1990) reported 50% loss of 1,1,1-trichloroethane, hexachloroethane, and tribromomethane, in times of 1.5, 0.25, and 0.75 hr, respectively. Gillham and O'Hannesin (1992) confirmed the results of Reynolds et al. (1990) and extended the work to include other metals. Iron and zinc (galvanized metal) were found to give similar rates of degradation, followed by aluminum, with brass and copper giving substantially lower rates. No degradation in the presence of stainless steel was noted. These authors proposed the use of metals for both in situ and aboveground treatment of ground water contaminated by halocarbons.

Senzaki and Kumagai (1988, 1989) and Senzaki (1991) considered the use of iron powder for removal of 1,1,2,2-tetrachloroethane and trichloroethylene from waste water. Under the conditions of their experiments, the results indicated that the time for 50% removal of tetrachloroethane decreases from about 4 hr to 1 hr as the temperature increases from about 20 to 50°C, the rates of degradation were highly sensitive to the surface area of iron available for degradation, and there appeared to be a significant decline in the degradation rate at pH values in excess of about 8.0.

As a consequence of the limited but highly encouraging results of previous tests, the present study was undertaken to evaluate the rate of degradation of a wide range of halogenated aliphatic compounds in the presence of zero-valent metal. Because it is readily available at low cost and because of the effectiveness demonstrated in previous tests, iron was selected as the metal to be used in the tests. Tests were conducted to confirm the abiotic nature of the reaction and to examine the effect of the surface area to solution volume ratio on the reaction rate. Though not exhaustive, some tests were performed to determine the breakdown products of the degradation process. Most tests were conducted using batch procedures; however, column tests were also performed to evaluate the process under conditions of flow.

Methods

Analytical

Fourteen organic compounds were studied. These included four halogenated methanes, tetrachloromethane (CT), trichloromethane (TCM), dichloromethane (DCM), and tribromomethane (TBM); four chlorinated ethanes, hexachloroethane (HCA), 1,1,2,2- and 1,1,1,2-tetrachloroethane (1,1,2,2-TECA and 1,1,1,2-TECA), and 1,1,1-trichloroethane (1,1,1-TCA); and six chlorinated ethenes, tetrachloroethene (PCE), trichloroethene (TCE), trans 1,2-dichloroethene (tDCE), cis 1,2-dichloroethene (cDCE), 1,1-dichloroethene (DCE), and vinyl chloride (VC). The various compounds were obtained as analytical grade chemicals.

All samples for analyses were collected in aqueous solution; however, because of the number of compounds considered, several analytical procedures were required. Most of the compounds were extracted from the aqueous phase using pentane with an internal standard of 1,2-dibromoethane, at a water to pentane volume ratio of 1:1. The samples were placed on a rotary shaker for 10 minutes to allow equilibration between the water and pentane phases. For analysis, a 0.5-1.0 μl aliquot of the equilibrated pentane was removed and injected directly into a Hewlett Packard 5710A gas chromatograph with a Hewlett Packard 3390A integrator. The chromatograph was equipped with a ^{63}Ni electron capture detector (ECD) and a glass column packed with 10% Squalane on Chromasorb P, AW-DMCS (80/100 mesh). The oven temperature was 110°C with a detector temperature of 300°C. The carrier gas was 5% methane and 95% argon, with a flow rate of 20 ml/min. For high aqueous organic concentrations, dilutions were necessary in order to work within the calibrated range of the gas chromatograph. When concentrations were low, the water to pentane ratio was increased to improve analytical sensitivity.

For compounds that are highly volatile, including VC, DCM, and the DCE isomers, a headspace was created within the sample vial with a ratio of 3.75 ml headspace to 11.25 ml solution. The samples were equilibrated for 15 minutes on a rotary shaker. For analysis, a 50 μl gas sample was injected directly onto a "Photovac," Model 10S50, and/or 10S70, gas chromatograph equipped with a photoionization detector (PID). The Model 10S50 chromatograph was fitted with a TFE packed column with 5% SE-30 on Chromosorb G, AW-DMCS (100/120 mesh). The oven temperature was 30° C and the carrier gas was ultra-zero air with a flow rate of 10 ml/min. The Model 10S70 was fitted with a capillary column CP-Sil5, with an isothermal oven temperature of 30° C and a carrier gas flow rate of 3 ml/min. Detection limits for all compounds studied, as given in Table 1, were determined using the EPA procedure for Method Detection Limit (MDL) (U.S. EPA, 1982).

Redox potential (Eh) was determined using a combination of Ag/AgCl reference electrode with a platinum button and a Markson™ Model 90 meter. The electrode was standardized with ZoBell™. Millivolt readings were converted to Eh, using the electrode reading plus the standard potential of Ag/AgCl electrode at a given temperature. The pH measurements were conducted using a combination of pH/reference electrode and a Markson™ Model 90 meter, standardized with the pH buffer 7 and the approprate buffer of either 4 or 10.

Batch Tests

In the batch tests, 10 g of 100 mesh (0.15 mm) electrolytic iron powder (obtained from Fisher Scientific Inc., and with no pretreatment) were added to 40 ml glass hypovials. The hypovials were then filled with an aqueous solution containing the organic compound of interest, leaving no headspace, and were sealed immediately with aluminum crimp caps with Teflon®-lined septa. BET analysis gave a specific surface area for the iron of 0.287 m^2/g. The above procedure gave a surface area-to-solution volume ratio of 0.078 m^2/ml. In addition to the organic compound of interest, the solution contained 40 mg/l of calcium carbonate ($CaCO_3$). The calcium carbonate was added to give inorganic characteristics to the solution (pH and specific conductance) that might be typical of a dilute ground water. Five hypovials were prepared for each sampling time, two blanks containing only solution, and triplicate reactive hypovials containing solution and iron. The hypovials were filled by gravity flow through tubing connected to a spigot at the bottom of a glass reservoir containing the stock solution. To check for losses by volatilization during the filling process, one blank was filled followed by the three reactive hypovials, then the second blank. The hypovials were placed on a rotating disc (two complete revolutions per minute), allowing for complete mixing without agitation. Sufficient hypovials were prepared to accommodate seven sampling times, over periods as long as 500 hr. At the selected times, a set of five hypovials, triplicate samples, and two controls, were removed from the shaker and subsamples were transferred to vials for extraction. The remaining solution was analyzed for pH and Eh.

Two sets of supplementary tests were performed using adaptations of the above procedure and TCE as the test compound. In the first, two tests were performed in which a bactericide was added to the solution. Formaldehyde was added at a concentration of 250 mg/l, and in the second test, sodium azide was added at a concentration of 1000 mg/l. In the second supplementary test, iron was added in amounts of 1, 5, 10, 20, and 50 g to the hypovials, resulting in surface area to solution ratios of about 0.0076, 0.038, 0.078, 0.15, and 0.45 m^2/ml.

Column Procedures

A schematic of the column apparatus is given in Figure 1. The column consisted of acrylic tubing, 50 cm long by 3.8 cm I.D. Tests similar to those reported in Reynolds et al. (1990) showed sorption of organics by acrylic to be measurable but slow (comparable to rigid PVC). Thus, considering the small surface area to volume ratio, sorption onto the acrylic was not expected to have a significant effect on the results. Four sampling ports were located at 10 cm intervals along the column, and three additional ports were located at distances of 2.5, 5, and 15 cm from the influent end (Figure 1). Each sampling port was constructed using a nylon Swagelok® fitting (0.16 cm O.D.) with a 16G Luer-Lok™ syringe needle 3.8 cm long. The needles were held permanently in place in the fittings with the needle tips located along the longitudinal axis of the column. The reactive column was packed with silica sand containing 10% by weight 100 mesh iron filings. This mixture resulted in a surface area of iron to solution volume ratio of about 0.14 m^2/ml. A control column was identical except that no iron was added to the silica sand.

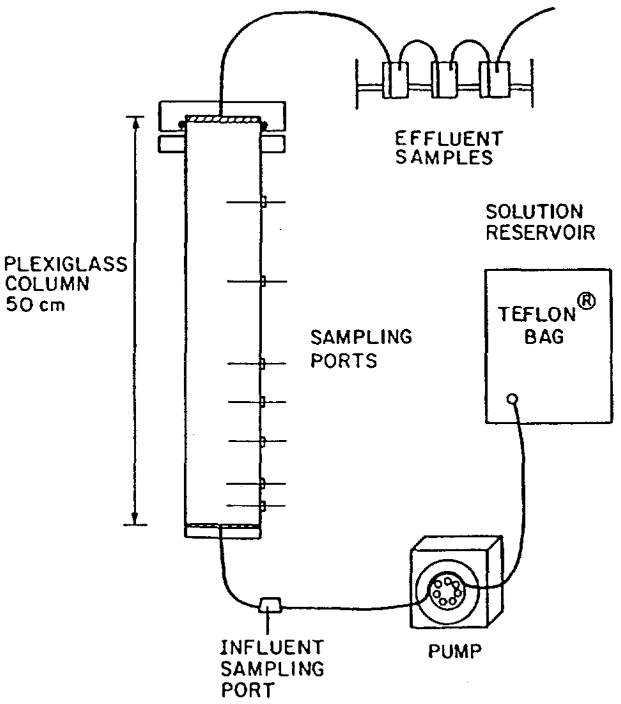

Fig. 1. Schematic of the apparatus used in the column experiments.

In order to assure complete saturation, the columns were initially flushed with carbon dioxide (CO_2) followed by several pore volumes of organic-free water. Solution containing the organic chemicals of interest was held in a collapsible Teflon® bag and was fed to the inlet end of the column by means of a peristaltic pump. With the exception of short lengths of Viton® tubing that passed through the pump, all tubing in the delivery system was Teflon®. A stainless steel "T" located in the delivery line, immediately before entering the column, was used to collect samples for determining the influent concentrations. Column tests were conducted for CT, TCE, and PCE.

Results and Discussion

Batch Tests

Figure 2 is an example of the results obtained from the batch tests. The organic compound in this case was TCE at an initial concentration of 1600 μg/l. As shown in Figure 2a, the concentration in the control hypovials remained relatively constant, declining by about 100 μg/l over the 100 hr duration of the experiment. The concentration in the reactive hypovials, on the other hand, showed what appeared to be an exponential decline in concentration to about 9.0 μg/l at the conclusion of the experiment. The log of relative concentration versus time, where relative concentration was calculated by dividing the measured concentration by the initial concentration, is included in Figure 2a, along with a least-squares fit of the first-order decay model. The half-life ($t_{1/2}$) obtained from the model was 13.6 hr, with a coefficient of variation (r^2) of 0.99. The high r^2 value suggests that the reaction is pseudo first order.

Corresponding trends in Eh and pH are included in Figure 2b. Eh declined from an initial value of almost 400 mV to −150 mV within the first 10 hr, then remained relatively constant at about −200 mV until a time of 50 hr. The Eh at the final sampling time, 100 hr, was about −500 mV. While it is clear that highly reducing conditions existed in the hypovials for almost the entire duration of the experiment, there do not appear to be significant changes in the rate of degradation (Figure 2a) corresponding to the changes in Eh. The pH increased from an initial value of 7.2 to 9.2 at a time of 24 hr then remained relatively constant for the duration of the experiment. Though previous studies (Senzaki and Kumagai, 1989) suggest that rates of degradation of TCE decrease at pH values above about 8, this observation is not supported by the results shown in Figure

Table 1. Table of Compounds Studied Showing the Method Detection Limit (MDL) for the Analytical Procedures, the Calculated Half-Lives ($t_{1/2}$), and the Regression Coefficients (r^2) Determined from Fitting the First-Order Decay Equation to the Experimental Data and Times for 50% Loss (t_{50}) and Normalized t_{50} Values (The Last Column Includes Half-Lives for Abiotic Degradation Taken from the Literature)

Organic compound	*MDL ($\mu g/l$)*	*Initial concentration ($\mu g/l$)*	$t_{1/2}$ [a] *(hr)*	r^2	t_{50} [b] *(hr)*	$t_{50\text{-}N}$ [c] *(hr)*	*Half-lives* [d] *(hr)*
Methanes							
CT	3.5	1631	0.25	0.993	0.25	0.020	3.6×10^5
TCM	2.6	2013	33.0	0.918	19.1	1.49	1.6×10^7
TBM	3.6	2120	0.24	0.999	0.52	0.041	6.0×10^6 [e]
DCM	4.2	2751	No decline				1.3×10^4 [e]
Ethanes							
HCA	3.1	3621	0.13	0.999	0.16	0.013	1.6×10^{13}
1122TECA	1.3	2513	19.2	0.887	0.68	0.053	3.5×10^3
1112TECA	1.6	2334	4.4	0.775	0.63	0.049	4.1×10^5
111TCA	2.9	683	5.3	0.920	0.83	0.065	9.6×10^3
Ethenes							
PCE	4.2	2246	17.9	0.860	3.6	0.28	8.7×10^{10}
TCE	4.4	1555	13.6	0.990	8.6	0.67	1.1×10^{10}
11DCE	1.2	2333	40.0	0.972	70.0	5.47	1.1×10^{12}
tDCE	0.8	1774	55.0	0.973	82.0	6.41	3.9×10^{14}
cDCE	1.1	1949	432.0	0.817	252.0	19.70	(both t & c)
VC	0.5	3663	374.0	0.849	160.6	12.55	—

[a] Calculated half-lives.
[b] Times for 50% loss.
[c] Normalized to 1 m^2/ml.
[d] Jeffers et al., 1989.
[e] Vogel et al., 1987.

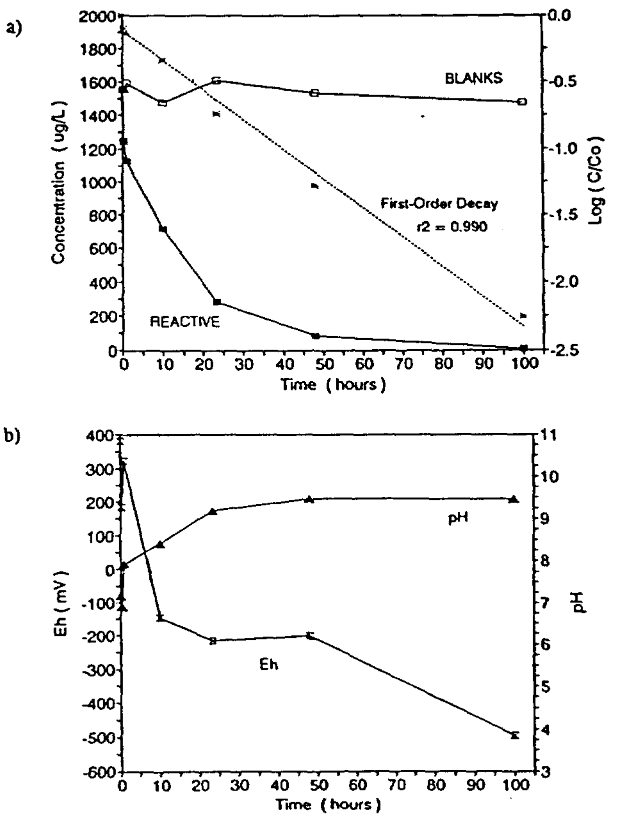

Fig. 2. Results of batch tests conducted using TCE. a) Concentration of TCE versus time; b) Eh and pH versus time.

2. In particular, the rate constant, as reflected in the linear semilog plot, did not appear to change significantly with changes in pH. Though the magnitude of the changes in Eh and pH varied from experiment to experiment, the trends were generally similar to those observed for TCE and therefore will not be discussed further.

Consistent with the observation of others (Senzaki and Kumagai, 1988, 1989) a headspace was observed to develop in the reactive hypovials over time. Though not quantified, consistent with the above references, the major components of the headspace were nitrogen and hydrogen. Other than the possibility of sample contamination, the only apparent source of nitrogen would be from air dissolved in the stock solution.

Table 1 summarizes the results for the 14 compounds tested. Of these, only DCM did not show a measurable decline in concentration. For the remaining 13, half-lives obtained by fitting the first-order decay model ranged from 0.13 hr for HCA to 432 hr for cDCE. The r^2 values varied from 0.999 for HCA to 0.775 for 1,1,1,2-TECA.

The variation in r^2 raises questions concerning the generality of our earlier conclusion based on the TCE results, that the reaction is pseudo first order. From an examination of the graphs (not shown), compounds that degraded slowly tended to reflect a declining rate constant at late time. This appeared as a slowly declining but persistent "tail" in the concentration versus time graphs. Indeed, in spite of the particularly high r^2 value, the distribution of the data points about the regression line of Figure 2a suggests the possibility of a declining rate constant with time. Thus, for compounds that degraded slowly, with an apparent decline in the rate constant at late time, the half-lives obtained by a least-squares fit of the first-order model are higher than the actual values at early time and lower than the actual values at late time. Fitting of zero- and second-order models, in general, gave poorer representations of the data. It should also be noted that for those compounds that did not reach the detection limit at the conclusion of the tests, because of the "tailing" effect, the reported half-lives and r^2 values would be influenced to some degree by the duration of the tests.

Based on the generally high r^2 values, but the late-time trends in the data for those compounds that degrade slowly, it is proposed that the reaction is indeed pseudo first order with respect to the parent compounds, but that the rate constant declines at late time as a consequence of secondary effects. These may include the accumulation of reaction products, increasing pH, or other unidentified changes in the reaction conditions.

As a second index of reaction rate, the time required for a 50% reduction in the initial concentration (t_{50}) is included in Table 1. Though the trends in the t_{50} and $t_{1/2}$ values are similar, as a consequence of the observed tailing, the t_{50} values are, in most cases, substantially lower than the half-lives, particularly for those compounds that degrade slowly.

Within each group of compounds, the rate of degradation increases with an increase in the degree of chlorination. Further, the only brominated compound that was tested (TBM, $t_{1/2} = 0.24$ hr) degraded much more rapidly than its chlorinated counterpart (TCM, $t_{1/2} = 33$ hr). These trends are consistent with the expectation that, under the reducing conditions of the tests, the more highly oxidized compounds would be the most susceptible to degradation.

Comparing the half-lives measured in this study with those reported in Jeffers et al. (1989) and Vogel et al. (1987), and included in Table 1, the presence of the iron enhanced the degradation rates by about 3 to 13 orders of magnitude.

Abiotic Tests

Figure 3 shows the results in which sodium azide was added to the solution phase. The two blanks (with and without azide) behaved in a similar manner, as did the two sets of reactive samples. At early time, both reactive tests showed a very similar and rapid decline in TCE concentration resulting in a t_{50} value for both tests of 0.5 hr. At later times, the samples containing azide showed a slightly slower rate of decline in TCE concentration, though the difference was small and was not believed to be significant. Bacterial counts confirmed that the azide inhibited both heterotrophic and anaerobic activity over the duration of the test. Though bacterial counts were not performed, the results of the degradation tests using formaldehyde (not shown) were very similar to those obtained for azide. Based on these results, there is little doubt that the degradation process is indeed abiotic.

Surface Area to Solution Volume Ratio

The results of tests to examine the effect of the surface area to solution volume ratio on the degradation rate of TCE are given in Table 2. At values greater than 0.078 m^2/ml (corresponding to 10 g of iron in a 40 ml hypovial), the t_{50} value appears to be inversely proportional to the surface area to volume ratio (the rate constant is directly proportional). At lower values of the surface area to volume ratio, the t_{50} values were disproportionately high. This is believed to be the result of mass transfer limitations in that on average, with small amounts of iron, a longer period of time would be required in order for the solute to contact an iron surface. It follows from this hypothesis that at area-to-volume ratios greater than about 0.078, the rate of degradation of TCE is limited by the reaction rate rather than by mass transfer rates in the bulk solution. Though similar trends are expected for other compounds, the area-to-volume ratio at which degradation would be limited by the reaction rate would be expected to increase as the reaction rate increases. It also follows that at low area-to-volume ratios, mass transfer would be influenced by the degree of agitation and thus observed rates of degradation could be a function of the shaking procedure. A second hypothesis could be that in the presence of small amounts of iron, a longer period of time is required in order for the necessary solution chemistry to develop. The threshold time for the start of degradation that this model implies was not observed.

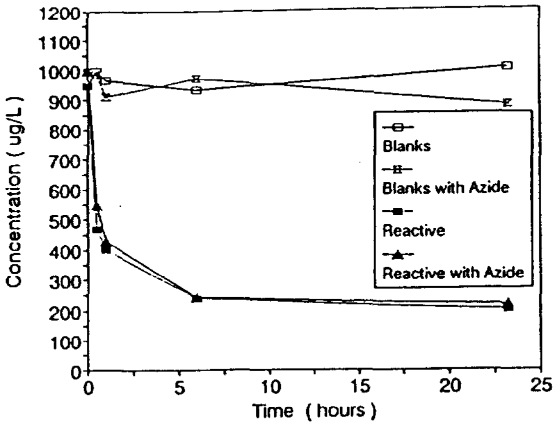

Fig. 3. Graph showing the effect of a bactericide (azide) on the rate of degradation of TCE.

Based on the above results, and to provide a convenient basis for comparison, the t_{50} values of Table 1 were normalized to an area-to-volume ratio of 1 m^2/ml. That is, the values obtained using 10 g of iron in a 40 ml hypovial (0.078 m^2/ml) were divided by 12.8. The rationale for using t_{50} values as an index for comparing rates of degradation is further supported by the results of the column tests.

Table 2. Effect of Surface Area to Volume Ratio on t_{50} Values for TCE Degradation

Mass of iron (g)	*Surface area/volume (m^2/ml)*	t_{50} *(hr)*
1	0.0076	110.0
5	0.038	1.0
10	0.078	0.24
20	0.15	0.12
50	0.45	0.05

Column Tests

Tests were conducted on two columns, one containing silica sand only (the control column) and the other containing 10% iron and 90% silica sand by weight. The column containing only silica sand gave a TCE breakthrough curve typical of a nonreactive solute. That is, the relative concentration in the effluent was approximately 0.5 after one pore volume had passed through the column, and by two pore volumes, the influent and effluent concentrations were approximately equal.

Distance along the column can be readily converted to residence time, provided the flow rate is known and is steady. Thus, if the reaction is indeed pseudo first order, a steady-state exponential decline in concentration would be expected along the length of the column. Further, a graph of log C/C_0 versus residence time should be a straight line, and if the reaction rate is independent of flow velocity, graphs of log C/C_0 versus residence time should coalesce.

After 10 pore volumes of solution had passed through the column, at a velocity of 242 cm/day, the concentration profile appeared to be stationary and to decline exponentially along the column. As the velocity was reduced in steps to 166, 59, and 38 cm/day, a new steady-state profile developed for each new velocity with, as expected, the profile receding toward the influent end with decreasing velocity.

The results of the column tests are plotted as log C/C_0 versus residence time in Figure 4. The least-squares fit of the first-order decay model to the data is included. The high degree of scatter in the data for $V = 38$ cm/day suggests sampling or analytical error, and thus this data will not be considered further. The high r^2 values and the similarity between the $t_{1/2}$ and t_{50} values suggest that the degradation process within the columns is indeed pseudo first-order. Excluding $V = 38$ cm/day, the graphs for the other three velocities are quite similar with the t_{50} values falling within a narrow range (3.96 to 4.12 hr). Thus, for the fourfold increase in velocity of this experiment, there appears to be little or no velocity dependence in the rate of degradation.

The average t_{50} value for the three column tests was 4.04 hr. Normalizing the area-to-volume ratio in the column (0.14 m^2/ml) to 1 m^2/ml gives a t_{50} value of 0.57 hr. Normalized t_{50} values were also calculated for the PCE and CT column tests. The results are given in Table 3, along with the corresponding batch test results from Table 1. It should be noted that because of the rapid rate of degradation, even at a velocity of 1,019 cm/day, CT appeared at very low concentrations at the sampling point 2.5 cm from the influent end and was nondetectable at a distance of 5 cm. In the absence of other data, the concentration was assumed to decline linearly to zero at a distance of 2.5 cm, and thus the t_{50} value was taken as the time required to travel a distance of 1.25 cm. Because the degradation process gives an exponential decline, this would overestimate the t_{50} value. Thus, the normalized value of Table 3 is given as < 0.01 hr. Referring to Table 3, and in view of the different procedures and various sources of uncertainty, the normalized t_{50} values obtained from the batch and column tests are remarkably similar.

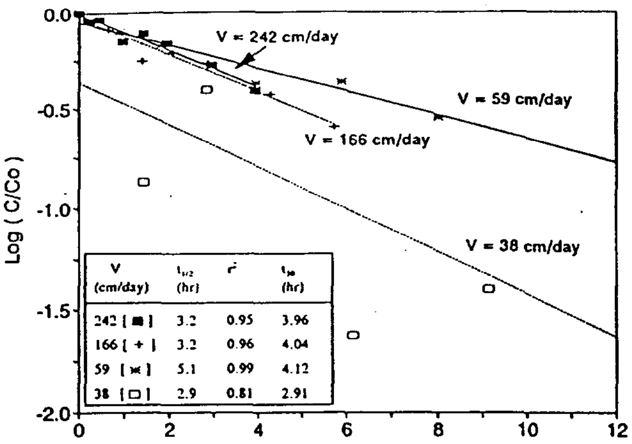

Fig. 4. Results of column tests for TCE conducted at four different pore-water velocities, expressed as log C/C_0 versus residence time.

Based on the small amount of data that is available, it is perhaps not reasonable to draw conclusions regarding relative reaction rates for batch tests and dynamic column tests. One can conclude, however, that the reaction does proceed under conditions of flow, and with no apparent adverse effect on the reaction rate.

It should also be noted that the tailing characteristic discussed previously for late time in the batch tests was not evident in the column tests. While this difference in behavior warrants further investigation, it appears to support the earlier hypothesis that the decline in the rate constant at late time in the batch tests was the result of the accumulation of reaction products. As discussed in a subsequent section of this paper, reaction products could include inorganic precipitates such as calcium carbonate, iron hydroxide, and siderite. Though as yet unconfirmed, accumulation of these products could reduce the reactivity of the iron surfaces.

Degradation Products

An exhaustive study of degradation products has yet to be performed; however, several important observations have been made. Figure 5 shows the results of batch tests in which tetrachloromethane (CT) was the only chlorinated compound present in the initial solution. The CT disappeared, rapidly accompanied by the appearance of trichloromethane (TCM). The peak TCM concentration (about 540 $\mu g/l$) occurred at a time of about 2 hr, then declined as the TCM itself degraded, though at a slower rate than CT (see Table 1). Accounting for the difference in molecular weight, only about 26% of the original CT appeared as TCM. Though chloromethane (CM) was not detected, trace

Table 3. Comparison of Normalized t_{50} Values for the Batch and Column Tests

	Normalized t_{50} (hr)	
	Batch	*Column*
TCE	0.67	0.57
PCE	0.28	0.12
CT	0.02	<0.01

concentrations of DCM were evident in the chromatograms.

As shown in the following section, degradation of PCE and/or TCE resulted in accumulations of cDCE and VC. The maximum total accumulation was about 10% of the parent concentration, and the degradation products also degraded over time.

Degradation Using Site Materials

The results reported to this point, using analytical grade organic compounds and laboratory grade electrolytic iron, provide considerable encouragement for the use of zero-valent metals in remediation of contaminated water at industrial sites. Unlike laboratory-grade organic chemicals, industrial chemicals are generally of lower purity, and often have chemicals added as preserving/stabilizing agents. Further, the high-purity iron used in the laboratory tests would not be practical in the large quantities that would normally be required at contaminated sites.

Laboratory tests have now been conducted on contaminated water from several industrial sites, using an iron material that is commercially available in large quantities. The iron is collected as a waste product from machining and foundry operations, and after processing, is marketed primarily as an additive to improve the wear characteristics of concrete. The material used in these tests had a grain between 0.57 and 2.0 mm and a specific surface area (determined by the BET method) of about 1.1 m^2/g. The following example is typical of the results that have been obtained.

Water was obtained from a zone of contaminated ground water in the vicinity of an electronics manufacturing facility. Organic contaminants included PCE (4,400 $\mu g/l$), TCE (900 $\mu g/l$), cDCE (190 $\mu g/l$), and 1,1-DCE (2 $\mu g/l$). The tests were conducted using the column procedure described previously, with the exception that the column contained only the iron material, giving a surface area-to-solution volume ratio of about 8.8 m^2/ml. Steady-state concentration profiles were determined at two flow velocities, 47 and 76 cm/day. Even at the highest velocity, PCE was not detected at a distance greater than 20 cm from the influent end of the column and as expected, with decreasing velocity, the profile receded toward the influent end (Figure 6a). Half-lives were 0.64 and 0.42 hr at velocities of 76 and 47 cm/day respectively, and semilog plots (not shown) gave no indication of declining rate constants with residence time, and thus the $t_{1/2}$ and t_{50} values were very similar. The TCE profile (not shown) was very similar, resulting in a half-life of 0.52 hr at a flow velocity of 47 cm/day (r^2 of 0.99). Though small transformations would not have been detected, from the shape of the TCE curve, it was clear that large amounts of TCE were not being generated as a consequence of PCE degradation.

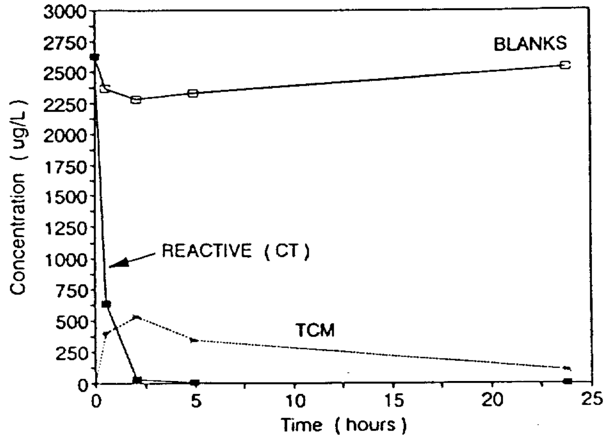

Fig. 5. Graph showing the accumulation and subsequent degradation of TCM during degradation of CT.

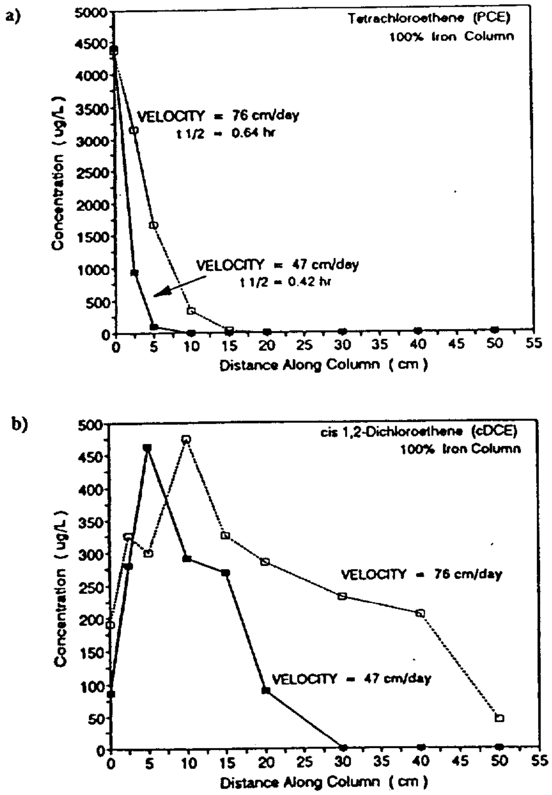

Fig. 6. Results of column tests conducted using commercial grade iron and ground water from a contaminant plume at an industrial site: a) PCE at two velocities; b) cDCE, showing an increase as a consequence of PCE dechlorination and subsequent cDCE degradation.

Figure 6b shows cDCE profiles along the column. Considering only the profile measured at a velocity of 76 cm/day, at a distance of 10 cm from the influent end of the column, the concentration had increased from the initial value of 190 $\mu g/l$ to about 475 $\mu g/l$, then declined to a value of 50 $\mu g/l$ at the effluent end. The profile measured for the lower velocity (47 cm/day) was similar but was displaced toward the influent end of the column. 1,1-DCE (not shown) increased from 2 $\mu g/l$ to about 6 $\mu g/l$, but was not detected beyond a distance of 15 cm from the influent end. Similarly, though no VC was present in the influent, maximum concentrations of about 14 $\mu g/l$ were detected at travel distances of about 10 to 20 cm. At the lower velocity there was no VC in the effluent, but at a velocity of 76 cm/day the effluent contained about 4 $\mu g/l$ of VC. No tDCE was detected, and the increase in cDCE, 1,1-DCE, and VC could account for only 10% of the initial PCE and TCE.

The results clearly show the process to be effective using materials (iron and industrial-grade solvents) of commercial relevance. Normalizing the measured half-lives to 1 m^2/ml gives an average value of 4.8 hr for PCE and 4.7 hr for TCE. These are on the order of 10 times greater than the normalized t_{50} values of Table 1. There are several possible reasons for the lower degradation rates: the commercial iron may be less reactive, the commercial solvents may be less reactive, the rates may be influenced by the different inorganic characteristics of the site water or indeed, the normalization procedure may not be applicable at the very high area-to-volume ratio of this particular test. Further tests are required to evaluate these possibilities. It is noteworthy, that while relatively small proportions of the parent compounds appear as chlorinated products, because of their longer half-lives, the chlorinated products of degradation may be the critical parameters in the design of treatment systems.

Degradation Process

In a review of transformation of organic chemicals, Baciocchi (1983) noted that because of the heterogeneous nature of the reactions, there is relatively little known concerning the mechanisms by which metals enhance organic transformation processes. Though an examination of the degradation process and pathways was not the purpose of the work reported here, several observations of relevance to the process can be made.

It is reasonable to conclude that the degradation process is abiotic and electrochemical in nature, involving oxidation of the iron and reductive dechlorination of the organic compounds. Figure 7 shows the log of the normalized t_{50} values of Table 1 (excluding DCM) plotted against the relative half-reaction reduction potentials for the respective compounds. Including all three groups of compounds contributes significant scatter to the data and to a relatively low r^2 (0.72) for the regression line. Nevertheless, there is an unmistakable trend, as one would expect for reductive dechlorination, toward decreasing rates of degradation (increasing t_{50} values) with declining reduction potential of the compounds. This is consistent with the observed increase in t_{50} values with decreasing degrees of chlorination. Based on Figure 7, DCM would be expected to degrade and thus appears to be an exception to the trend.

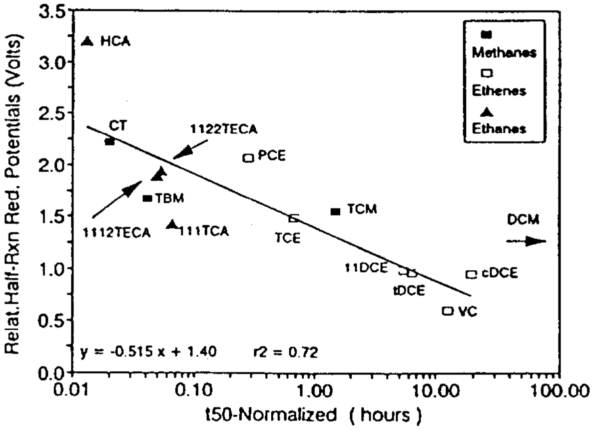

Fig. 7. Log of the normalized t_{50} values versus the half-reaction reduction potential of the respective compounds (calculated using the expression given in Vogel et al., 1987).

The formation of hydrogen, along with the increase in pH, is evidence of the dissociation of water. Supplementary tests in which water without organics was added to the iron powder resulted in the formation of a headspace, a decline in Eh and increase in pH, indicating that the dissociation reaction proceeds independently of the degradation reaction. It is, however, uncertain if the dissociation of water is necessary in order for the degradation reaction to proceed. Considering only the presence of water, zero-valent iron and a chlorinated organic compound X-Cl, the following equations are suggested:

$$
\begin{array}{c}
2Fe^0 \rightarrow 2Fe^{2+} + 4e \\
3H_2O \rightarrow 3H^+ + 3OH^- \\
2H^+ + 2e \rightarrow H_2 \\
\text{X-Cl} + H^+ + 2e \rightarrow \text{X-H} + Cl^- \\
\hline
2Fe^0 + 3H_2O + \text{X-Cl} \rightarrow 2Fe^{2+} + 3OH^- + H_2 + \text{X-H} + Cl^-
\end{array}
\quad \ldots . (1)
$$

In this case, for each mole of Cl^- released to the solution phase, 2 moles of Fe^{2+} should also appear in solution. On the other hand, if the dissociation of water is not included, the overall reaction can be written:

$$Fe^0 + \text{X-Cl} + H_2O \rightarrow Fe^{2+} + OH^- + \text{X-H} + Cl^- \quad (2)$$

In this case, only one mole of Fe^{2+} would be released to the solution phase for each mole of Cl^-. Thus, the complete dechlorination of 1.0 mg/l of CT would result in a chloride concentration of 0.92 mg/l, and would contribute 2.8 or 1.4 mg/l of iron, based on equation (1) or (2), respectively. Total iron measured in column effluent ranged from nondetectable to about 6 mg/l, and because of the low Eh conditions, Fe^{2+} was considered to be the dominant species. Because corrosion of iron by water proceeds independently of the organic degradation reaction, there was no apparent relationship between iron concentration and organic degradation. Furthermore, under the pH and Eh conditions of the tests, precipitation of ferrous hydroxide [$Fe(OH)_2$] can be expected (at a pH of about 9.2) and further, with the addition of $CaCO_3$ to the stock solution, precipitation of siderite ($FeCO_3$) could also occur. Thus, should secondary mineral phases form during the tests, very low dissolved iron concentrations in the effluent should not be surprising. No attempt has yet been made to identify iron precipitates in the column materials. Further, because of the formation of secondary minerals, stoichiometry is of little value in attempting to verify equations (1) and (2).

In an additional supplementary test, iron was added to water containing only $CaCO_3$ until an Eh value of about −400 mv was reached. The water was then decanted, and while taking care to exclude oxygen, CT was added to the solution, which was then sealed in hypovials. Under the highly reducing conditions of these tests, but in the absence of metallic surfaces, no dechlorination was observed. Two additional batch tests were conducted in which ferrous chloride and ferric oxide were added to the initially reduced solution. In both cases, no degradation of CT was observed.

The fact that no degradation products other than less chlorinated forms of the parent compound have been detected suggests the degradation process to be simple reductive dechlorination, with Fe^0 serving as the source of electrons. Further, the fact that only small proportions of the parent compound appear as less chlorinated products suggests a precipitous transfer of electrons. This is likely to occur only through direct contact between the organic molecules and the iron surface. The apparent mass transfer limitation observed in the area-to-volume ratio studies further supports the hypothesis that direct contact between the organic solute and the metal surface is required in order for the degradation process to proceed.

Considering pure-phase degradation of CT in contact with metals, Archer and Simpson (1977) proposed the transfer of a single electron from the metal to a chlorine atom. As a consequence, the chlorine is partially bonded to both the metal and the carbon atom until a second electron is transferred, releasing a chloride ion and a metal ion to the liquid phase. The authors suggest that the mechanism could apply to other chlorinated solvents. Though plausible with respect to the results of the present study, there is no direct supportive evidence. Further research is required to identify the mechanism and indeed, there may be several mechanisms depending upon the compound and test conditions.

Conclusions

The batch tests confirmed that zero-valent iron is highly effective in enhancing the rate of degradation of a wide range of chlorinated aliphatic compounds in aqueous solution. Of the 13 halogenated methanes, ethanes, and ethenes tested, with the exception of DCM, all showed significant rates of degradation. The rates of degradation increased with an increase in the ratio of surface area of iron to volume of solution and though there was significant scatter in the data, there is a strong indication that the rate declines logarithmically as the reduction potential of the compounds declines. This is consistent with the observation that the rate of degradation declined with decreasing degree of chlorination.

The batch experiments suggested that the reactions are pseudo first order with respect to the organic compounds. Though the batch tests tended to show "tailing" at late times, this was not evident in the column tests, and thus it appears that the same rate constant is applicable over the concentration range used in the tests, from a few milligrams per liter to the detection limit (generally a few micrograms per liter). No attempt was made to determine the upper limit of concentration for which the process is applicable.

The reaction appears to be reductive dechlorination with the metallic iron serving as the source of electrons. The fact that only small proportions of the parent compound appear as breakdown products is strong evidence that the process does not require sequential dechlorination. The organic compound may be attracted to the iron surface until sufficient electrons have been transferred for complete dechlorination or upon contact, there may be a precipitous transfer of electrons. In either case, direct contact between the organic molecule and the metal surface would be required. This is consistent with the apparent proportionality between the rate constant and the surface area-to-volume ratio.

Using the values normalized to 1 m^2 iron/ml of solution, the degradation rates are indeed rapid with t_{50} values ranging from 0.013 to 20 hr for the compounds tested (with the exception of DCM which did not degrade at a measurable rate). These values are about 5 to 15 orders of magnitude lower than half-lives reported for natural abiotic degradation processes. A further increase in the surface area-to-volume ratio, through the use of greater amounts of iron, or iron of finer grain size, should result in even lower t_{50} values.

The measured rates of degradation are highly encouraging for both in situ and aboveground treatment applications. For example, a decrease in concentration from 1.0 mg/l to 1.0 μg/l requires 10 half-lives. Using the upper and lower limits of the normalized t_{50} values, 10 half-lives would correspond to residence times of 200 to 0.13 hr, respectively. Clearly, the design of both in situ and aboveground treatment systems would be based on the initial concentration of the parent compound and/or the concentration of chlorinated breakdown products, the relevant half-lives, the objective concentration, and the velocity of the contaminated water. However, for normal ground-water velocities, in situ permeable reaction walls, as proposed in Gillham and O'Hannesin (1992) and discussed further in Gillham and Burris (1994), should be applicable for a wide range of ground-water contamination problems. In order to avoid unreasonably large containment structures, aboveground treatment could be limited to those compounds with relatively short half-lives.

The applicablility of the metal-enhanced degradation process is further encouraged by the availability and relatively low cost of granular iron, by the fact that the process does not appear to be significantly inhibited through the use of commercial grade iron and organic solvents, and by the fact that once installed, the treatment system should be entirely passive. Further, though the iron is consumed by the reaction, it should nevertheless be very persistent. For example, based only on the electron requirement for reduction of the organic, 1 kg of iron could completely dechlorinate CT in 0.5 million liters of water at an initial concentration of 1 mg/l. Though encouraging, it must be recognized that corrosion of the iron through dissociation of water undoubtedly consumes iron at a greater rate than the dechlorination reaction. Though corrosion rates of iron were not investigated, it is quite reasonable to expect that in situ walls or aboveground canisters could be constructed such that the iron would persist for many years or even decades.

Further investigations of breakdown products are required. In this study, reduction of CT resulted in very low but persistent concentrations of DCM, while reduction of PCE resulted in the production of low concentrations of

DCE isomers and VC. In the latter case, however, the chlorinated products of degradation were not persistent. Degradation products formed as a consequence of dechlorination of the ethanes were not tested for, and no tests were conducted on, the dichloro and monochloro ethanes. Because of the lower degradation rates associated with less chlorinated compounds, the degradation products may be the critical compounds in the design of treatment systems, even though they generally appear at concentrations that are low relative to the parent compound (< 20%).

Further uncertainties in application concern effect on the inorganic chemistry. Though not within the scope of this study, formation of siderite ($FeCO_3$) and ferrous hydroxide $Fe(OH)_2$ is anticipated. Further, the observed increase in pH, depending upon the inorganic characteristics of the water, could result in the formation of other solid phases. Should precipitates form within the reactive material they could, over time, fill the pore spaces reducing the permeability. Precipitates may also adhere to the iron surfaces, blocking reaction sites and thus reducing the reactivity of the iron. Further studies of the inorganic consequences of the reactions and means of controlling these consequences are in progress.

Acknowledgments

The authors wish to acknowledge Paul Tratnyek of the Oregon Graduate Institute, Eric Reardon and Jim Warren of the Waterloo Centre for Groundwater Research, and Mark Pritzker of the Chemical Engineering Department, University of Waterloo for their helpful comments at various stages over the course of the study. We also wish to thank Greg Friday for his tireless efforts in conducting many of the laboratory tests. This research was funded by the Waterloo Centre for Groundwater Research, an Ontario Centre of Excellence supported by the Ontario Technology Fund, and by the Ontario Ministry of the Environment through the Environmental Technology Program (ETP). Industrial matching funds for the ETP grant were provided by Beak Consultants Ltd. of Brampton, Ontario.

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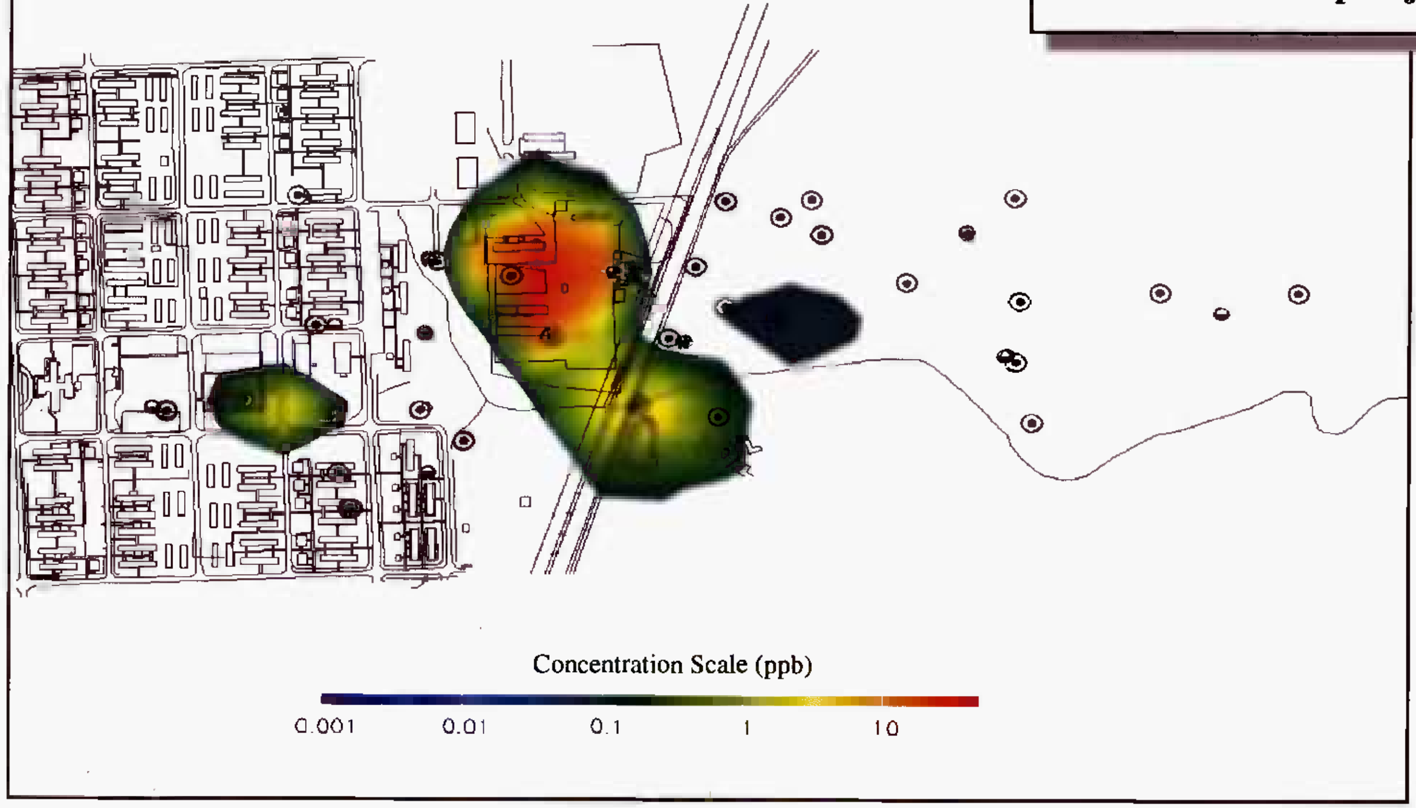
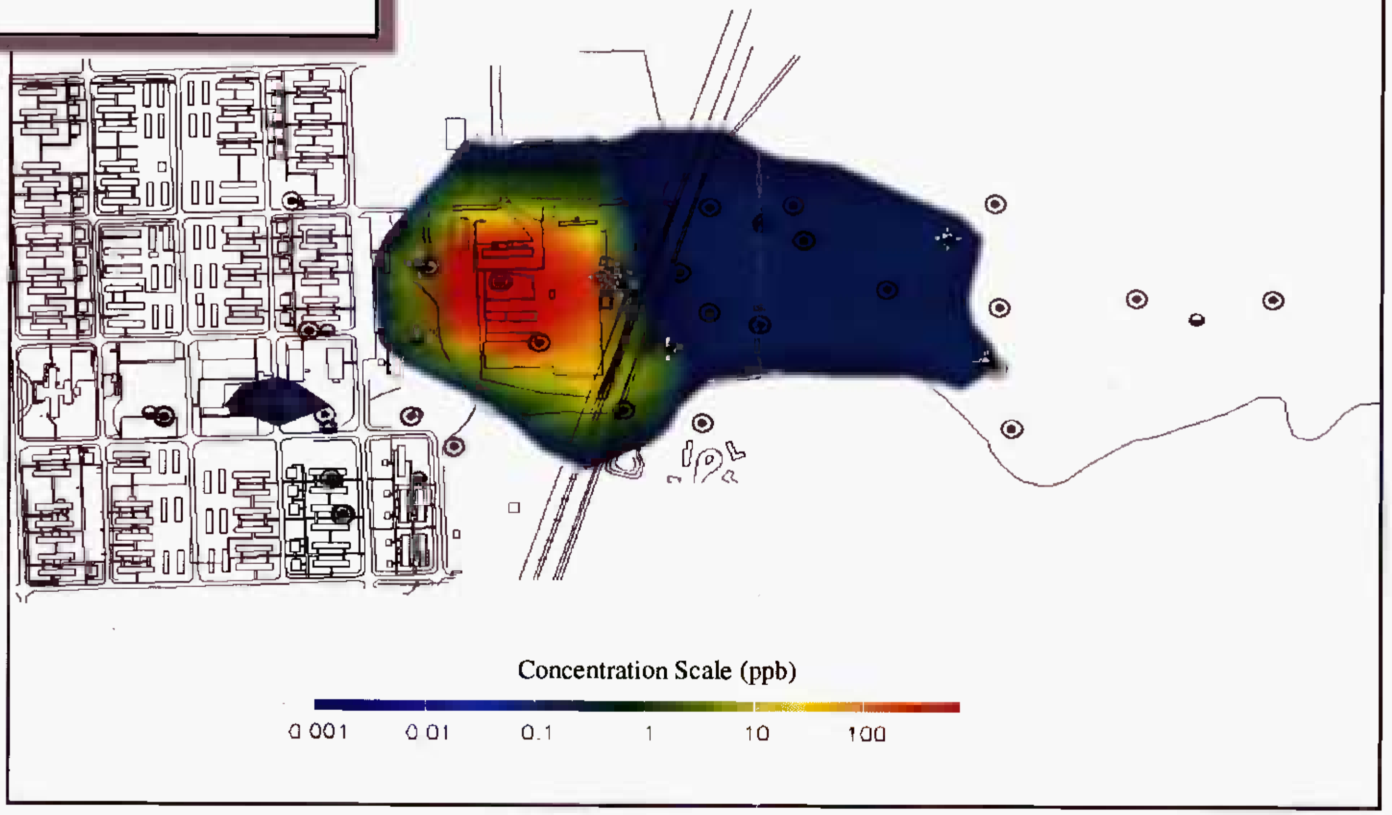
APPENDIX B
3-DIMENSIONAL PLUME CONCENTRATION MODELS

Contaminant Concentrations Exceeding 0.1 ppb
Operable Unit No. 16 (Sites 89 & 93)
MCB Camp Lejeune, North Carolina

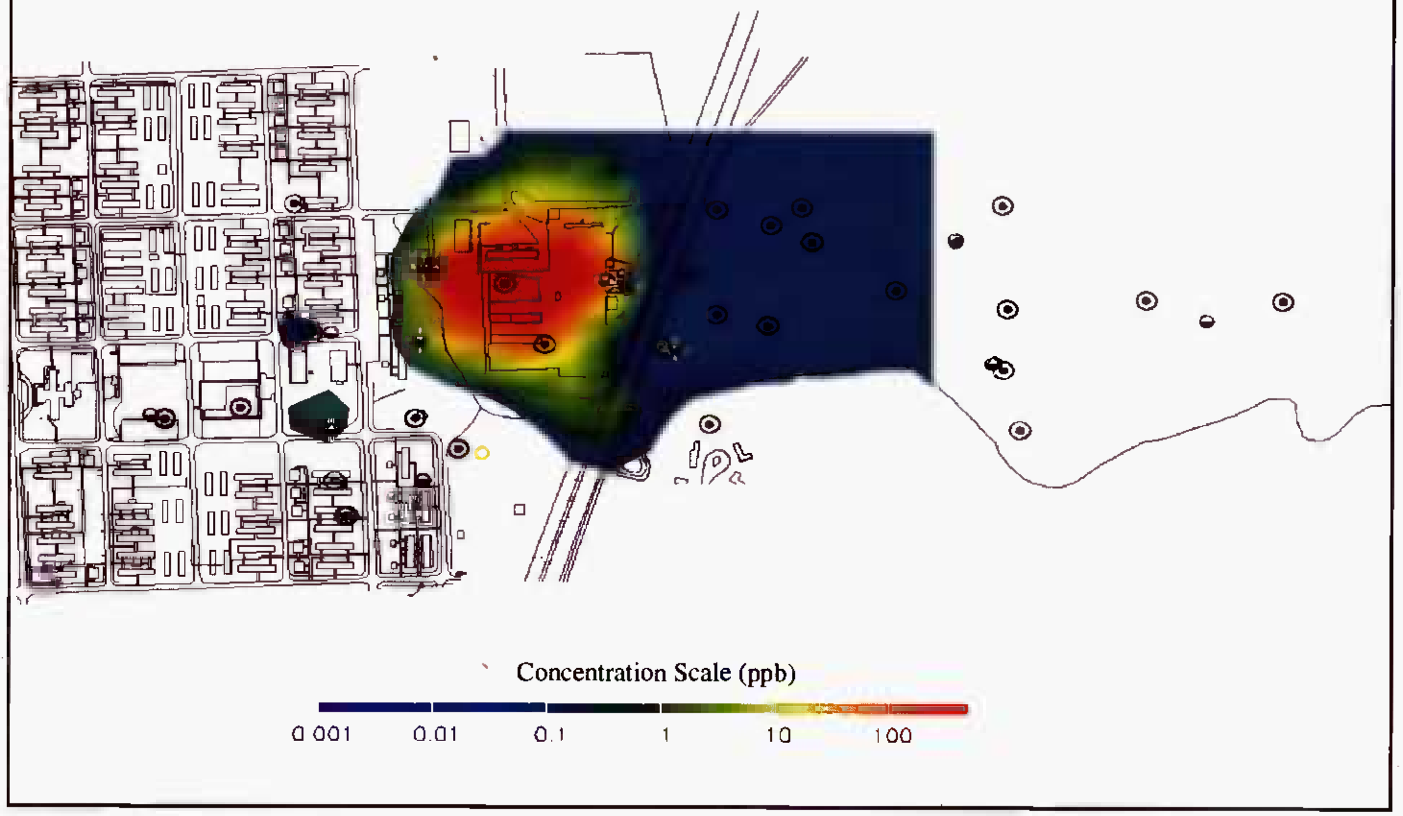
PCE Concentrations Exceeding 0.1 ppb



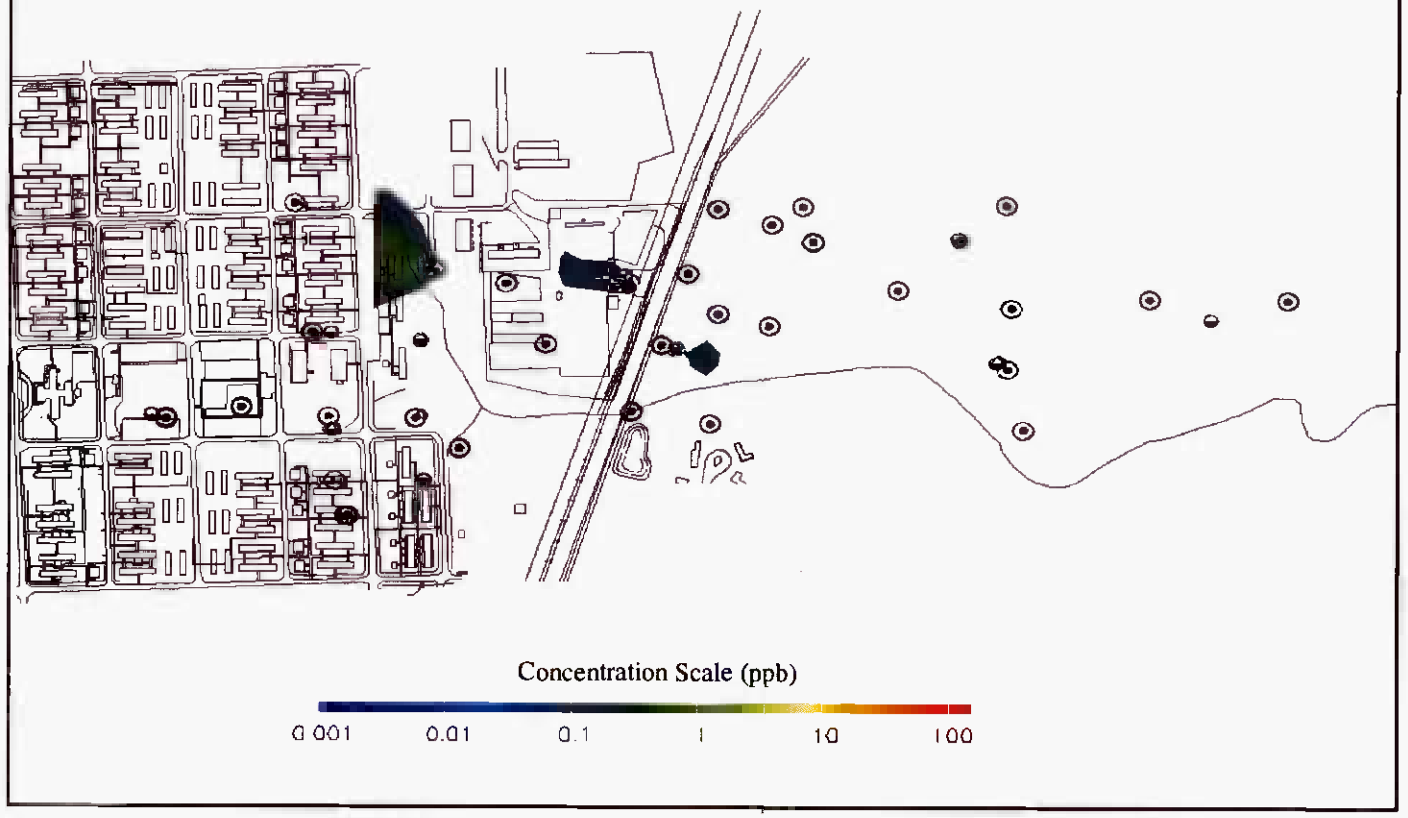
TCE Concentrations Exceeding 0.1 ppb



1,2-DCE (Total) Concentrations Exceeding 0.1 ppb



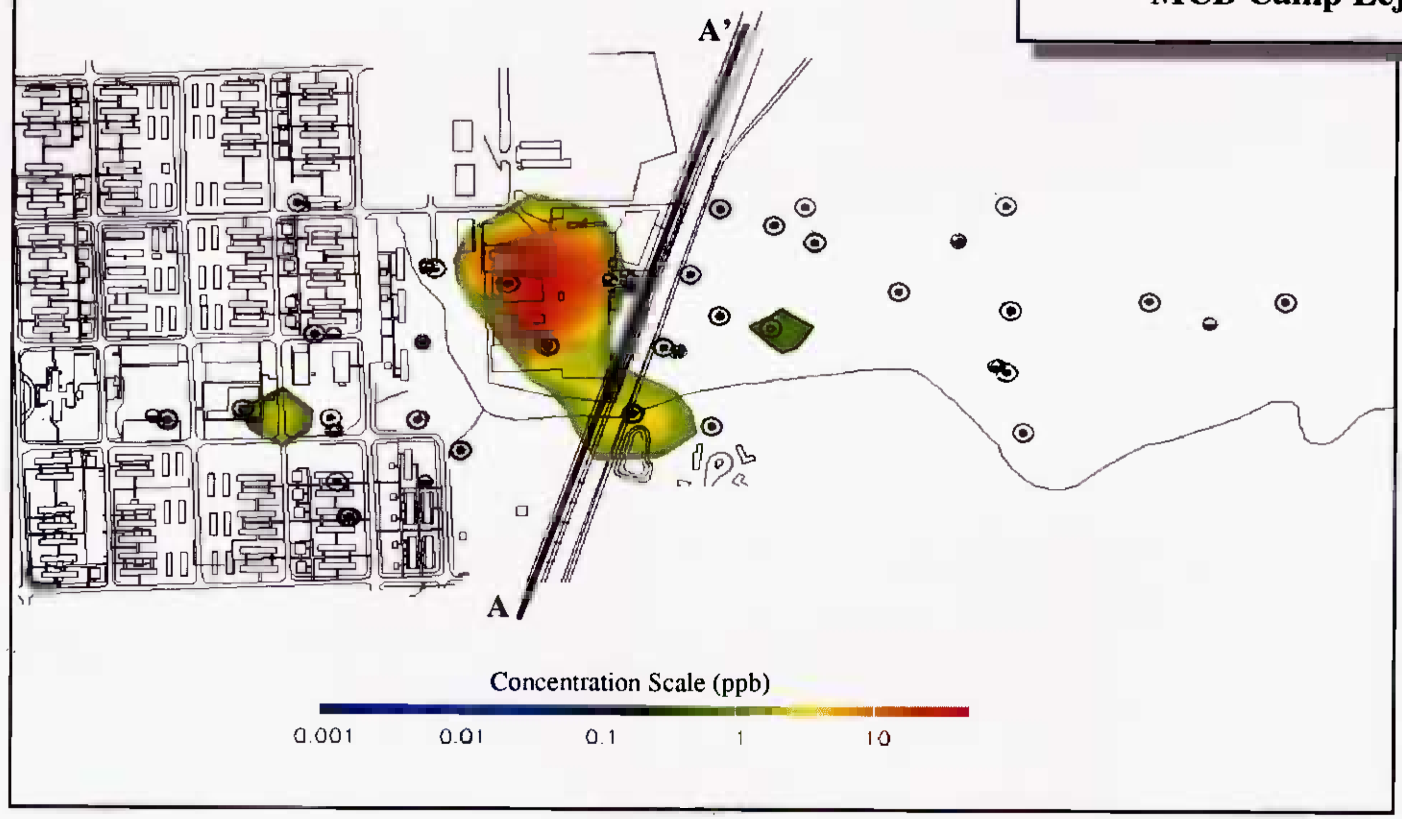
Vinyl Chloride Concentrations Exceeding 0.1 ppb



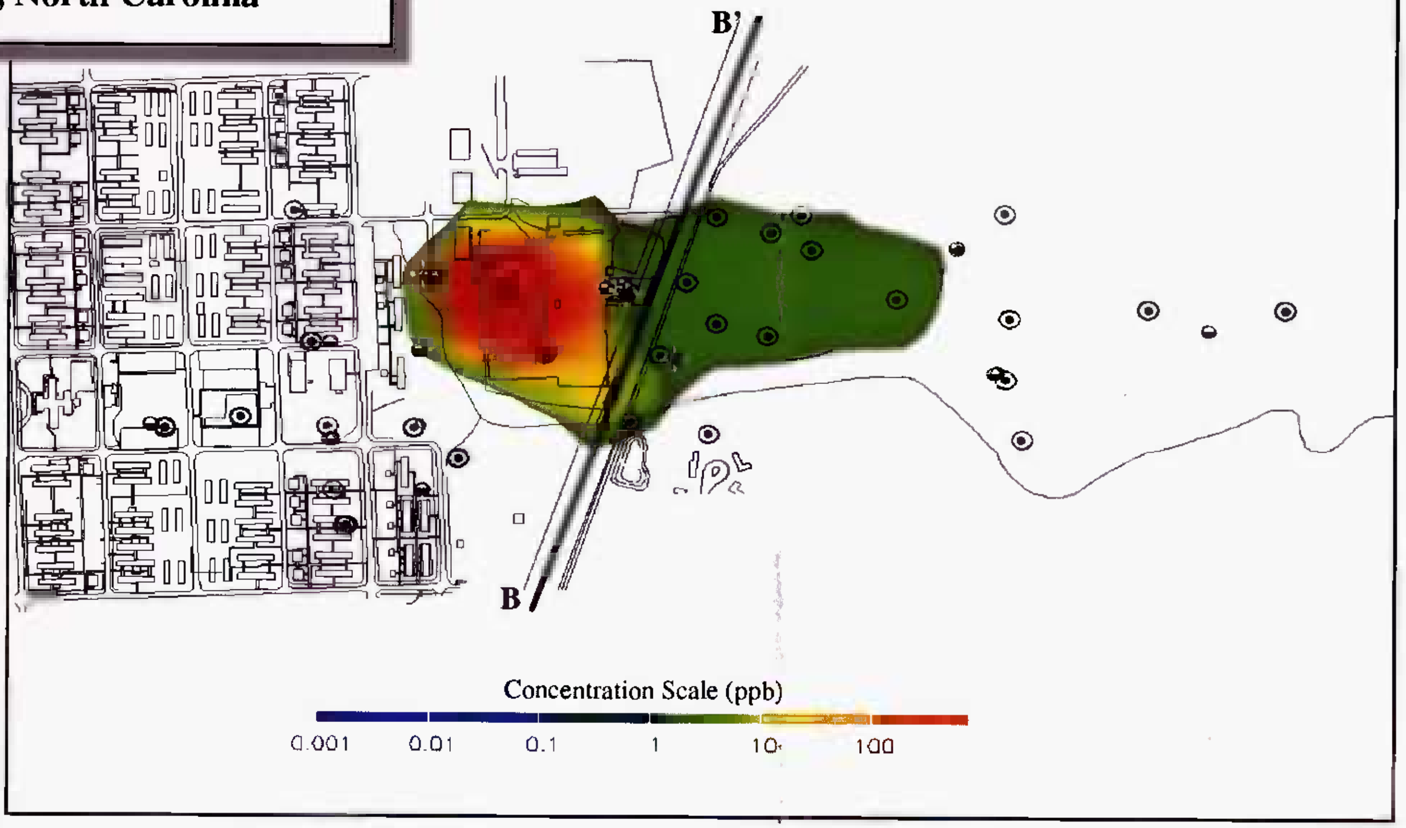
00163FFB4Y

Contaminant Concentrations Exceeding Standards
Operable Unit No. 16 (Sites 89 & 93)
MCB Camp Lejeune, North Carolina

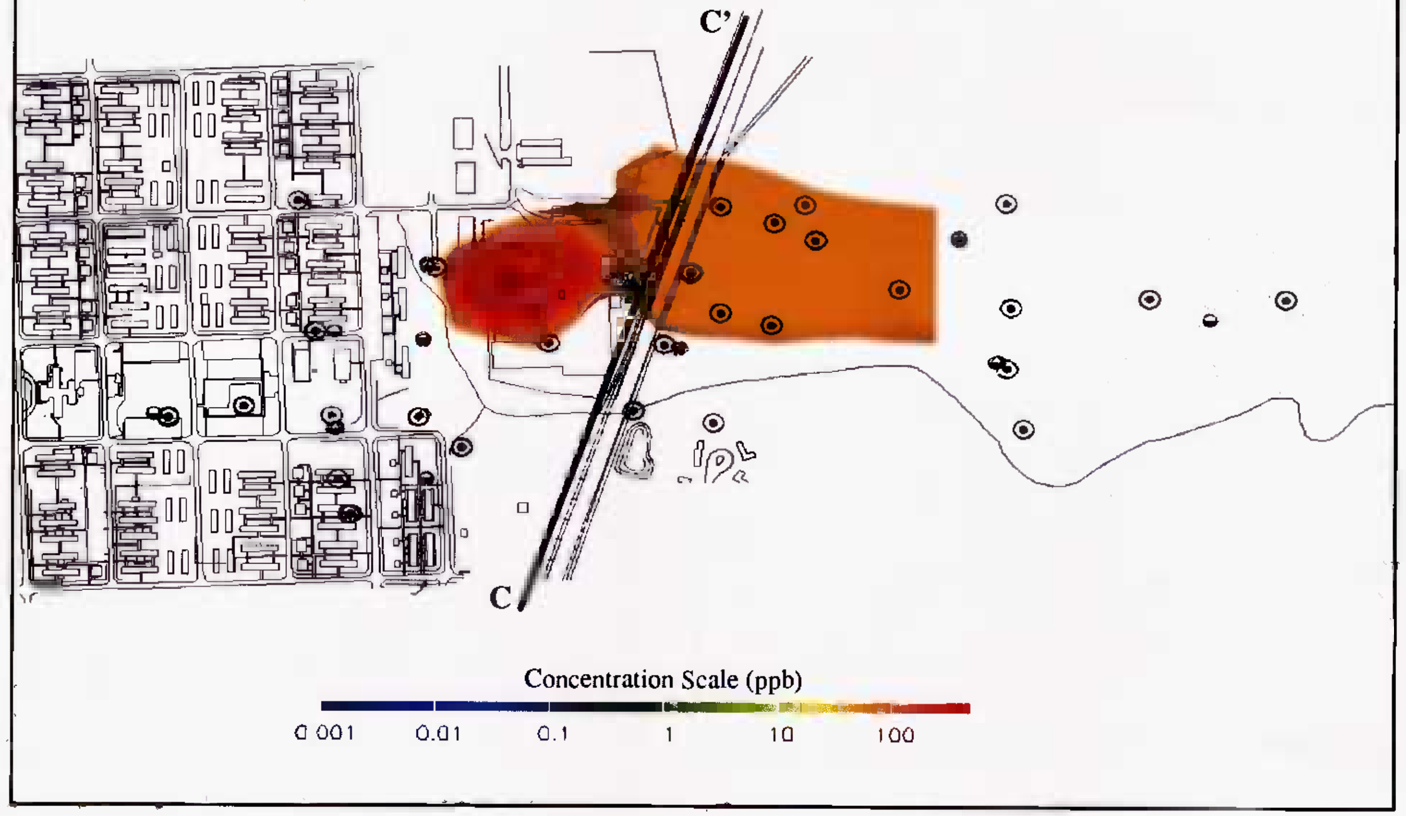
PCE Concentrations Exceeding 0.7 ppb



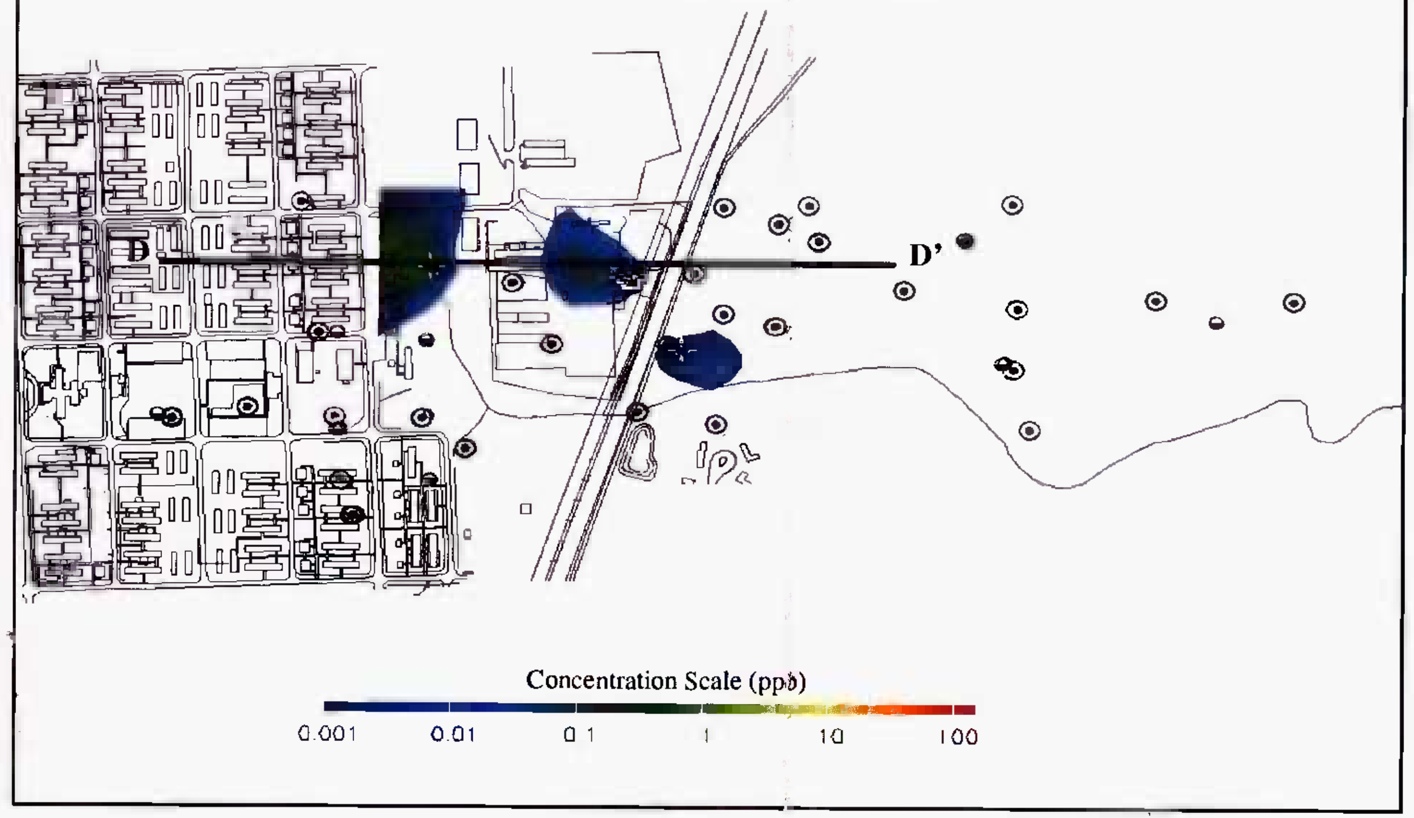
TCE Concentrations Exceeding 2.8 ppb



1,2-DCE (Total) Concentrations Exceeding 70 ppb

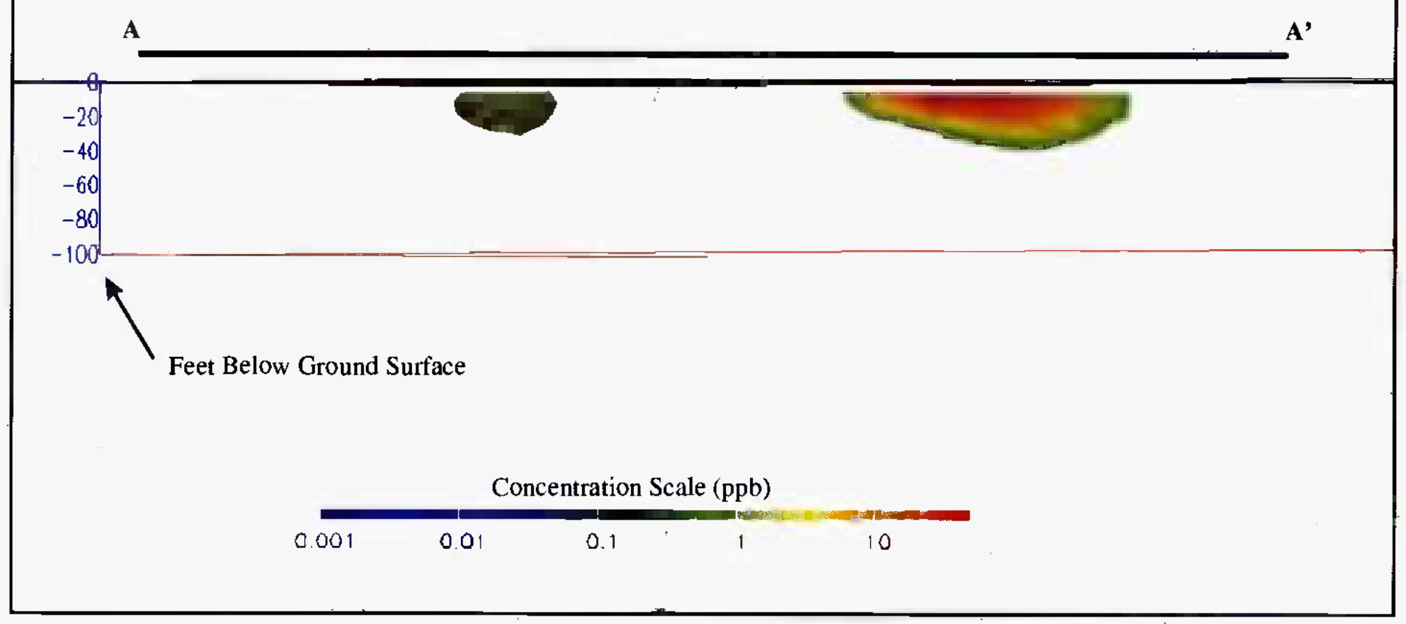


Vinyl Chloride Concentrations Exceeding 0.015 ppb

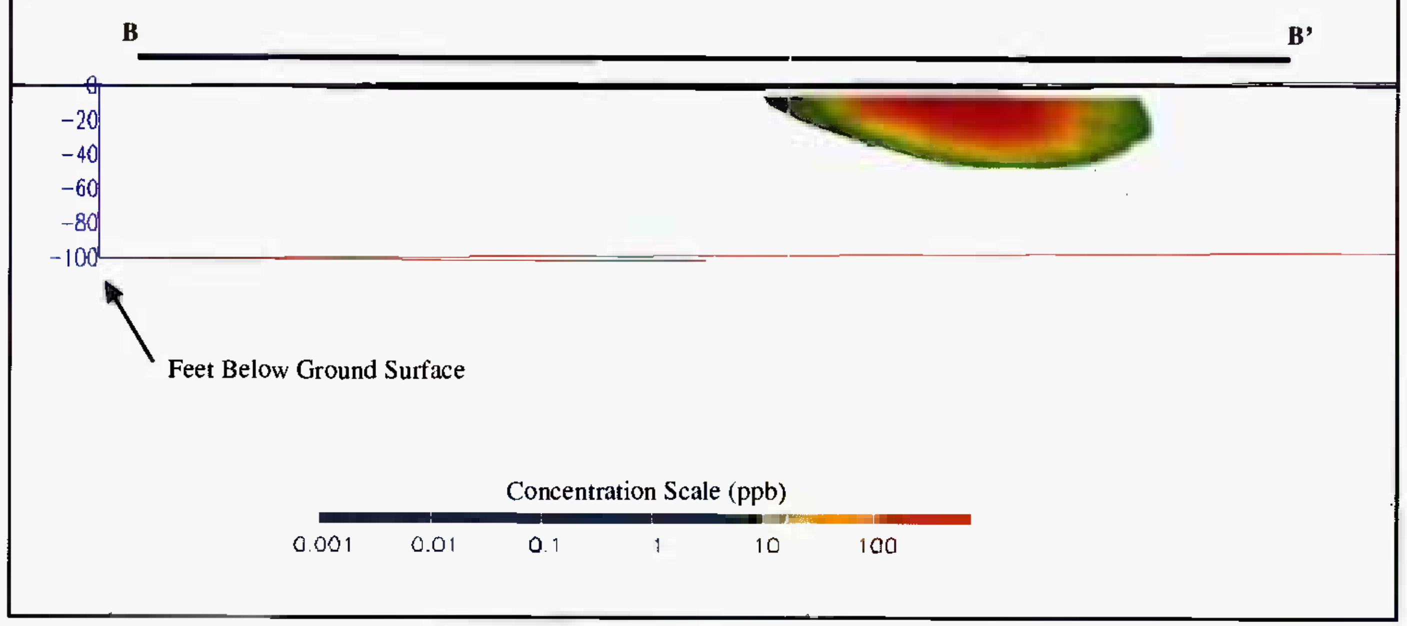


Contaminant Cross-Sections
Operable Unit No. 16 (Sites 89 & 93)
MCB Camp Lejeune, North Carolina

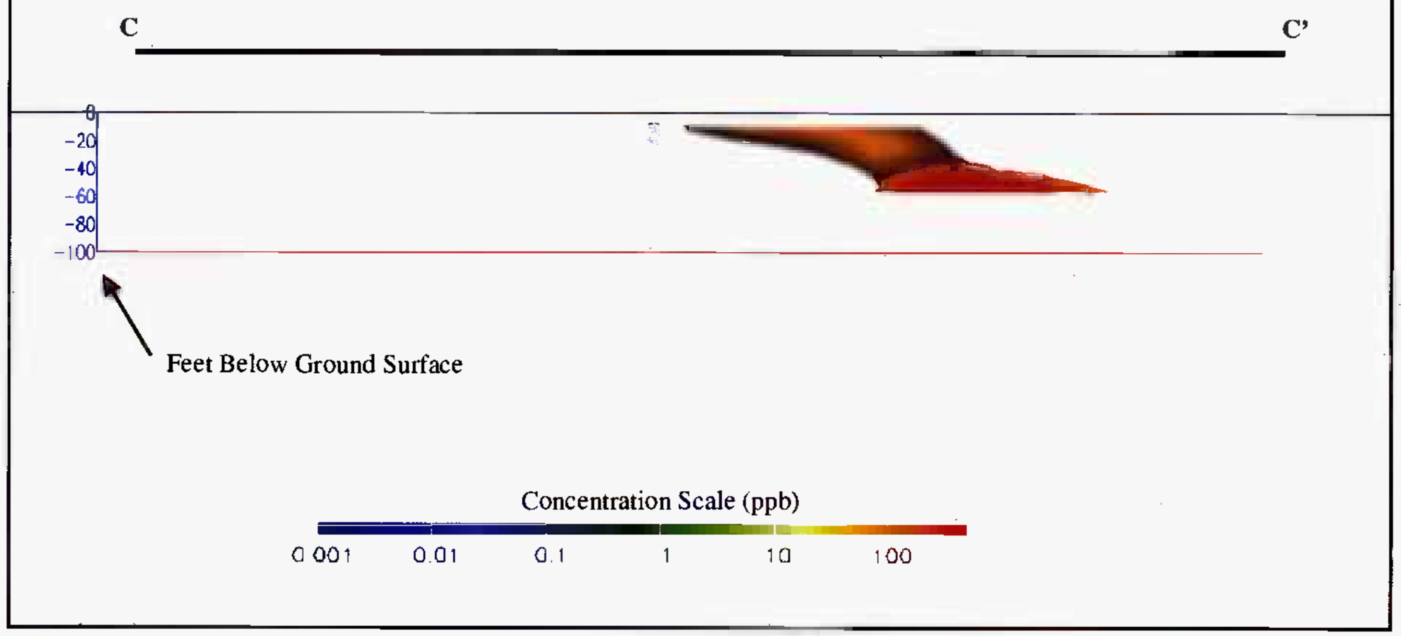
PCE Concentrations Exceeding 0.7 ppb



TCE Concentrations Exceeding 2.8 ppb



1,2-DCE (Total) Concentrations Exceeding 70 ppb



Vinyl Chloride Concentrations Exceeding 0.015 ppb