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FINAL CORRECTIVE MEASURES STUDY SOLID WASTE MANAGEMENT UNIT 360 (SWMU 360) MCB CAMP LEJEUNE NC

10/1/2007

CH2M HILL

FINAL

Corrective Measures Study
SWMU 360

Marine Corps Base Camp Lejeune
Jacksonville, North Carolina

Prepared for

Department of the Navy

Naval Facilities Engineering Command
Mid-Atlantic
Norfolk, Virginia

Contract No. N62470-02-D-3052
CTO-100

October 2007

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Acronyms and Abbreviations

bgs	below ground surface
CA	corrective action
CLEAN	Comprehensive Long-Term Environmental Action Navy
CMS	Corrective Measures Study
COCs	constituents of concern
CSI	Confirmatory Sampling Investigation
CVOC	chlorinated volatile organic compound
cis-1,2-DCE	cis-1,2-dichloroethene
DNAPL	dense, nonaqueous-phase liquid
DoN	Department of the Navy
EPA	U.S. Environmental Protection Agency
ERD	enhanced reductive dechlorination
ft^2	square feet
HWS	Hazardous Waste Section
ISCO	in-situ chemical oxidation
LUC	Land Use Control
LUC IP	Land Use Control Implementation Plan
LUCAP	Land Use Control Assurance Plan
MCB	Marine Corps Base
MCUL	media cleanup level
NC	North Carolina
NCDENR	North Carolina Department of Environment and Natural Resources
O&M	operations and maintenance
PCE	tetrachloroethene
PRG	preliminary remedial goals
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SOD	soil oxidant demand
SSL	soil screening level
SVE	soil vapor extraction
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TCE	trichloroethene

UST	underground storage tank
VOC	volatile organic compound
yd^3	cubic yard(s)

Executive Summary

The purpose of this Corrective Measures Study (CMS) Report for Solid Waste Management Unit (SWMU) 360 at Camp Lejeune, North Carolina, is to assemble and evaluate alternatives for corrective measures to address groundwater contamination. This CMS Report provides a basis for final remedy selection for SWMU 360.

ES.1 Site Description

SWMU 360 is the site of a former 300-gallon waste oil underground storage tank (UST), positioned near Building 1817 in the Hadnot Point Industrial area of Camp Lejeune. Elevated concentrations of chlorinated compounds, primarily tetrachloroethene (PCE), were detected in groundwater beneath the UST location. The site does not pose a significant threat of human exposure under the current land use and does not present any significant risks to ecological receptors. However, the PCE in groundwater does pose a health risk under the hypothetical future residential and industrial land uses, including ingestion of groundwater.

ES.2 Nature and Extent of Contamination

The primary contaminant of concern in the groundwater at SWMU 360 is PCE. The source of the PCE contamination was the former UST. Monitoring well 1817-MW01, located within the former UST pit, contains the highest concentrations of PCE and degradation products, historically as high as 5,100 µg/L, and recently 3,100 µg/L in the shallow groundwater zone (approximately 20 to 30 ft below grade). TCE, cis-1,2- DCE, and vinyl chloride were all detected in groundwater at concentrations exceeding screening criteria, but not at the magnitude of the PCE concentrations.

Groundwater within the intermediate zone (approximately 40 ft below grade) also contains chlorinated volatile organic compounds (CVOCs) at concentrations in excess of screening criteria. The maximum PCE and TCE concentrate`ons detected in the intermediate zone in 2006 were 9.3 µg/L and 4.7 µg/L, respectively.

It appears that a preferential groundwater pathway for the PCE plume is relatively narrow, extending beneath Building 1855 and southeast of the UST location. In situ degradation has been occurring outside of the narrow PCE plume pathway, as evidenced by the higher ratio of DCE to TCE to PCE.

ES.3 Corrective Measures Alternatives

The corrective measures alternatives developed at SWMU 360 are:

- Alternative 1— enhanced reductive dechlorination (ERD)
- Alternative 2— air sparging

- Alternative 3—in-situ chemical oxidation (ISCO)

After corrective measures have been completed, monitored natural attenuation may be assumed to reduce the groundwater concentrations to the North Carolina (NC) 2L values.

The alternatives were evaluated on the basis of three performance standards:

- Protection of Human Health and the Environment
- Attainment of Media Cleanup Objectives
- Source Remediation

The following balancing criteria designated in the Camp Lejeune RCRA Part B Permit were also used to evaluate the alternatives:

- Performance
- Reliability
- Implementability
- Safety
- Relative Cost

SECTION 1

Introduction

1.1 Purpose

This document presents the Resource Conservation and Recovery Act (RCRA) Corrective Measures Study (CMS) Report for Solid Waste Management Unit (SWMU) 360 at Marine Corps Base (MCB) Camp Lejeune, North Carolina (the Base) (**Figure 1-1**). SWMU 360 is defined as the former waste oil underground storage tank (UST) at Building 1817. This document has been prepared by CH2M HILL, Inc. under Contract Task Order 100 of the Department of the Navy's (DoN's) Comprehensive Long-Term Environmental Action Navy Program (CLEAN).

Corrective Action (CA) activities are being conducted under RCRA with the North Carolina Department of Environment and Natural Resources (NCDENR) as the lead agency for CA activities at the Base. All RCRA CA activities are performed in accordance with the Part B Permit (Permit No. NC 617 002 2580).

The purpose of this CMS Report for SWMU 360 is to assemble and evaluate alternative corrective measures for groundwater volatile organic compound (VOC) contamination which may have been caused by SWMU operations. Upon approval by the Base, the DoN, and the NCDENR; the recommended corrective measure presented in this report will be submitted as the final remedy for the SWMU in the Statement of Basis.

The extent of groundwater impacts are based primarily on the findings of the Final SWMU 360 RCRA Facility Investigation Report (Baker Environmental, 2005) and the SWMU 360 Amended RCRA Facility Investigation Report (CH2M HILL, 2006). The CMS briefly summarizes the results of these documents.

Specific objectives of the CMS at SWMU 360 are as follows:

- Develop corrective measure alternatives that meet the media cleanup objectives for media contaminated at concentrations exceeding media cleanup levels (MCULs).
- Evaluate the corrective measure alternatives and develop the basis for selection.

1.2 Report Organization

This report is organized into six sections. Sections 1 through 4 provide a presentation of the physical situation, nature and extent of contamination, rationale for media cleanup objectives, development of alternative corrective measures, and analysis of the corrective measures. Section 5 presents a summary of Conclusions. Section 6 lists the works cited.

1.3 Site Description and Previous Investigations

SWMU 360 is the site of a former 300-gallon waste oil UST, positioned near Building 1817. Building 1817 is located in the Hadnot Point Industrial Area between Duncan Street and "O" Street and one block north east of McHugh Boulevard (**Figure 1-2**). The 8th Communication Battalion operates Building 1817 as the Hazardous Materials Consolidation Center. The actual SWMU is located in the eastern portion of the compound, which is being used as a temporary staging area for batteries, refrigeration units and other used equipment prior to disposal and or reutilization. The entire compound is fenced in and has limited access. A new wash pad has been built near the area of the UST excavation and is utilized by the Marine Units occupying the facility.

1.3.1 UST Removal and Investigation

The 300-gallon waste oil UST was removed in July of 1997, and confirmatory samples were collected (Clean East Associates, Inc, 1997). Additional sampling was completed in December 1997 (Catlin/Law Engineers and Scientists, 1997), indicating a petroleum release had occurred at the SWMU. Catlin/Law Engineers and Scientists also performed a limited site assessment, which included installing monitoring well 1817MW01 within the former UST excavation. Upon discovery of elevated concentrations of chlorinated compounds in groundwater, the site was removed from the UST program and included in the Confirmatory Sampling Investigation (CSI) under RCRA, performed by Baker Environmental (Baker).

1.3.2 Confirmatory Sampling Investigation

The CSI, conducted in 2002 by Baker, included surface and subsurface soil sampling and the installation and sampling of four temporary wells.

The CSI identified the following COPCs in groundwater, based on comparison to North Carolina Groundwater Quality Standards (2L Standards) and to Region IX PRGs for residential tapwater:

- VOCs – cis-1,2-dichloroethene (DCE), PCE, and trichloroethene (TCE)
- Semivolatile organic compounds (SVOCs) – 4-methylphenol and acetophenone
- Pesticides – DDE, DDT, aldrin, alpha-chlordane, gamma-chlordane, heptachlor, heptachlor epoxide, alpha-BHC, and beta-BHC

1.3.3 RCRA Facility Investigation

A RCRA Facility Investigation (RFI) for the SWMU was also completed by Baker in October 2005. The primary goal of the RFI was to investigate the nature and extent of any contamination related to SWMU 360. The RFI objectives were met through a field program that consisted of soil borings, collection of surface and subsurface soil samples, groundwater sample collection via Geoprobe Screen Point Sampler, and installation of permanent monitoring wells.

Sample results were compared against residential PRGs and NC Hazardous Waste Section (HWS) SSLs, and against background concentrations for metals. PCE was detected in the subsurface soil, at concentrations less than Region IX PRGs for residential exposure.

PCE and TCE were detected in groundwater samples collected around SWMU 360. Pesticides and SVOCs identified during the CSI were not detected in groundwater during the RFI, and it was concluded that previous detections of those COPCs had likely resulted from turbidity in the CSI groundwater samples.

The maximum concentrations of PCE and its degradation products in groundwater were detected from samples collected within the original UST well, 1817-MW01. In the 2003 samples, PCE was detected at a concentration of 5,100 micrograms per liter (µg/L), and TCE was detected at 460 µg/L. The PCE plume extended downgradient from the UST location, dissipating to less than 20 µg/L approximately 500 feet southeast of the SWMU. Low levels of TCE, on the order of 10 µg/L, were detected upgradient of the SWMU. The down gradient, up gradient, and the vertical extent of groundwater contamination were not defined during the RFI.

1.3.4 Amended RFI

In January of 2006, CH2M HILL conducted a groundwater investigation as part of the Amended RFI including DPT borings in the down-gradient and side-gradient areas of the groundwater plume. Groundwater samples were collected in the shallow aquifer (approximately 22 to 26 ft bgs) and in the intermediate aquifer (approximately 38 to 42 ft bgs). Four additional monitoring wells were installed in the shallow aquifer, and two in the intermediate groundwater zone. New and existing site groundwater monitoring wells were sampled for VOCs. Results are described in Section 1.5, Nature and Extent of Groundwater Contamination.

1.4 Geology and Hydrogeology

The geology and hydrogeology of SWMU 360 was assessed during the advancement of DPT borings and installation of monitoring wells at the site. Locations of two cross-sections are shown on **Figure 1-3.** Stratigraphic cross-sections generated from the monitoring well boring logs are presented on **Figure 1-4** and **Figure 1-5**.

Cross-section A-A′ trends southeast-northwest and crosses the central region of SWMU 360 including Building 1817 (**Figure 1-4**). Cross-section B-B′ trends northeast-southwest (**Figure 1-5**). Both sections include the stratigraphic sequence of the undifferentiated formation of Holocene and Pleistocene age sediments, which consists of mostly fine to medium grained, medium dense sands with a lesser amount of silt and clay, present to depths of 20 ft to 30 ft bgs, and the underlying Oligocene age River Bend Formation. Within the vicinity of SWMU 360, the River Bend formation is present as discontinuous lenses composed of sands, silt, shell and fossil fragments, and trace amounts of clay. Some of the sands were identified as being cemented within the formation. The amount of shell fragments within the formation decreases with depth down to approximately 25 ft bgs. Below the shell fragments fine silty sands extend to depths of 45 ft bgs.

Vadose zone soils are confined to the shallow undifferentiated formation. The undifferentiated formation varies in depth across the A-A′ cross-section, varying from approximately 25 feet deep within the vicinity of SWMU 360 (near monitoring well SWMU 360-MW02IW) to approximately 20 feet deep southeast of SWMU 360 (within the vicinity of monitoring well SWMU360-MW10IW). Along cross-section A-A′ and near monitoring well SWMU360-MW02 the lithology of the undifferentiated formation consists mostly of fine silty sand. A discontinuous, semi-plastic, silty clay layer is present within the vicinity of SWMU 360 from approximately 5.5 ft to 10 ft bgs and identified within the boring logs for monitoring wells SWMU360-MW01 and SWMU360-MW02. However, this shallow clay lens was not identified northwest (at boring log for well SWMU360-MW08) or southeast (at boring log for well SWMU360-MW04) of SWMU 360 along the A-A′ cross section. In addition, a discontinuous, semi-plastic, silty clay and clayey sand layer is present within the vicinity of SWMU 360 at depths of 20 ft to 25 ft bgs. This discontinuous clay zone was identified within the boring logs for monitoring wells SWMU360-MW08, SWMU360-MW02, and SWMU360-MW04, but appears to pinch-out downgradient of SWMU 360 and is not present at the boring for well SWMU360-MW10. Fossil shells and partially cemented sands in the upper portion of the River Bend formation, were identified between 20 to 25 ft bgs and were generally discontinuous across the A-A′ cross section at SWMU 360. Shell fragments were identified in the boring logs for well SWMU360-MW08 at 24 ft to 26 ft bgs and well SWMU360-MW04 at 21.5 ft to 28 ft bgs. The fossil layer is an identifying characteristic of the River Bend formation (Cardinell et al., 1993).

Cross section B-B′ trends southwest-northeast within the vicinity of SWMU 360 (**Figure 1-3**). The undifferentiated formation consisted of silty sands near the surface and a discontinuous, semi-plastic, silty clay layer present at approximately 5.5 ft to 10 ft bgs within the vicinity wells SWMU360-MW02 and SWMU360-MW01 along the B-B′ cross section. However, the clay layer pinches out northeast of SWMU 360 as indicated by only thin clay lenses at approximately 6.5 ft bgs within the boring log for well SWMU360-MW07. In addition, a discontinuous, plastic, silty clay and clayey sand layer is present within the vicinity of SWMU 360 at depths of 12 ft to 25 ft bgs across the B-B′ cross section. This discontinuous clay zone was identified within the boring logs for monitoring wells SWMU360-MW07, SWMU360-MW01, and SWMU360-MW02, but was not identified at SWMU360-MW05. Fossil shells and partially cemented sands of the upper portion of the River Bend formation were generally discontinuous across the B-B′ cross section and only observed within the boring log for well SWMU360-MW07 (between 16 ft to 24 ft bgs).

1.4.4.1 Site Hydrogeology

During the January 2006 well gauging event performed by CH2M HILL (as part of the Amended RFI), the static water level elevations of the unconfined Surficial Aquifer at SWMU 360 ranged from 4.14 feet msl at monitoring well 360-MW12 to 7.47 feet msl at well 360-MW08. Depth to groundwater at the site ranges from approximately 15 to 21 feet bgs. SWMU 360 monitoring wells within the Surficial Aquifer are screened from 15 to 28 feet bgs. In general, groundwater flow direction within the shallow aquifer of SWMU 360 is to the southeast. A groundwater contour map of the shallow zone is shown on **Figure 1-6**.

The horizontal hydraulic gradient in January 2006 within the shallow zone ranged from approximately 0.002 feet per foot (ft/ft) between wells SWMU360-MW08 and SWMU360-MW10.

Static water level elevations in January 2006 within the intermediate zone ranged from 3.18 feet msl at SWMU360-MW02IW to 4.97 feet msl at well SWMU360-MW01IW. The horizontal hydraulic gradient within the intermediate zone at SWMU 360 was approximately 0.001 ft/ft between wells SMWU360-MW01IW and SWMU360-MW10IW. A groundwater contour map of the intermediate zone is shown on **Figure 1-7**.

Aquifer testing was performed by CH2M HILL in January 2006 through the use of slug tests on three shallow wells (SWMU360-MW01, SWMU360-MW09, and SWMU360-MW10) and three intermediate-depth wells (SWMU360-MW01IW, SWMU360-MW09IW, and SWMU360-MW10IW). The hydraulic conductivity in the shallow wells ranged from 2.36 feet per day (ft/day) at well SWMU360-MW09 to 17 ft/day at well SWMU360-MW01, or 0.001 cm/s to 0.006 cm/s respectively. The mean hydraulic conductivity within the shallow wells was 7.8 ft/day or 0.003 cm/s. However, the hydraulic conductivity determined for well SWMU360-MW01 may be biased high due to the poor quality of the slug test curve generated with the plotted data collected in the field. The mean hydraulic conductivity value of 7.8 ft/day determined during the RFI Addendum field activities is slightly higher than the value of 4.2 ft/day determined during the RFI.

Limited studies on the vertical permeability within the vadose zone near and downgradient of SWMU 360 were also conducted in January 2006. Vertical permeabilities measured from undisturbed Shelby tube samples taken from within the poorly graded sand layers ranged from 1.3 ft/day (2 to 4 ft bgs from SWMU360-SB33) to 3.1 ft/day (8 to 10 ft bgs from SWMU360-MW09), while the vertical permeability of the finer grained silty sands was measured to be 0.21 ft day (14 to 16 ft bgs from SWMU360-MW10).

Vertical hydraulic potentials were calculated between the shallow and intermediate zones using the water-level data between adjacent wells screened in the respective intervals (well pairs MW01 and MW01IW, MW09 and MW09IW and MW10 and MW10IW). The water-level data from January 2006 appears to indicate that the vertical gradient potential varies slightly, but is generally downward throughout the area.

1.5 Nature and Extent of Groundwater Contamination

The primary contaminant of concern in the groundwater at SWMU 360 is PCE. The source of the PCE contamination was the former UST. Monitoring well 1817-MW01, located within the former UST pit, contains the highest concentrations of PCE and degradation products, historically as high as 5,100 µg/L, and recently 3,100 µg/L, within the shallow groundwater zone. The PCE concentrations decrease to less than 100 µg/L within 130 feet downgradient of the former UST location. TCE, cis-1,2- DCE, and vinyl chloride were all detected in groundwater at concentrations exceeding screening criteria, but not at the magnitude of the PCE concentrations. **Figure 1-8** presents concentrations for PCE from samples collected from the shallow zone during the initial RFI (Baker, 2005) and the Amended RFI. PCE isoconcentration lines are also presented on **Figure 1-8**.

TCE isoconcentration lines for the shallow aquifer are presented in **Figure 1-9**. Data from the initial RFI (Baker, 2005) and the Amended RFI were used to aid in drawing the isoconcentrations. Although another upgradient source of TCE is evident, the majority of

the TCE in groundwater at the UST location is probably associated with the release at the SWMU, as a degradation product within the groundwater.

Groundwater within the intermediate zone also contains chlorinated volatile organic compounds (CVOCs) at concentrations in excess of screening criteria. The maximum PCE and TCE concentrations detected in the intermediate zone during the Amended RFI were 9.3 µg/L and 4.7 µg/L, respectively. CVOC data from the Amended RFI are presented in **Figure 1-10**.

It appears that a preferential groundwater pathway for the PCE plume is relatively narrow, extending beneath Building 1855 and southeast of the UST location. In this area, PCE concentrations exceed TCE and DCE, while in upgradient and side-gradient areas, the daughter product DCE has successively higher concentrations than the TCE. In situ degradation has been occurring outside of the narrow PCE plume pathway, as evidenced by the higher ratio of DCE to TCE to PCE.

During the 2006 Amended RFI sampling event, groundwater parameters including temperature, pH, oxidation-reduction potential (ORP), and dissolved oxygen (DO) were recorded. DO concentrations were less than 5 mg/L in fifteen of nineteen samples, ORP ranged from -145 mV to 304 mV, temperature was between 20°C and 22°C, and pH values were between 5 to 9 for eighteen of the nineteen monitoring wells sampled. **Table 1-1** presents a summary of these groundwater parameters.

1.6 Human Health Risk Assessment

A baseline Human Health Risk Assessment (HHRA) was completed as part of the 2005 Baker RFI for SWMU 360 to evaluate if unacceptable risks may be associated with potential exposure to existing conditions at the site. The HHRA indicated no unacceptable risks or hazard levels for current military personnel or future construction workers, who would be exposed to site groundwater. However, the detection of PCE, TCE and heptachlor epoxide in groundwater (from CSI data) exhibited a risk to human health for future adult and child residents. This risk is based on contact with groundwater and the possibility that the Base may become a future residential area. The HHRA was reviewed with respect to data from the Amended RFI, and the conclusions remain the same: **There are no unacceptable health risks associated with exposure to the soils at the site. Risk levels exceed the acceptable range for potential future residential exposure to groundwater**.

The future industrial worker scenario, which includes potential future exposure to groundwater beneath the site, was not evaluated during the HHRA, nor was potential indoor vapor intrusion from groundwater. RGOs based on risk to human health were not developed for soil, as no health-based COPCs were identified in soil.

1.7 Ecological Risk Assessment

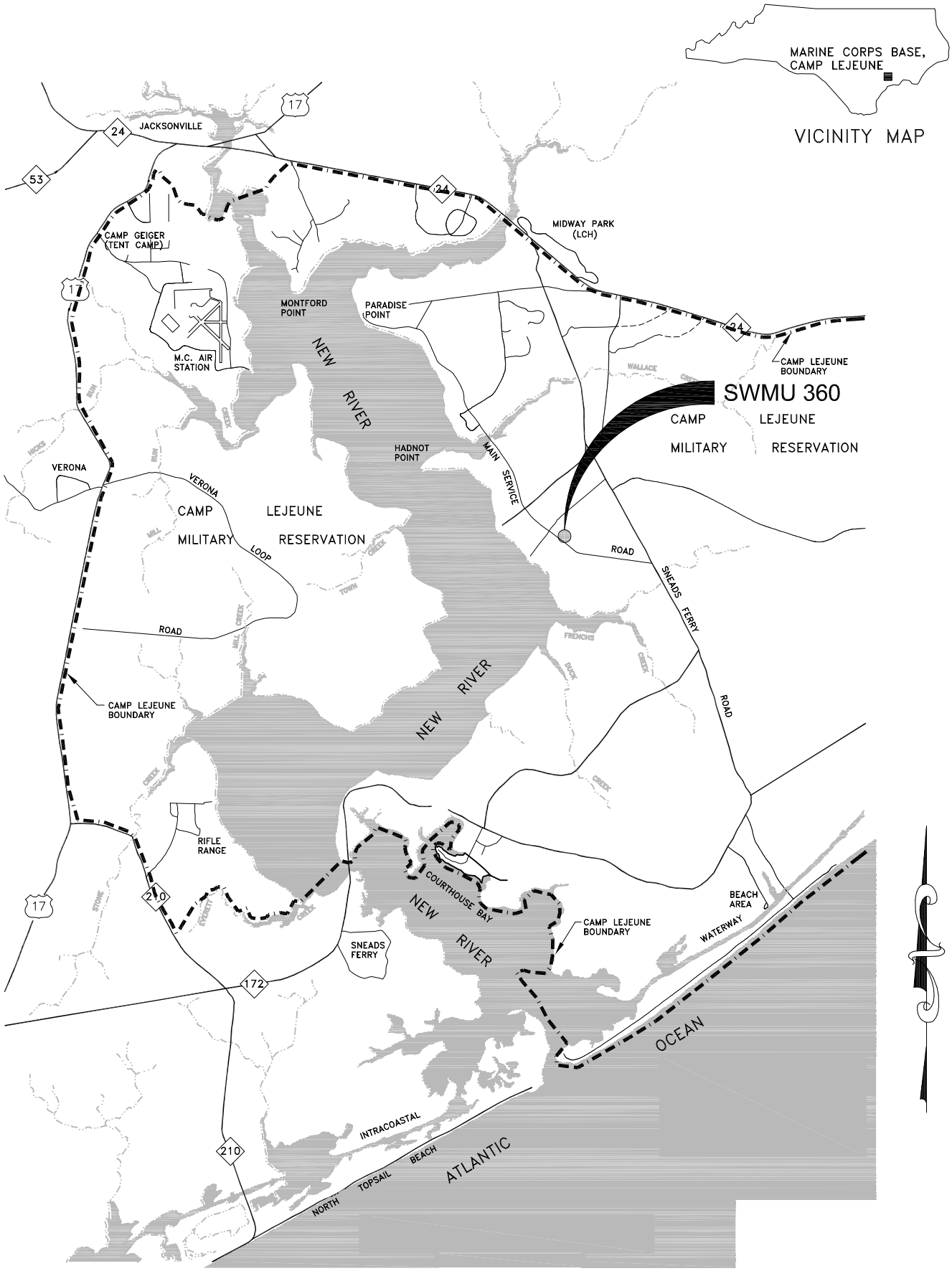
An Ecological Risk Assessment (ERA) was completed as part of the 2005 Baker RFI in order to evaluate the likelihood that adverse ecological effects would occur or are occurring as a result of exposure to one or more physical or chemical stressors. The assessment evaluated the potential effects of chemicals on terrestrial and aquatic receptors (e.g., flora and fauna)

and their habitats; including the consideration of protected species and sensitive or critical habitats. It identified particular chemical stressors that may cause adverse effects. The ERA found that risk is not likely at the SWMU based on a negligible terrestrial habitat that does not warrant ecological evaluation and aquatic habitat is not present on or near the study area.

Table 1-1
Summary of Groundwater Quality Parameters
SWMU 360 CMS Report
MCB Camp Lejeune

Monitoring Well ID	Sample Date	Depth to Water (ft bgs)	Temperature (°C)	Conductivity (umhos/cm)	Dissolved Oxygen (mg/L)	pH (SU)	Oxidation/ Reduction Potential (mV)	Turbidity (NTU)
SWMU360-MW01	1/19/06	21.19	21.46	0.623	0.26	7.74	84	20.5
SWMU360-MW01IW	1/19/06	21.35	20.94	0.322	0.00	8.21	-145	15.7
SWMU360-MW02	1/19/06	19.90	20.32	0.534	0.52	7.35	109	27.7
SWMU360-MW02IW	1/19/06	21.90	20.14	0.600	0.16	7.76	81	8.2
SWMU360-MW03	1/19/06	18.98	21.56	0.635	0.15	7.79	35	18.0
SWMU360-MW03IW	1/19/06	19.02	21.17	0.300	0.03	8.50	-113	4.0
SWMU360-MW04	1/19/06	20.10	21.00	0.567	0.11	7.74	109	16.6
SWMU360-MW05	1/19/06	16.64	21.29	0.211	7.21	4.99	304	9.5
SWMU360-MW06	1/19/06	17.45	21.48	0.149	7.57	6.36	220	14.3
SWMU360-MW07	1/19/06	18.99	20.55	0.605	0.96	6.94	122	4.8
SWMU360-MW08	1/19/06	18.85	21.23	0.679	1.12	6.77	142	8.4
*1817-MW01	1/19/06	19.40	21.44	1.000	1.51	6.15	109	4.5
SWMU360-MW09	1/18/06	14.84	22.09	0.275	5.05	7.08	205	12.2
SWMU360-MW09IW	1/18/06	14.80	21.20	1.260	6.45	13.41	-127	16.5
SWMU360-MW10	1/18/06	19.32	22.10	0.596	1.07	7.81	110	18.4
SWMU360-MW10IW	1/18/06	19.18	20.80	0.438	0.12	8.85	50	5.9
SWMU360-MW11	1/19/06	19.23	20.90	0.682	0.57	7.64	-21	73.8
SWMU360-MW12	1/19/06	16.50	22.00	0.545	0.30	7.57	48	59.2
IR78-GW39	1/19/06	14.78	19.80	0.270	2.60	5.13	300	7.9

Notes:
ft bgs = feet below ground surface
umhos/cm = micromhos per centimeter
mg/L = milligrams per liter
SU = Standard Units
mV = millivolts
NTU = Nepholometric Turbidity Unit



NOT TO SCALE

FIGURE 1–1
MCB CAMP LEJEUNE GENERAL LOCATION MAP
CORRECTIVE MEASURES STUDY
SMWU 360 CTO –0100
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

SOURCE: MCB CAMP LEJEUNE, 2000.

CH2MHILL

EBL\NAVY CLEAN\CAMPLEJCADD\SWMU 360\CADD\CMS\Figure1-1.dwg

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Legend

- Waste Oil UST
- Buildings
- Road Line
- Streams

N
W E
S

0 50 100 200 300
Feet

Figure 1-2
Former UST Location
SWMU 360 Soil CMS
Marine Corps Base, Camp Lejeune, North Carolina

CH2MHILL

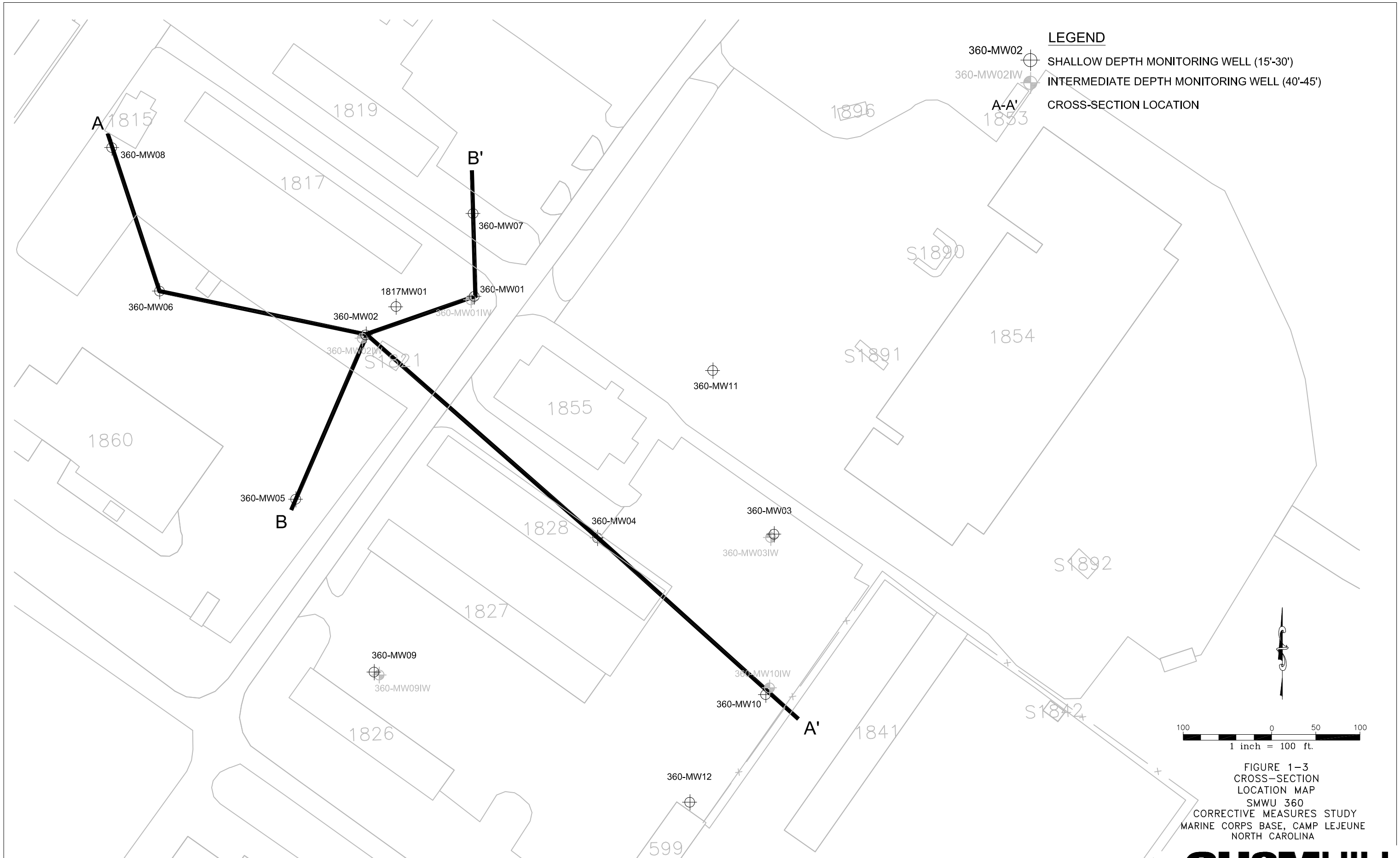

FIGURE 1–3
CROSS–SECTION
LOCATION MAP
SMWU 360
CORRECTIVE MEASURES STUDY
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

CH2MHILL

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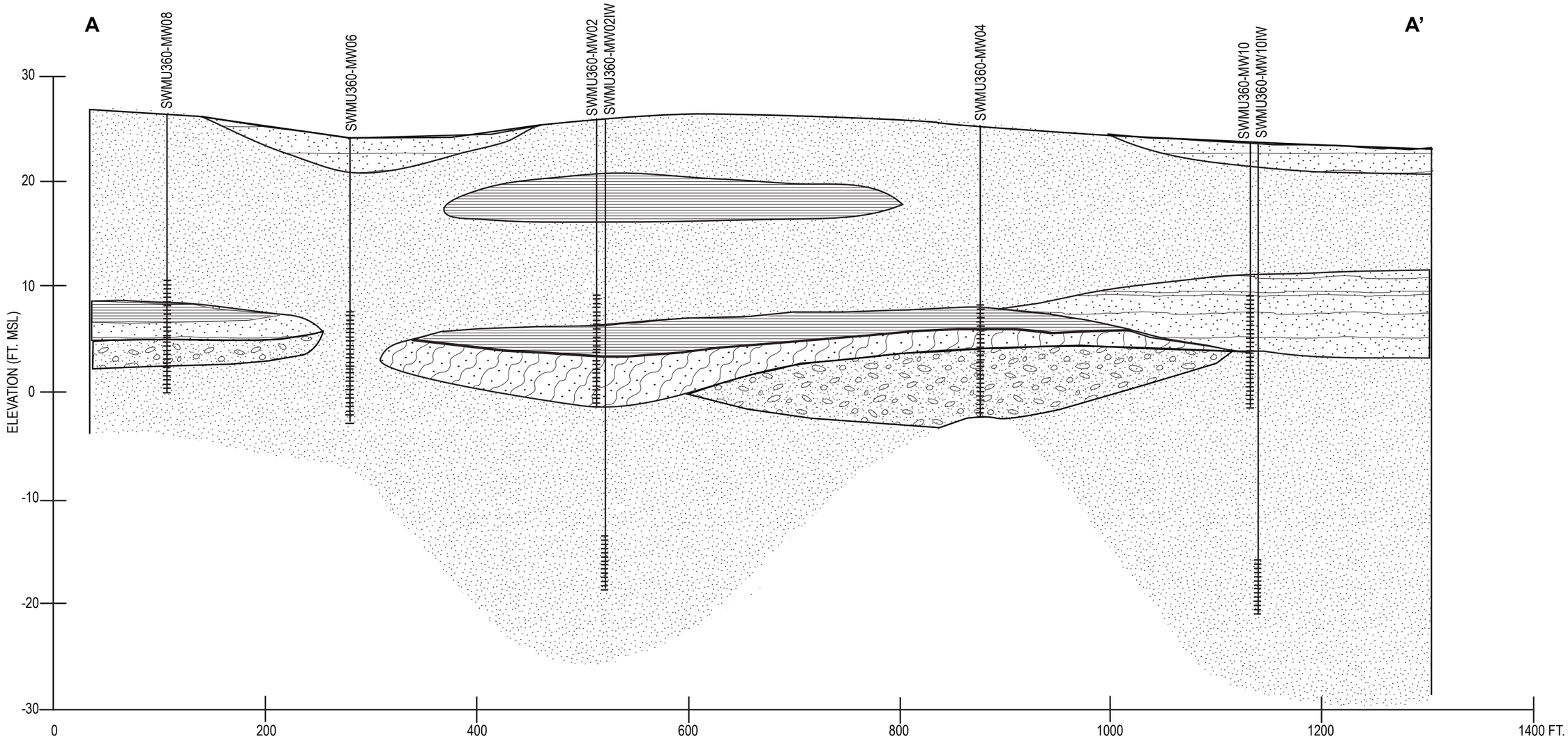
SOURCE: MCB CAMP LEJEUNE, 2000.



LEGEND:

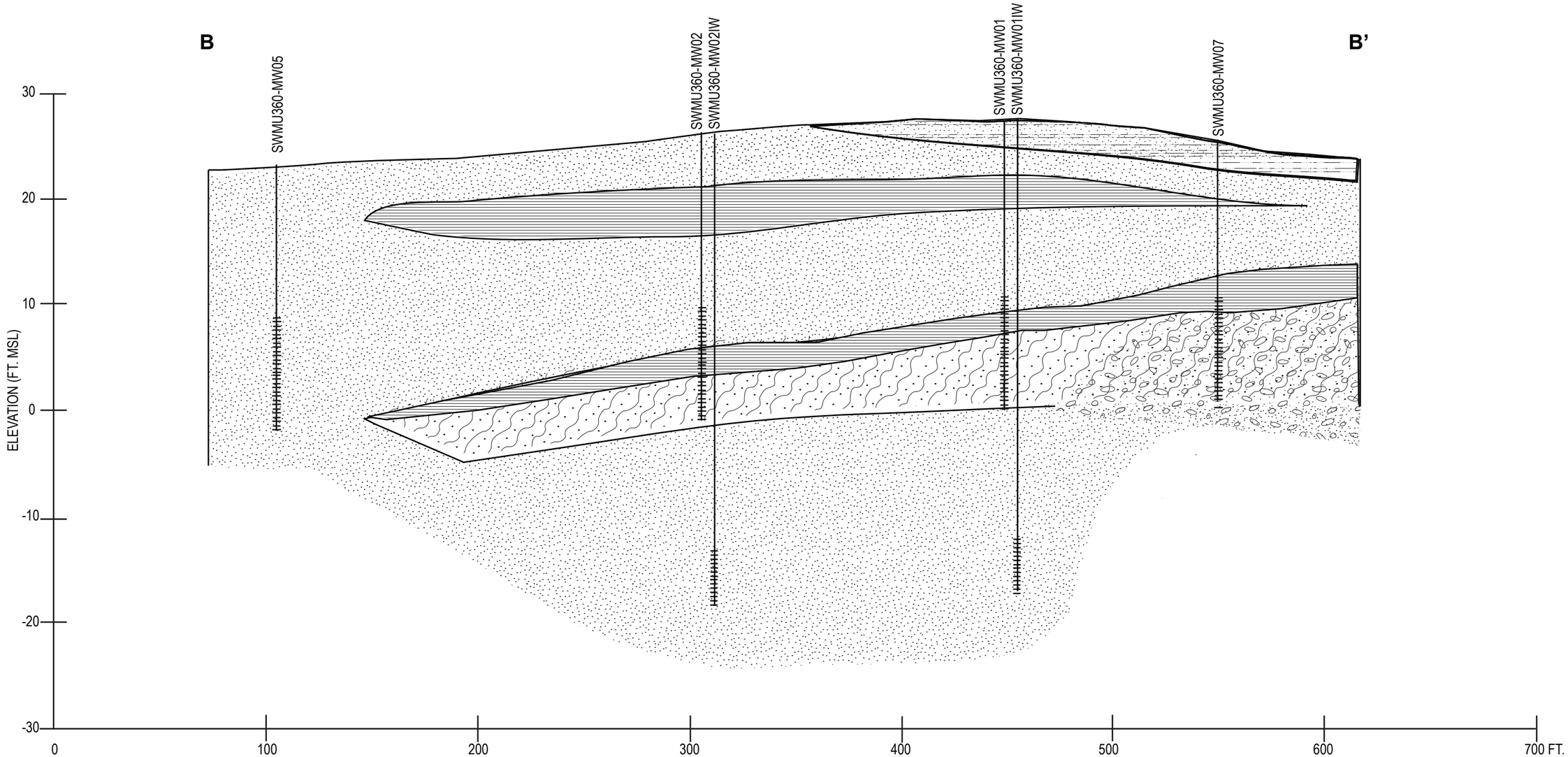
- Silty Sand (SM)
- Fine Sand with some Silt (SP-SM)
- Inorganic Clay (CL)
- Monitoring Well
- Clayey Sand (SC)
- Fine Sand (SP) w/ Shell Fragments

HORIZONTAL SCALE: 1'=100'
VERTICAL SCALE: 1'=10'

Notes:
The depth and thickness of the subsurface strata indicated on this section (profile) were generalized from and interpolated between test locations. Information on actual subsurface conditions applies only to the specific locations and dates indicated. Subsurface conditions and water levels at other locations may differ from conditions occurring at the indicated locations.

FIGURE 1-4
GENERALIZED GEOLOGIC CROSS-SECTION A-A'
SWMU 360
CORRECTIVE MEASURES STUDY
MCB CAMP LEJEUNE, NORTH CAROLINA

CH2MHILL



LEGEND:

- Inorganic Silt (ML)
- Fine Sand with some Silt (SP-SM)
- Inorganic Clay (CL)
- Monitoring Well
- Clayey Sand (SC)
- Fine to Coarse Sand (SW) with Shell Fragments

HORIZONTAL SCALE: 1'=50'
VERTICAL SCALE: 1'=10'

Notes:
The depth and thickness of the subsurface strata indicated on this section (profile) were generalized from and interpolated between test locations. Information on actual subsurface conditions applies only to the specific locations and dates indicated. Subsurface conditions and water levels at other locations may differ from conditions occurring at the indicated locations.

FIGURE 1-5
GENERALIZED GEOLOGIC CROSS-SECTION B-B'
SWMU 360
CORRECTIVE MEASURES STUDY
MCB CAMP LEJEUNE, NORTH CAROLINA

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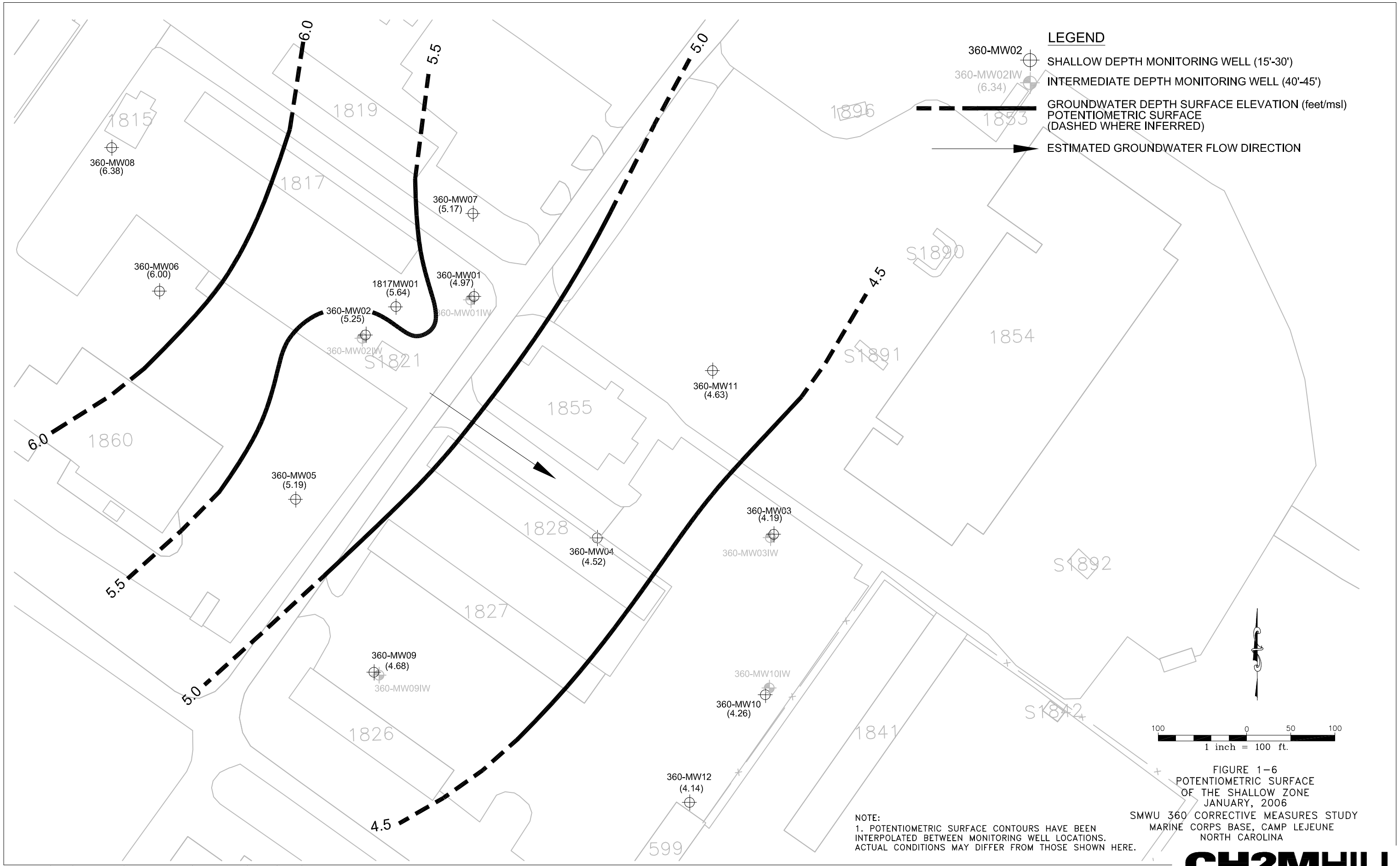

NOTE:
1. POTENTIOMETRIC SURFACE CONTOURS HAVE BEEN INTERPOLATED BETWEEN MONITORING WELL LOCATIONS. ACTUAL CONDITIONS MAY DIFFER FROM THOSE SHOWN HERE.

FIGURE 1–6
POTENTIOMETRIC SURFACE
OF THE SHALLOW ZONE
JANUARY, 2006
SMWU 360 CORRECTIVE MEASURES STUDY
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

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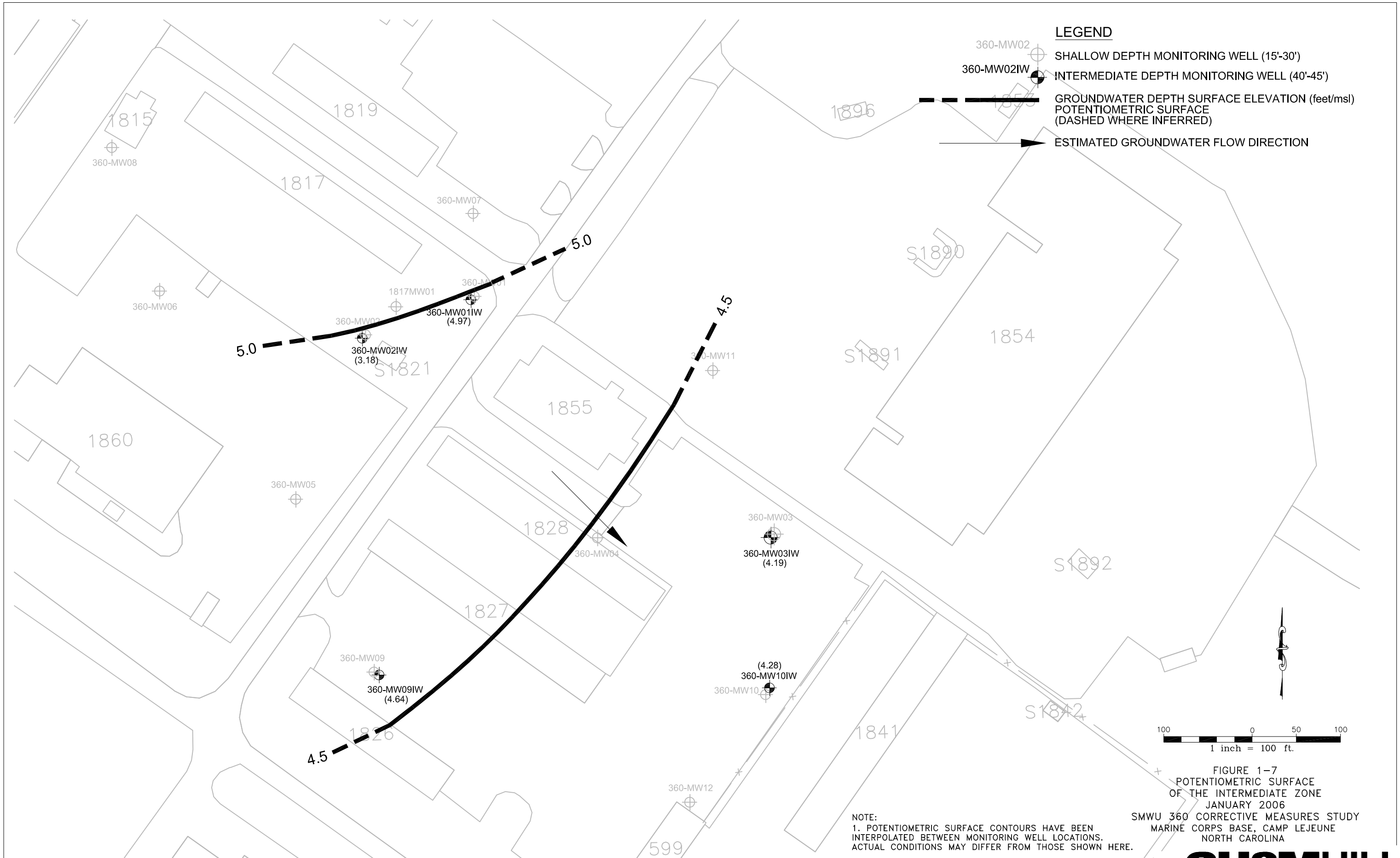
SOURCE: MCB CAMP LEJEUNE, 2000.



NOTE:
1. POTENTIOMETRIC SURFACE CONTOURS HAVE BEEN INTERPOLATED BETWEEN MONITORING WELL LOCATIONS. ACTUAL CONDITIONS MAY DIFFER FROM THOSE SHOWN HERE.

FIGURE 1–7
POTENTIOMETRIC SURFACE
OF THE INTERMEDIATE ZONE
JANUARY 2006
SMWU 360 CORRECTIVE MEASURES STUDY
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

CH2MHILL

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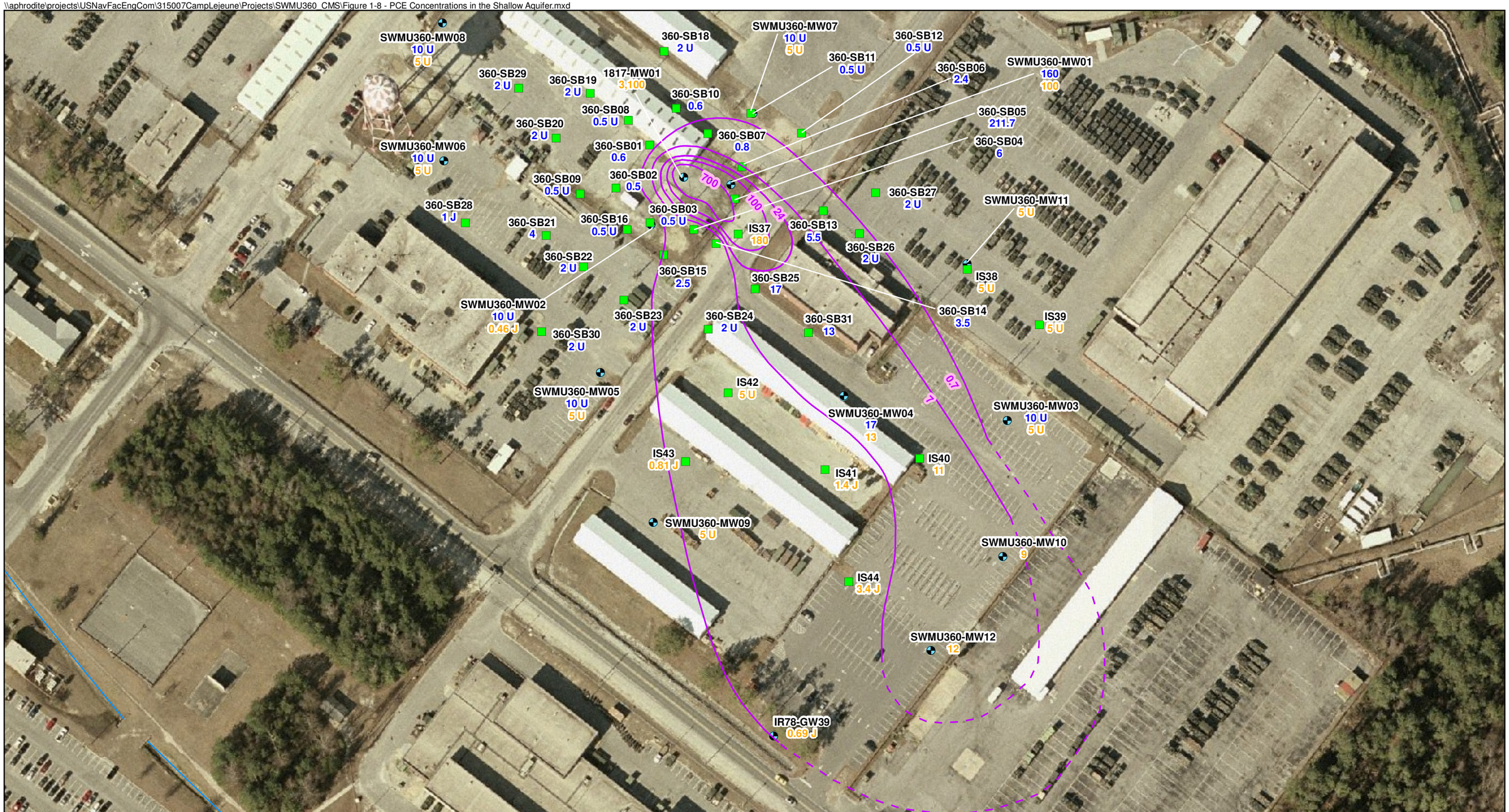
SOURCE: MCB CAMP LEJEUNE, 2000.

\\aphrodite\projects\USNavFacEngCom\315007CampLejeune\Projects\SWMU360_CMS\Figure 1-8 - PCE Concentrations in the Shallow Aquifer.mxd



Legend

- DPT Sample Locations
- Monitoring Well Location
- PCE Isoconcentrations ug/L; dashed where inferred
- Surface Water Line
- Buildings

PCE - Tetrachloroethene - NC2L = 0.7 ug/L
J - Reported value is estimated
U - Not detected; reporting limit is presented
All data is presented in ug/L.
Blue text indicates data collected in 2003.
Orange text indicates data collected in 2006.

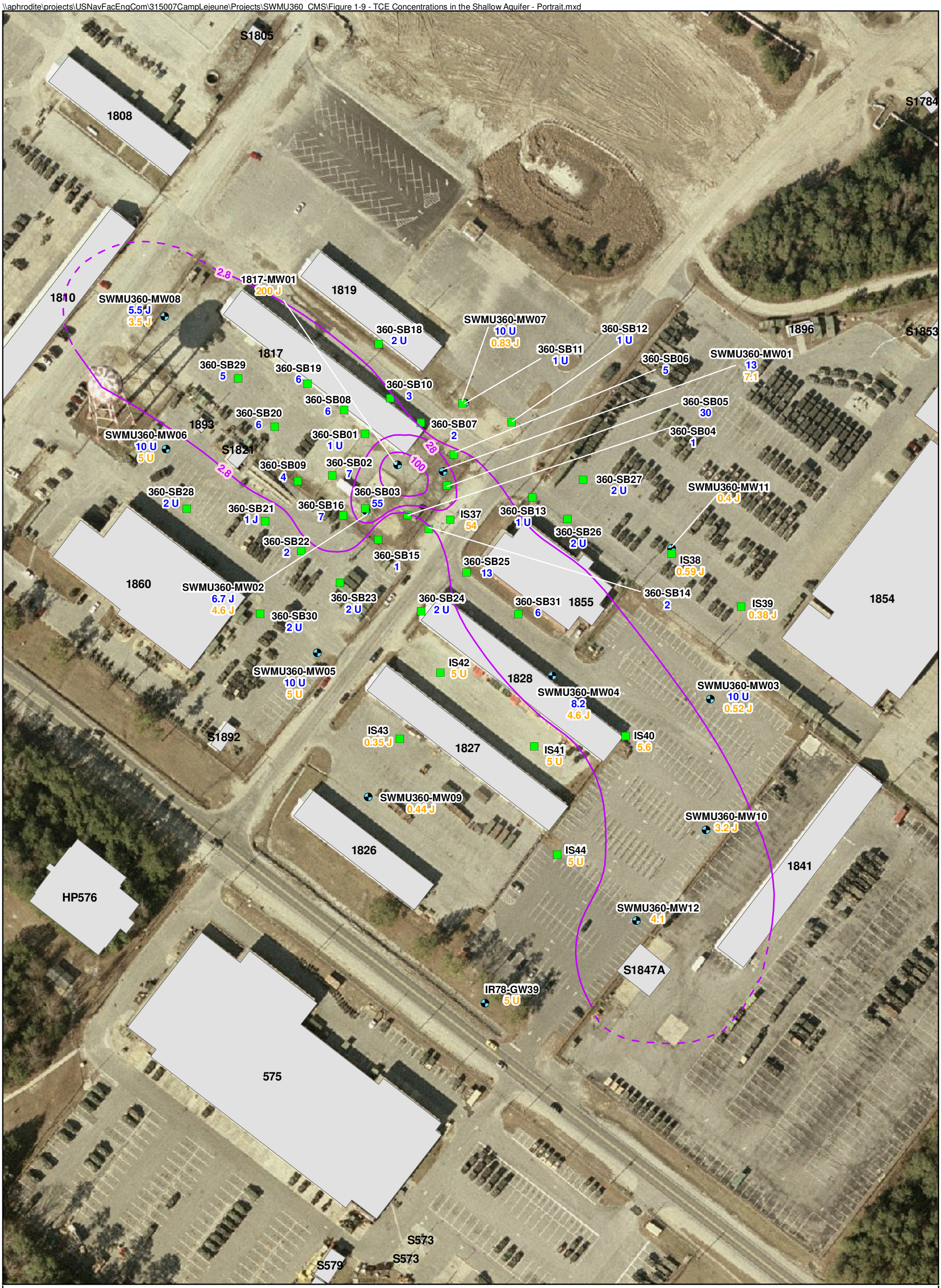
N
W E
S

0 60 120
Feet

Figure 1-8
PCE Concentrations in the Shallow Aquifer
MCB Camp Lejeune
North Carolina

CH2MHILL

\\aphrodite\projects\USNavFacEngCom\315007CampLejeune\Projects\SWMU360_CMS\Figure 1-9 - TCE Concentrations in the Shallow Aquifer - Portrait.mxd



Legend

- DPT Sample Locations
- Monitoring Well
- PCE Isoconcentrations ug/L; dashed where inferred
- Buildings

TCE - Trichloroethene - NC2L = 2.8 ug/L
J - Reported value is estimated
U - Not detected; reporting limit is presented
All data is presented in ug/L.
Blue text indicates data collected in 2003.
Orange text indicates data collected in 2006.

N
W E
S

0 60 120
Feet

Figure 1-9
TCE Concentrations in the Shallow Aquifer
MCB Camp Lejeune
North Carolina

CH2MHILL

File Path: X:\USNavFaceNGCom\315007CampLejeune\Projects\SWMU360_CSM\Figure 1-10 - COVC Concentrations in the Intermediate Aquifer.mxd

Legend

- DPT
- Monitoring Wells

J- Reported value is estimated
PCE- Tetrachloroethene
TCE- Trichloroethene
cis 1,2-DCE- Cis 1,2-Dichloroethene
TRANS-1,2-DCE- Trans-1,2-Dichloroethene
VC- Vinyl Chloride
CVOCs- Chlorinated Volatile Organic Compounds
Bold Red indicates exceedance of NC2LGW screening criteria

U - Not detected; reporting limit is presented
All data is presented in ug/L
Data collected 12/14/06 through 1/19/06

N
W E
S

0 62.5 125
Feet

Figure 1-10
CVOC Concentrations in the Intermediate Aquifer
SWMU 360 Corrective Measures Study
Marine Corps Base, Camp Lejeune, North Carolina

CH2MHILL

SECTION 2

Development of Corrective Action Objectives

2.1 Introduction

The corrective action objectives (CAOs) for the SWMU 360 CMS are based on the protection of human health and the environment from the risks identified in the human health and ecological risk assessment. Contaminant concentrations in groundwater are at an acceptable risk for current military and construction personnel, but are higher than human health risk values for future adult and child residents.

2.2 Groundwater Corrective Action Objectives

The cleanup objective for groundwater beneath SWMU 360 is to enable safe exposure of the groundwater to any potential receptor. The health risk to current military personnel and future construction workers is within the acceptable range, and therefore no remediation is necessary for those populations. Therefore, the cleanup objective is to safeguard potential future industrial workers and residents from exposure to groundwater contamination. These objectives may be met by permanently restricting residential use of the site until CVOC concentrations have reduced through natural attenuation, or by treating the contamination through active remediation.

As described in USEPA's Region IV guidelines, Remedial goal options (RGOs) were developed for chemicals identified as risk-drivers, and encompass a range of risk factors, from 1×10^{-6} to 1×10^{-4} excess lifetime cancer risk, and a noncancer hazard quotient of 0.1 to 3.

RGOs were developed for two scenarios: industrial and residential land uses. Several chlorinated VOCs were identified as risk drivers in groundwater, which were further screened to identify chemicals of concern (COCs) that were addressed during RGO development, as shown in **Table 2-1**. RGOs were developed for the following chemicals in groundwater:

- tetrachloroethene,
- trichloroethene,
- cis-1,2-dichloroethene
- vinyl chloride

The results of the HHRA indicated that risks higher than USEPA risk reduction objectives were associated with selected chlorinated VOCs in groundwater. RGOs were back-calculated from the target risk levels identified by USEPA Region IV. The RGOs in groundwater, which were based on direct contact with water (ingestion, inhalation from

indoor use and dermal contact), are shown in **Table 2-2**. CAOs were derived from the RGOs for a specific risk level.

It is proposed to define a specific cleanup area surrounding the source, and designate monitored natural attenuation (MNA) and land use controls (LUCs) for the remaining, lower concentration areas. The CAOs for the lower concentration areas will be based upon the NC 2L standards. The LUCs would consist of controls on aquifer use only, until concentrations reach acceptable levels.

The cleanup area would be defined by those groundwater concentrations in excess of the proposed RGO risk level and the future industrial worker exposure scenario. The future industrial worker exposure scenario is suggested because:

1) Site groundwater is not currently used as a potable water supply,

2) There are no groundwater receptors located in the vicinity of the site,

3) SWMU 360 is in an industrial portion of an active military Base, and

4) Land use restrictions may be imposed against residential development.

The CAO was chosen from the RGOs assuming an allowable excess cancer risk level of 1 in 10,000 (1×10^{-4}) and a Hazard Quotient of 1 for the future industrial worker scenario. The maximum site concentrations of the COCs at SWMU 360 were compared to the CAOs. As shown in **Table 2-3** and **Figure 1-10**, CAOs are not exceeded in the intermediate groundwater beneath the site, and cis-1,2-DCE and vinyl chloride concentrations in the shallow aquifer are less than the CAOs. PCE was selected to define the target remediation effort, as TCE will also be addressed with any remedial option used for PCE.

Assuming a 10^{-4} carcinogenic risk factor and industrial worker exposure scenario, the following remediation goals for PCE and TCE were developed for the shallow groundwater zone:

PCE: 24 ug/L
TCE: 129 ug/L

Accordingly, corrective action objectives for groundwater at SWMU 360 are:

1. Treat TCE and PCE concentrations in the Surficial Aquifer to less than risk based criteria for an industrial worker exposure scenario: 129 µg/L and 24 µg/L, respectively;

2. Protect human health and the environment by treating high concentration source areas which "feed" the dissolved plumes in the Surficial Aquifer.

Based on these objectives, identification and screening of technology types and process options, comprising the remainder of this CMS, will focus specifically on removal and/or treatment of source areas where PCE and TCE concentrations in groundwater exceed the specified risk-based criteria.

The areas of impact within the Surficial Aquifer are shown within the 24 µg/L contour in **Figure 1-9**. The total area of impacts is estimated to be 18,000 square feet. The target groundwater treatment zone is from the groundwater table at approximately 20 feet bgs to the semi-confining zone at 30 feet bgs.

Table 2-1
Identification of Chemicals of Concern in Groundwater for RGO Development
SWMU 360 CMS
MCB Camp Lejeune

Chemical	Retained for CMS?	Rationale for Exclusion from CMS
Shallow Groundwater		
Benzene	No	Risk within EPA's risk range (1E-04 to 1E-06); infrequently detected.
cis-1,2-Dichloroethene	Yes	N/A
Heptachlor epoxide	No	Infrequently detected; presence has not been confirmed
Tetrachloroethene	Yes	N/A
Trichloroethene	Yes	N/A
Vinyl chloride	Yes	N/A
Intermediate Groundwater		
Tetrachloroethene	Yes	N/A
Trichloroethene	Yes	N/A
Vinyl chloride	Yes	N/A

N/A = Not Applicable

Table 2-2
Remedial Goal Options (RGOs) in Groundwater
SWMU 360 CMS
MCB Camp Lejeune

Chemical	**Preliminary Remediation Goals (PRGs) - ug/L**						
	Based on Target Cancer Risk				**Based on Target Noncancer Hazard Quotient**		
Adult Resident (ingestion, dermal contact and inhalation exposure pathways)							
	$1x10^{-6}$	**$1x10^{-5}$**	**$1x10^{-4}$**		**0.1**	**1**	**3**
Tetrachloroethene	0.1	1.2	12.0		21.0	210	629
Trichloroethene	3.5	35.5	355		7.6	75.9	228
cis-1,2-Dichloroethene	--	--	--		33.9	339	1,018
Vinyl chloride	0.1	1.3	13.1		7.5	75.2	226
Child Resident (ingestion, dermal contact and inhalation exposure pathways)							
	$1x10^{-6}$	**$1x10^{-5}$**	**$1x10^{-4}$**		**0.1**	**1**	**3**
Tetrachloroethene	0.2	1.8	18.0		7.1	71.4	214
Trichloroethene	2.5	25.4	254		1.3	13.3	39.8
cis-1,2-Dichloroethene	--	--	--		14.6	146	437
Vinyl chloride	0.2	1.9	19.2		1.9	19.2	57.5
Industrial Worker (ingestion, dermal contact and inhalation exposure pathways)							
	$1x10^{-6}$	**$1x10^{-5}$**	**$1x10^{-4}$**		**0.1**	**1**	**3**
Tetrachloroethene	0.2	2.4	24.0		42.8	428	1,284
Trichloroethene	5.9	58.7	587		12.9	129	388
cis-1,2-Dichloroethene	--	--	--		89.7	897	2,692
Vinyl chloride	0.3	3.2	31.9		16.1	161	483
Adult Resident (vapor intrusion and indoor inhalation)							
	$1x10^{-6}$	**$1x10^{-5}$**	**$1x10^{-4}$**		**0.1**	**1**	**3**
Tetrachloroethene	5.2	52.2	522		501	5,010	15,030
Trichloroethene	26.9	269	2,693		55.4	554	1,662
cis-1,2-Dichloroethene	--	--	--		139	1,390	4,170
Vinyl chloride	1.3	13.0	130		38.3	383	1,149
Child Resident (vapor intrusion and indoor inhalation)							
	$1x10^{-6}$	**$1x10^{-5}$**	**$1x10^{-4}$**		**0.1**	**1**	**3**
Tetrachloroethene	8.9	89.5	895		215	2,147	6,441
Trichloroethene	46.2	462	4,616		23.7	237	712
cis-1,2-Dichloroethene	--	--	--		59.6	596	1,788
Vinyl chloride	2.2	22.2	222		16.4	164	492
Industrial Worker (vapor intrusion and indoor inhalation)							
	$1x10^{-6}$	**$1x10^{-5}$**	**$1x10^{-4}$**		**0.1**	**1**	**3**
Tetrachloroethene	20.8	208	2,080		2,080	20,795	62,386
Trichloroethene	108	1,076	10,758		231	2,305	6,916
cis-1,2-Dichloroethene	--	--	--		412	4,120	12,360
Vinyl chloride	10.4	104	1,044		161	1,608	4,823

Table 2-3
Comparison of Site Concentrations to CAOs
SWMU 360 CMS
MCB Camp Lejeune

	CAO		Maximum Site Concentrations			
	Target Cancer Risk	Hazard Quotient	Shallow Aquifer		Intermediate Aquifer	
	1.00E-04	1	Historical	Current	Historical	Current
Tetrachloroethene	24.0	428	5100	3100	10	9.3
Trichloroethene	587	129	460	200	10	4.7
cis-1,2-Dichloroethene	--	897	750	370	37	31
Vinyl chloride	31.9	161	ND	2.8	2	0.58

ND = none detected

SECTION 3

Identification, Screening and Development of Corrective Measures Alternatives

3.1 Identification and Screening of Remedial Technologies and Process Options

Remedial technologies and process options applicable to the media cleanup objectives for groundwater were identified. Each remedial technology type and process option is either a demonstrated process or a promising process that has been shown to be effective in laboratory trials or bench-scale testing. Technologies or process options evaluated are those considered technically appropriate considering physical site conditions, the contaminant characteristics, and the presence of other contaminants that could interfere with or otherwise limit the effectiveness of the technology.

As described in the Camp Lejeune Part B RCRA Permit, the technology types and process options are screened on the basis of the qualitative evaluation of four criteria: performance, reliability, implementability, and safety. Relative cost is also used in the evaluation of technology options.

- **Performance** refers to effectiveness of the technology, i.e., the ability of the process option to perform adequately to achieve the media cleanup objectives alone or as part of an overall system, and to the length of time the level of effectiveness can be maintained.
- **Reliability** refers to whether the technologies have been used effectively under similar conditions, whether the failure of any one technology has an immediate effect on receptors, and whether the corrective measure has the flexibility to deal with uncontrollable changes at the site. Reliability also includes the frequency and complexity of necessary operations and maintenance activities.
- **Implementability** refers to the relative degree of difficulty expected in implementing a particular measure, in terms of practical, technical, regulatory, and/or schedule constraints.
- **Safety** refers to the potential hazards to nearby communities and environments, as well as site workers, during implementation.
- **Relative cost** is comparative only and judged similar to the performance criterion. It is used to preclude further evaluation of process options that are relatively high cost, when other alternatives are available which achieve comparable effectiveness.

The screening of technologies and process options for SWMU 360 are presented in **Table 3-1**. The remedial technologies and process options eliminated in the screening process are shaded in boldface font/type.

The remedial technologies retained from the screening process are summarized in **Table 3-2**.

3.2 Corrective Measures Alternative Development – Groundwater

The remedial alternatives presented and evaluated herein are intended to reduce dissolved-phase impacts within the highest concentration areas associated with the SWMU. Remediation of *all* VOC impacts exceeding NCGWQS downgradient of SWMU 360 is not cost-effective or practical, since the plume extends over 500 feet from the source. Current low-level impacts to groundwater away from the former UST location are considered minimal risk and will be addressed by monitored natural attenuation over time, once the source zone is addressed. Accordingly, the identification and screening of technology types and process options comprising this section are specifically focused on the portion of the groundwater plume exceeding the RGO of 24 ug/L, as described in Section 2.

Budgetary cost estimate summaries for each alternative are included in Appendix A. Costs are considered "order of magnitude" estimates, with an expected accuracy of –30% to +50%. Basic assumptions associated with each alternative are also included on the detail sheets. All capital cost estimates include a 15% contingency factor; operations and maintenance cost estimates also assume a 15% contingency factor.

3.2.1 Enhanced Reductive Dechlorination

Biodegradation of chlorinated solvents is well documented to occur in anaerobic conditions through a process known as reductive dechlorination. Reductive dechlorination is a process in which indigenous microorganisms (e.g., fungi, bacteria, and other microbes) degrade chlorinated organic contaminants found in the subsurface. During reductive dechlorination, also known as dehalorespiration, a carbon atom in the chlorinated solvent accepts an electron from an electron donor (reduction), causing the release of a chlorine atom (dechlorination). The more chlorine atoms a compound has, the more oxidized its carbon is, and therefore, the more susceptible it is to reductive dechlorination. For anaerobic biodegradation to be successful, adequate quantities of electron donors must come into contact with the active microbial consortia and the target contaminants. Not all natural groundwater systems have the essential microorganisms needed to achieve complete reductive dechlorination of PCE to ethene. *Dehalococcoides ethenogenes* (or similar species) is thought by some researchers to be needed to *completely* dechlorinate PCE to ethene, so at some sites, the addition of a microbial consortium containing *Dehalococcoides ethenogenes* may be an alternative to increase natural degradation of chlorinated compounds. No data exists concerning the presence of these microbes at SWMU 360. However, for the purposes of this CMS it is assumed that they are on site.

To support reductive dechlorination, a biological substrate is added to provide a source for hydrogen atoms to replace the chlorine atoms. The hydrogen atoms are a fermentation product of the biological substrate. Biological substrates have been successfully injected at Camp Lejeune Sites 89 and 35 using direct push methods, and direct push is also recommended for SWMU 360. A one-time application of 50% lactate and 50% emulsified soybean oil was assumed for SWMU 360 because of the relatively low CVOC impacts at

site. The prescribed mixture of oil and lactate is considered beneficial for enhancing the fraction of soluble electron donor, while also providing a long-term, slow release organic substrate. The target injection depth is 20 to 40 feet bgs, corresponding to the transition zone between the surficial and intermediate aquifer, where the bulk of the impacts have historically been detected. The target dose of substrate is based on an assumed 8% mobile porosity and an Enhanced Reductive Dechlorination (ERD) solution that is approximately a 1% mixture of emulsified soybean oil and lactate in water by volume. A conceptual layout of 20 direct push borings, spaced approximately 30 feet apart, is depicted in **Figure 3-1**. The target dose is 1,052 pounds of substrate per location (refer to Appendix B for dosage calculation spreadsheet). Groundwater samples will be collected on a quarterly basis for a period of one year following injection of the substrate and analyzed for VOCs and natural attenuation indicator parameters.

Effectiveness of bioremediation is contingent upon distribution of the substrate (limited by subsurface permeability and heterogeneity), presence of appropriate dechlorinating bacteria, and site geochemical conditions. Preliminary results from the Site 82 and 89 pilot tests indicate reductive dechlorination is occurring at Camp Lejeune.

The estimated time frame to complete injections at 20 locations is 14 days, using direct push.

3.2.2 Air Sparging

Air sparging is an in-situ technology involving the injection of air into the aquifer or water-bearing zone at a depth of at least 10 to 20 feet below the water table interface, and can be used to induce mass transfer (stripping) of VOCs from groundwater. Air sparging wells can be installed as either a series of vertical wells in a grid-like pattern or as a horizontal directionally drilled (HDD) well. Implementation of either vertical-well or horizontal-well air sparging includes: (1) installation of air sparge wells with screened intervals positioned below the contaminated target zone, and connected to a blower or air compressor through above-grade or below-grade system piping, (2) injection of air into the wells, which rises through the saturated zone in a complex and non-uniform series of finger-like channels, the path of which is strongly influenced by subsurface heterogeneity, and (3) installation of vapor collection probes using direct push methods around the perimeter of Building 1817 and/or 1855, and connecting to a small blower housed in a shipping container or similar temporary building.

Because the target plume underlies Duncan Street and a portion of Building 1855 to the south, HDD is considered the preferred option for air sparge implementation at SWMU 360. A conceptual layout for an HDD sparge well with approximately 200 feet of "screen" (slotted pipe) and 280 feet of casing is illustrated on **Figure 3-2**. The well would be "blind ended" in order to avoid creating a pathway for vapors to follow the casing beneath Building 1855.

A compressor capable of 100 standard cubic feet per minute (scfm) would be needed to supply the air for the horizontal well which assumes 0.5 scfm per foot of "screen". Because the target area is in a relatively high-traffic area, the use of shallow conveyance piping/trenching will be minimized. Target depth of the sparge well is 55 feet bgs.

Air sparging of VOC plumes is well known, with numerous field applications successfully completed, including Site 86. Air sparging through an HDD well at Site 86 achieved greater than 98% reduction in VOCs. Hydraulic conductivities in the intermediate aquifer zones at

SWMU 360 and Site 86 are very similar. Use of horizontal wells would minimize site disturbance and maximize air contact with the plume (the bulk of which is 25 to 40 feet bgs), for the purpose of mass transfer and volatilization.

The time frame to complete installation of the horizontal well is estimated to be 10 days. The compressed air system would be operated continuously for at least one year. Air sparging is a well known technology with numerous field applications, which primarily used vertical sparge wells. There are currently a limited number of vendors that can install HDD sparge wells, which could affect project schedule or cost.

3.2.3 In-Situ Chemical Oxidation Using Permanganate

In-situ chemical oxidation (ISCO) involves delivering chemical oxidants into the groundwater so that contaminants are completely oxidized into carbon dioxide or converted into innocuous compounds. There are a number of chemicals that successfully degrade chlorinated solvents via chemical oxidation. Permanganate is an oxidizing agent with a unique affinity for organic compounds containing carbon double bonds, such as PCE and TCE. The oxidation strength and specificity of the permanganate ion improves its longevity, relative to non-specific oxidizers, such as hydroxyl radicals and ozone.

Two permanganate compounds are commonly used in the environmental industry: potassium and sodium permanganate. The associated cation (sodium or potassium) has no bearing on the oxidation strength of the permanganate ion. Potassium permanganate comes in crystalline form and can be mixed in concentrations up to 5%. Sodium permanganate comes in liquid form at a concentration of 40% (by weight), but the typical concentration for sodium permanganate injections is less than 25%. Either compound can be used; however, potassium permanganate is much safer to handle in the field and therefore use of this material is assumed for the cost estimate.

The permanganate solution (5%) will be injected using direct push methods. The target vertical interval is the same as that used for ERD: 20 to 40 feet bgs. A value of 8% mobile porosity was also assumed. The layout of direct push borings would be identical to that shown **Figure 3-1** (20 direct push borings, spaced approximately 30 feet apart). The target dose is 764 pounds or 1,740 gallons of substrate per location (refer to Appendix C for dosage calculation spreadsheet). Groundwater samples will be collected on a quarterly basis for a period of one year following injection of the substrate and analyzed for VOCs and natural attenuation indicator parameters.

TABLE 3-1
Initial Screening of Remedial Technologies and Process Options
SWMU 360 CMS
MCB Camp Lejeune

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Comments	Retain for Further Evaluation
Institutional Controls	***Access and Use Restrictions***	Land Use Controls	Land Use Controls issued for property within potentially contaminated areas to restrict property use and well installation	Prevents human exposure	Yes
		Fences	Security fences installed around potentially contaminated areas to limit access.	Not applicable to site contamination.	No
	Alternative Drinking Water Source	Cisterns or Tanks	Drinking water is dispensed to users from a central point.	Not applicable, no drinking water wells affected	No
		Bottled Water	Drinking water is obtained from a commercial vendor.	Not applicable, no drinking water wells affected	No
		Deeper or Upgradient Wells	Wells are installed deep or upgradient if these areas are isolated from contamination	Not applicable, no drinking water wells affected	No
		Relocation of Intake	Intake is relocated to an uncontaminated area	Not applicable, no drinking water wells affected	No
		Municipal Water Supply	Additional water sources are established	Not applicable, no drinking water wells affected	No
Monitoring	***Monitoring***	Monitoring	Short- and/or long-term monitoring is implemented to record site conditions and contamination and groundwater levels.	Potential approach for use with natural attenuation. Will be a component of any remedial alternative.	Yes
Containment	Vertical Barriers	Soil-Bentonite Slurry Wall	Trench downgradient of contaminated area excavated and filled with a bentonite slurry. Trench backfilled with a soil-bentonite mix.	Containment of the plume will not achieve clean-up objectives.	No
		Cement-Bentonite Slurry Wall	Trench downgradient of contaminated area excavated and filled with a cement bentonite water slurry. Cement sets and forms the wall.	Containment of the plume will not achieve clean-up objectives	No

TABLE 3-1
Initial Screening of Remedial Technologies and Process Options
SWMU 360 CMS
MCB Camp Lejeune

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Comments	Retain for Further Evaluation
Containment (cont'd)	Vertical Barriers (cont'd)	Permeable Reactive Barrier (PRB)	Trench downgradient of contaminated area filled with permeable materials, such as ZVI or mulch/compost with a sand/gravel "binder" material. Groundwater is treated as it moves through the barrier by natural gradient.	Containment of the plume will not achieve clean-up objectives.	No
		Grout Curtains	Grout is pressure-injected along contamination boundaries in a regular overlapping pattern of drilled holes.	Containment of the plume will not achieve clean-up objectives	No
		Sheet/Piling "Funnel and Gate"	Steel sheet piling driven at downgradient periphery of the plume, with "gate" containing groundwater purge wells or permeable barrier.	Containment of the plume will not achieve clean-up objectives.	No
	Horizontal Barriers	Block Displacement	Controlled injection of slurry in notched injection holes produces a horizontal barrier beneath contamination. Experimental process option.	Containment of the plume will not achieve clean-up objectives	No
		Grout Injection	Grout pressure injected at depth through closely spaced drilled holes.	Not appropriate for groundwater contamination.	No
		Liners	Liners placed to restrict vertical flow can be constructed of the same materials considered for cap construction.	Will not achieve groundwater cleanup objectives, but would reduce infiltration. Not as cost-effective as surface pavement.	No
Removal	Groundwater Extraction	Conventional Pump/Treat (vertical wells)	Conventional groundwater extraction involves pumping in vertical wells. Other extraction devices include vacuum enhanced recovery, jet-pumping systems, etc. Extracted groundwater may be discharged to a sanitary sewer, or treated as required and then discharged, or treated and re-injected.	Ineffective for treatment if dissolved plumes within lower permeability materials. Requires operation of long-term groundwater pump and treatment system. Containment of the plume will not achieve clean-up objectives.	No

TABLE 3-1
Initial Screening of Remedial Technologies and Process Options
SWMU 360 CMS
MCB Camp Lejeune

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Comments	Retain for Further Evaluation
Removal (cont'd)	Groundwater Extraction (cont'd)	Vacuum Enhanced Recovery	Application of strong vacuum to recovery wells can be used to enhance the capture zone and yield of groundwater recovery wells.	Commonly used for remediation of low transmissivity, perched water bearing zones. Ineffective for treatment of saturated zones which are not readily dewatered. Offers no advantage over conventional pump and treat at SWMU 360, groundwater production would be significant. Requires operation of long-term groundwater pump and treatment system.	No
		Horizontal Wells	Directionally drilled horizontal wells to increase groundwater capture.	Groundwater pump and treat (containment) will not achieve clean-up goals.	No
		One-pass trenching	Groundwater collection technique to increase production rate from low permeability areas.	May be used with PRB (see previous). No effective for groundwater extraction/removal.	No
		Drains	Underground gravel-filled trenches generally equipped with tile or perforated pipe are installed to collect contaminated groundwater and leachate.	Not effective for groundwater capture in low permeability formations.	No
Treatment	In-situ Biological Treatment	***Anaerobic Bioremediation (Enhanced Reductive Dechlorination)***	Injection of electron acceptor (oxygen) to enhance aerobic biodegration.	Aerobic bioremediation is a potential option for treatment of cis-1,2-DCE and CV. Retained with air sparge alternative.	No
		Phytoremediation	Use of plants and their associated rhizospheric microorganisms to remove, degrade, or contain chemical contaminants in groundwater.	Depth to water is too deep for phytoremediation to be effective.	No
	In-situ Physical Chemical Treatment	In-situ Physical Chemical Treatment	Creation of apertures in the soil to enhance bulk permeability, using pressurized gas or liquid slurry	Pneumatic fracturing is an effective method to enhance secondary permeability of "tight" soils. Fracturing at depths less than 20 feet bgs may result in "daylighting". This technology has been used successfully at Site 89 to enhance secondary permeability in the Surficial Aquifer	No

TABLE 3-1
Initial Screening of Remedial Technologies and Process Options
SWMU 360 CMS
MCB Camp Lejeune

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Comments	Retain for Further Evaluation
Treatment (cont'd)	In-situ Physical Chemical Treatment (cont'd)	In-situ Physical Chemical Treatment (cont'd)		Conventional hydraulic fracturing is considered prohibitively expensive and time consuming for implementation over large areas. localized hydraulic fracturing using a geoprobe and high pressure pumps is possible, although results tend to be erratic. "Fracturing" using direct push methods has not been evaluated at the Base. Not recommended.	No
		Soil Vapor Extraction	Air is extracted from the subsurface under vacuum to remove contaminants via mass transfer	Soil vapor extraction of chlorinated solvents is used to remove solvents via in-situ mass transfer ("stripping"). Because of the presence of clay in some areas of the vadose zone at SMWU 360, SVE is not recommended unless fracturing is performed to enhance secondary permeability. Based on CH2M HILL's previous experience, pneumatic fractures tend to "close": under vacuum, and proppant filled hydraulic fracturing is prohibitively expensive for smaller sites. Pneumatic fracturing is best combined with pressurized air injection in the vadose zone and/or saturated zone (sparging). Vapor extraction in shallow collector wells can also be performed to mitigate fugitive vapor migration.	No
		Soil Mixing	Impacted soil column is homogenized using large diameter augers or other mechanical devices such as the Lang Tool. Chemical oxidation reagents, reduction reagents, or biological substrates are typically mixed with the soil. Effective for treatment of low permeability/heterogeneous materials.	Soil mixing, combined with zero valent iron, was pilot tested at Site 88. Prohibitively expensive for treatment of low level impacts at SWMU 360	No

TABLE 3-1
Initial Screening of Remedial Technologies and Process Options
SWMU 360 CMS
MCB Camp Lejeune

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Comments	Retain for Further Evaluation
Treatment (cont'd)	In-situ Physical Chemical Treatment (cont'd)	***Air Sparging***	Air is injected into saturated soil to remove contaminants via mass transfer.	Air sparging is used to remove solvents via mass transfer ("stripping"). Effectiveness decreases in low permeability of heterogeneous materials because of low air channel density and/or "bypassing" of dense soils. Silty sands can be effectively sparged, as proven at Sites 86, 89 and 73; dense clays will resist treatment. Clay at SWMU 360 is primarily restricted to the vadose zone. Pneumatic fracturing can be used to enhance effectiveness in clays.	Yes
		Electrical Resistive Heating (ERH)	A thermal remediation technology which involves installation of electrodes in hexagonal or three point arrays and application of high voltage electrical power to cause boiling of volatile compounds in groundwater. Volatilized compounds are removed by SVE, treated, and discharged under permit.	ERH was pilot tested at Site 89 in 2003 (refer to Section 2.2). Prohibitively expensive for treatment of low level impacts at SWMU 360.	No
		Thermal Conduction Heating (TCH)	Also referred to as In Situ Thermal Desorption (ISTD), TCH is a thermal technology comparable to ERH. TCH involves heating the soil in-situ by conduction/convection, using heaters installed at relatively close spacing. Although it can be more expensive, TCH is capable of producing much higher temperatures than ERH and is generally considered a more "aggressive" thermal technology than ERH.	Prohibitively expensive for treatment of low level impacts at SWMU 360.	No

TABLE 3-1
Initial Screening of Remedial Technologies and Process Options
SWMU 360 CMS
MCB Camp Lejeune

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Comments	Retain for Further Evaluation
Treatment (cont'd)	In-situ Physical Chemical Treatment (cont'd)	Steam Injection	The third commonly applied thermal technology, steam injection entails the introduction of hot air and team to boil off contaminants. Contaminants mobilized from the subsurface are subsequently collected in dual-phase (liquid and vapor) extraction wells located near the steam injection point. Equally effective in both saturated and unsaturated zones, and can be used in heterogeneous site conditions with careful design. However, the efficiency of steam injection for subsurface heating is reduced in zones of low permeability. System infrastructure typically consists of a steam generation plant, injection/extraction well field, and a groundwater and condensable vapor treatment plant. The well field (generally constructed of stainless steel, which increase costs significantly) is designed to both inject steam and to extract groundwater and vapors from the contaminated subsurface. The treatment plant is used to treat or reclaim contaminated water, vapor, or free-phase NAPL liberated from the well field before discharge.	Prohibitively expensive for treatment of low level impacts at SWMU 360.	No
		Surfactant, Cosolvent Flushing ("SEAR")	Introduction of a surfactant solution which enhances solvent solubility, mobility, transport and recovery, particularly in DNAPL impacted zones in sandy formations. Generally involved closely spaced injection/recovery wells and discrete injection/recovery events, as opposed to continuous pump and treat. The "SEAR" (surfactant enhanced aquifer remediation) technology was previously tested in the Surficial Aquifer at Site 88.	Surfactant flooding was not effective at Site 88, and is generally not recommended for application in low permeability, heterogeneous soils, where dense materials are bypassed by the injected solution.	No

TABLE 3-1
Initial Screening of Remedial Technologies and Process Options
SWMU 360 CMS
MCB Camp Lejeune

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Comments	Retain for Further Evaluation
Treatment (cont'd)	In-situ Physical Chemical Treatment (cont'd)	***In-Situ Chemical Oxidation***	Injection of oxidizing agents (Fenton's reagent, permanganate, ozone) to promote abiotic in-situ destruction of chlorinated organic compounds.	Chemical oxidation of PCE impacts in groundwater is feasible, although scavenging associated with natural TOC is expected, and rebound will likely occur. Half life of various oxidants is expected to be short (i.e. a few months or less). The technology is included in this CMS as a possible alternative.	Yes
		In-Situ Chemical Reduction	Injection of reducing agents (zero-valent iron) to promote abiotic in-situ destruction of chlorinated organic compounds.	Use of nano-scale ZVI at SWMU 360 is considered prohibitively expensive, and effectiveness is not well established. Micro-scale ZVI would need to be emplaced using soil mixing or fracturing methods, both of which are considered prohibitively expensive. preliminary data for the "Ferox" pilot study at Site 89 also indicates less than satisfactory performance.	No
		Hot Water or Steam Flushing, Stripping	Steam is forced into the aquifer through injection wells to vaporize volatile and semivolatile contaminants. Vaporized components rise to the unsaturated zone, where they are removed by vacuum extraction and treated.	Cost prohibitive and impractical for small sites.	No
	Ex-situ Physical, Chemical Treatment	Chemical Reduction	Reducing agents (zero-valent iron) are used to destroy organic contaminants in an ex-situ reactor.	Requires pump and treat for groundwater capture and recovery. Pump and treat is not effective in heterogeneous, low permeability materials.	No

TABLE 3-1
Initial Screening of Remedial Technologies and Process Options
SWMU 360 CMS
MCB Camp Lejeune

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Comments	Retain for Further Evaluation
Treatment (cont'd)	Ex-situ Physical, Chemical Treatment	Air Stripping	Volatile organics are partitioned from groundwater by increasing the surface area of the contaminated water exposed to air. Aeration methods included packed towers, diffused aeration, tray aeration, and spray aeration. Emissions from the air stripping system need to be monitored and may need to be treated to conform with federal (Clean Air Act) and local air emission monitoring requirements	Requires pump and treat for groundwater capture and recovery. Pump and treat is not effective in heterogeneous, low permeability materials.	No
		Filtration	Solid particles are isolated by running a fluid stream through a porous medium. The driving force is either gravity or a pressure differential across the filtration medium.	Not applicable for site contaminants.	No`
		Ion Exchange	Ions from the aqueous phase are removed by exchange with innocuous ions on the exchange medium	Not applicable for site contaminants	No
		Liquid-Phase Carbon Absorption	Groundwater is pumped through a series of canisters or columns containing activated carbon to which dissolved organic contaminants absorb. Periodic replacement or regeneration of saturated carbon is required. Wastes produced from the saturated carbon needs to be properly managed.	Requires pump and treat for groundwater capture and recovery. Pump and treat is not effective in heterogeneous, low permeability materials.	No
		Precipitation	Dissolved contaminants are transformed into an insoluble solid, facilitating the contaminants' subsequent removal from the liquid phase by sedimentation or filtration. Usually includes pH adjustment, addition of a chemical precipitant, and flocculation.	Not applicable for site contaminants	No

TABLE 3-1
Initial Screening of Remedial Technologies and Process Options
SWMU 360 CMS
MCB Camp Lejeune

General Response Actions	Remedial Technology Types	Process Options	Descriptions	Comments	Retain for Further Evaluation
	Ex-situ Thermal Treatment	On-Site Thermal Desorption	Thermal desorption is a physical separation process, and is not designed to destroy organics. Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system. The bed temperatures and residence times designed into these systems will volatilize selected contaminants but will typically not oxidize them, especially low temperature thermal desorption (LTTD).	On-site thermal desorption was previously used at Site 89 to treat shallow impacted soils (0-5 ft. bgs). Considered cost prohibitive for SWMU 360 ($140-$180/CY, less excavation costs).	No
	Land Application	Land Application	Liquid wastes that are primarily organic are incorporated in to the upper soil horizon so they can be degraded, transformed or immobilized.	Requires pump and treat for groundwater capture and recovery.	No
Disposal	Wastewater Discharge	POTW	Wastewater is discharged to Base WW plant for treatment. Must comply with Base effluent standards.	Requires pump and treat for groundwater capture and recovery.	No
		Surface Waters	Wastewater is discharged to surface receiving streams. Must comply with NPDES permit standards and sampling requirements.	Requires pump and treat for groundwater capture and recovery.	No
		Reinjection	Treated groundwater is reinjected into on-site wells. Federal and state regulations are very restrictive.	Requires pump and treat for groundwater capture and recovery.	No
		Deep Well Injection	Wastewater is injected into Class I wells. Federal and state regulations are very restrictive.	Requires pump and treat for groundwater capture and recovery.	No
		Evaporation Ponds	Surface impoundments are used to contain treated or untreated wastewater or groundwater until it evaporates.	Requires pump and treat for groundwater capture and recovery.	No

TABLE 3-2
Remedial Technologies Retained
SWMU 360 CMS
MCB Camp Lejeune

Groundwater
Groundwater Use Restrictions
Enhanced Reductive Dechlorination
Air Sparging
In-Situ Chemical Oxidation

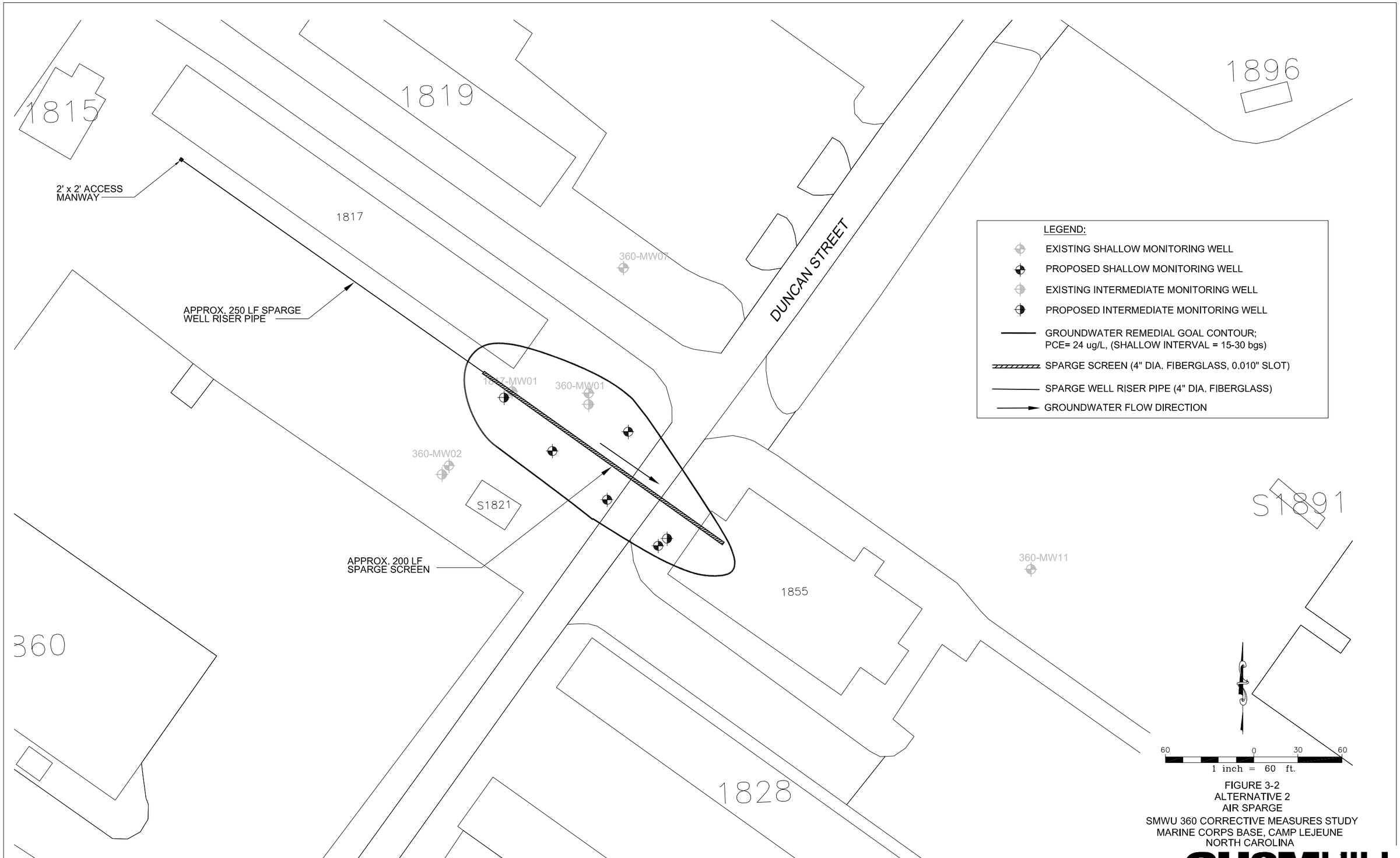


FIGURE 3-2
ALTERNATIVE 2
AIR SPARGE
SMWU 360 CORRECTIVE MEASURES STUDY
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

CH2MHILL

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SOURCE: BAKER, 2005

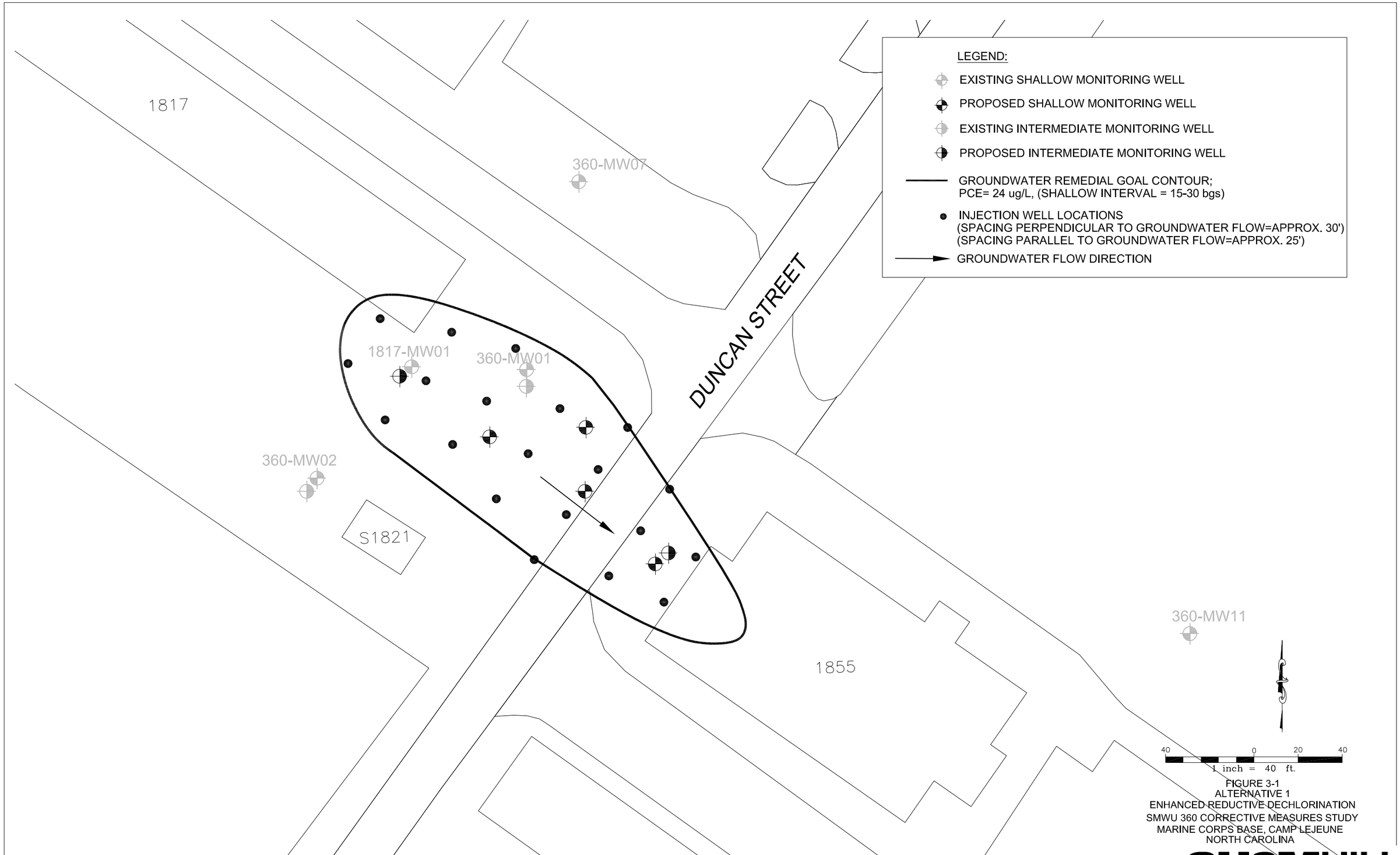

FIGURE 3-1
ALTERNATIVE 1
ENHANCED REDUCTIVE DECHLORINATION
SMWU 360 CORRECTIVE MEASURES STUDY
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

CH2MHILL

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SOURCE: BAKER, 2005

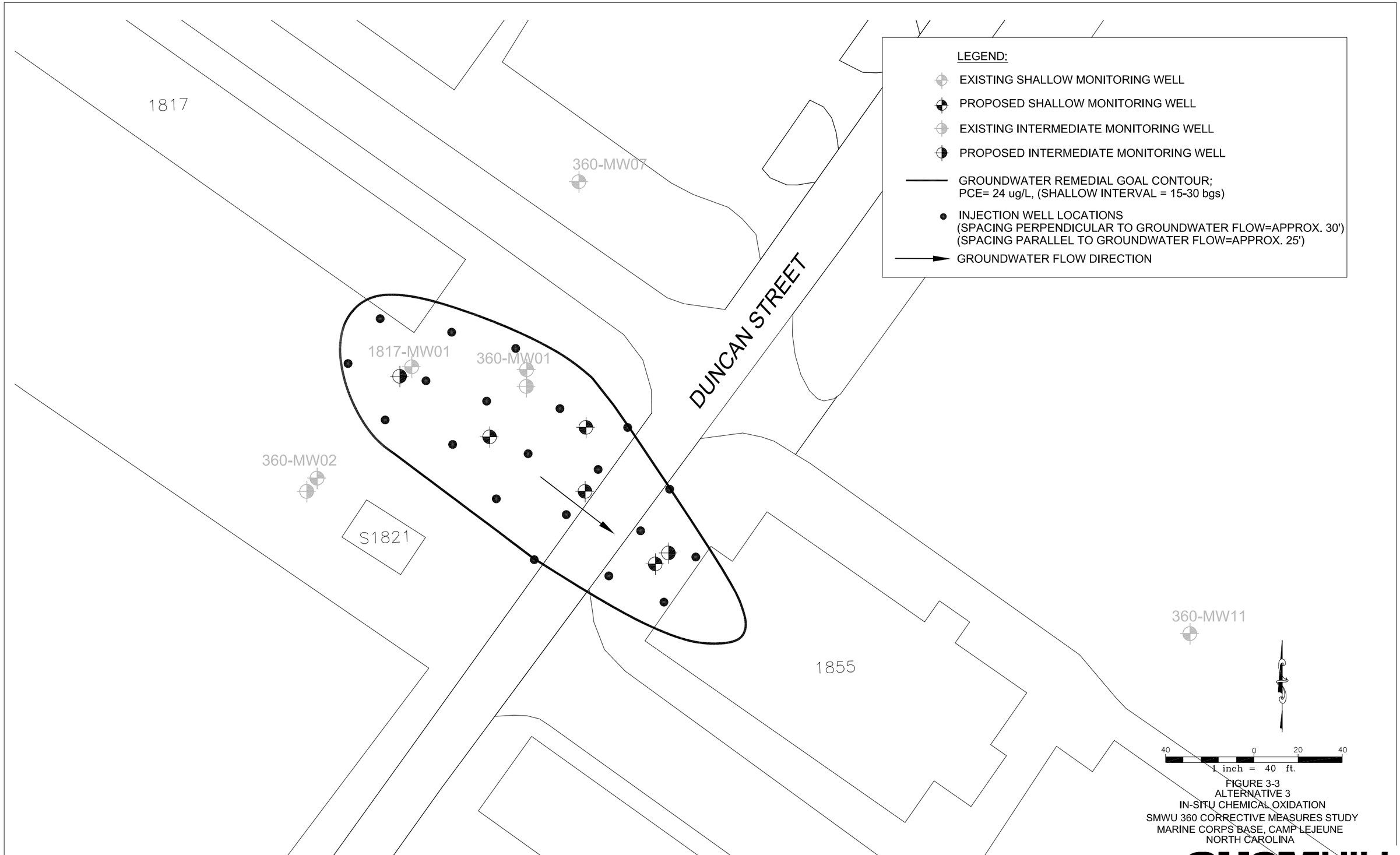

FIGURE 3-3
ALTERNATIVE 3
IN-SITU CHEMICAL OXIDATION
SMWU 360 CORRECTIVE MEASURES STUDY
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

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SOURCE: BAKER, 2005

CH2MHILL

SECTION 4

Detailed Analysis of Corrective Measure Alternatives

4.1 Introduction

The detailed analysis of the selected corrective measures alternatives is presented in two parts as follows:

- Evaluation of each corrective measures alternative in terms of prescribed evaluation criteria
- Comparative evaluation of the corrective measures alternatives against each other

These two levels of corrective measures evaluations are presented below.

4.2 Evaluation Criteria

The evaluation criteria are divided into two groups, threshold and balancing criteria. Threshold criteria must be met by a particular alternative for it to be eligible for selection as a corrective measure. Three performance standards are considered threshold criteria:

- Protect Human Health and the Environment
- Attain Media Cleanup Objectives
- Remediate Sources

The balancing criteria weigh the trade-offs between alternatives. A low rating on one balancing criterion can be compensated by a high rating on another. The balancing criteria include:

- Performance
- Reliability
- Implementability
- Safety
- Relative Cost

The evaluation criteria are defined in **Table 4-1**.

4.3 Detailed Evaluation of the Corrective Measures Alternatives

The following corrective measures alternatives for groundwater were developed and described in Section 3:

- Alternative 1—Anaerobic Bioremediation
- Alternative 2—Air Sparging

- Alternative 3—In-Situ Chemical Oxidation

Each alternative for groundwater assumes an indefinite period of monitored natural attenuation, which is not included in the cost comparison, since the associated long term expenditures will be equivalent.

These corrective measures alternatives were evaluated in detail using the evaluation criteria described in Section 4.2. The detailed evaluations for these corrective measures alternatives are presented in **Table 4-2**.

4.4 Comparative Evaluation of the Corrective Measures Alternatives for Groundwater

4.4.1 Enhanced Reductive Dechlorination

Implementation Concerns

Injection of biological substrate would be conducted using direct push methods, expected to be completed within 14 days. Impact to the site during this period is expected to be minimal (traffic control in isolated areas). The injection borings will be grouted upon completion of the work.

Effectiveness

The effectiveness of reductive dechlorination is dependent on contact with the aquifer. Direct push injections generally result in some degree of channelization/bypassing in heterogeneous formations (more so than air sparging). However, the technique is simple, cost effective, and emulsified vegetable oils (EVO) generally persist in the subsurface for more than a year (up to three years has been reported in some cases). The cost estimate prepared for this alternative assumes a one time injection of lactate and EVO. "Rebound" of PCE in groundwater over time is possible, as well as formation of undesirable "daughter" products, such as VC.

Cost

Capital cost is estimated to be $261,000 for injection of EVO/lactate at 20 locations, over a vertical interval of 20 feet (20 to 40 feet bgs). Cost associated with one year of monitoring is expected to be approximately $75,000.

4.4.2 Air Sparging

Implementation Concerns

The primary concern associated with air sparging at SWMU 360 is vapor intrusion in Buildings 1817 and/or 1855, both of which are occupied, with concrete slab on grade foundations. Soil gas monitoring would be performed to ensure vapor concentrations do not exceed applicable regulatory standards. If the results of vapor monitoring activity indicate corrective measures are required, the air sparge flow rate will first be adjusted (pulsing may also be considered) as an initial response action. The response action will be to install vapor collection probes using direct push methods around the perimeter of Building 1817 and/or 1855, connected to a small blower housed in a shipping container or similar temporary building.

Effectiveness

The effectiveness of air sparging using HDD has been proven elsewhere at the Base, where characteristic dense silty sand and cemented sands are present, and TCE levels close to or less than drinking water standards have been achieved, without the formation of undesirable "daughter" products. In these conditions, air sparging results in both increased lateral distribution of air and increased channel density, both of which improve performance. Sparged air will not penetrate dense silty clay overburden (vadose zone) soils at SWMU 360, and "breather" wells may need to be installed in this case, to permit the air to escape to atmosphere. A significant advantage of air sparging is that if "rebound" occurs, the system can be re-activated and operated until target levels are again achieved.

Cost

Capital cost is estimated to be $441,000 for installation of one blind end HDD sparge well, vapor control system, and several new monitoring wells. Cost associated with start-up and operation of the system for one year is estimated at $137,000.

4.4.3 In-Situ Chemical Oxidation Using Permanganate

4.4.3.1 Implementation Concerns

The primary concern associated with application of chemical oxidants at SWMU 360 is soil oxidant demand (SOD). SOD analytical results for samples collected from 14-18 ft bgs (direct push soil samples) were highly variable, ranging from < 1 g/kg to 15 g/kg. Although the referenced depth is representative of the vadose zone, variable SOD increases the likelihood that chemical oxidation treatment will result in non-uniform treatment, with potential long term "rebound". The injection approach and reagents used are relatively standard, with multiple vendors available.

4.4.3.2 Effectiveness

Permanganate reactions are effective over a wide range of pH (3.5 to 12) conditions, and have been shown to be effective at reducing concentrations of PCE and daughter products. Once the injections are complete, there are no other operational requirements, except monitoring.

Potassium permanganate was previously used at Site 35 with limited success. Based on the Site 35 pilot study, permanganate would be expected to persist in the subsurface for a period of one to two months, increasing the likelihood of contaminant "rebound".

4.4.3.3 Cost

Capital costs associated with injection of potassium permanganate are estimated at $278,000. The cost associated with operation and maintenance for one year is estimated at $69,000 for all of the injection scenarios.

TABLE 4-1
Detailed Evaluation Criteria
SWMU 360 CMS
MCB Camp Lejeune

Performance Standards	
Protect Human Health and the Environment	Protectiveness is the primary requirement that remedial actions must beet under Resource Conservation and Recovery Act Sections 3004 and 3008. A remedy is protective if it adequately eliminates, reduces, or controls all current and potential risk posed by the site through each exposure pathway. The assessment against this criterion describes how the alternative achieves and maintains protection of human health and the environment.
Attain Media Cleanup Objectives	Media cleanup objectives include media cleanup levels, points of compliance and the remediation time frames. The media cleanup objectives should be appropriate to the anticipated land use and current and potential beneficial uses of water resources.
Remediation of Sources	Remediation of sources to the extent practicable to minimize release that might pose a threat to human health or the environmental is considered by the U.S. EPA to be a critical part of corrective action activities. A source includes both the original location of the release as well as locations where significant mass of contaminants have migrated.
Balancing Criteria	
Performance	This criterion refers to effectiveness of the technology, i.e., the ability of the process option to perform adequately to achieve the media cleanup objectives alone or as part of an overall system, and to the length of time the level of effectiveness can be maintained.
Reliability	Reliability indicates whether the technologies have been used effectively under similar conditions, whether the failure of any one technology has an immediate effect on receptors, and whether the corrective measure has the flexibility to deal with uncontrollable changes at the site. Reliability also includes the frequency and complexity of necessary operations and maintenance activities.
Implementability	Implementability addresses the ease or difficulty of remedy implementation, considering, as appropriate, the technical feasibility of constructing, operating and monitoring the remedy; the administrative feasibility of coordinating with and obtaining the necessary approvals and permits from regulatory agencies; and availability of services and materials, including capacity and location of needed treatment, storage and disposal services.
Safety	Safety relates to the potential hazards to nearby communities and environments during implementation. It includes hazards associated with site workers during the construction, operation and maintenance activities.
Relative Cost	Cost of estimates are based on conceptual descriptions of the corrective measures. They are order-of-magnitude (+50 percent and -30 percent) level cost estimates. They include the following: direct capital costs, indirect costs such as engineering fees, operation and maintenance costs and present worth costs of capital and operations and maintenance (maximum period of 50 years and a discount rate of 3.9 percent used per EPA guidance). The cost estimates used in the Corrective Measures Study are for comparative purposes only and should not be used to construction budgeting.

TABLE 4-2
Comparative Analysis of Remedial Alternatives
SWMU 360 CMS
MCB Camp Lejeune, North Carolina

Evaluation Criteria	Alternative 1 Enhanced Reductive Dechlorination	Alternative 2 Air Sparging	Alternative 3 In-Situ Chemical Oxidation
PERFORMANCE STANDARDS			
Protection of Human Health and the Environment	Protects human health by reducing source area dissolved impacts within a relatively short period of time (generally one year or less) Potential for formation of cis-1-2 DCE and VC plumes in some cases.	Protects human health by reducing source area dissolved impacts within a relatively short period of time (generally one year or less). No "daughter" products are produced by the process. However, the potential exists for vapor intrusion in adjacent buildings.	Protects human health by reducing source area dissolved impacts via electron transfer to promote chemical oxidation. Potassium permanganate will oxidize VOCs, resulting in non-toxic by-products.
Attain Media Cleanup Objectives	Potential to achieve media cleanup objectives in short period of time (one year). "Rebound" is possible in heterogeneous materials. Does not address capillary fringe zone impacts.	Potential to achieve media cleanup objectives in short period of time (one year). "Rebound" is possible in heterogeneous soils, although continued low cost operation of the sparge system will typically address this issue.	Potential to achieve media cleanup objectives in short period of time (one year). "Rebound" is possible in heterogeneous materials. Does not address capillary fringe zone impacts.
Remediation of Sources	Directly remediates source areas in groundwater.	Directly remediates source areas in groundwater.	Directly remediates source areas in groundwater.
BALANCING CRITERIA			
Performance	Permanent removal of source zone impacts, assuming daughter products are fully degraded. This alternative assumes one-time injection. Remediation expected within a year, although "rebound" of groundwater impacts is possible over the long term.	Permanent removal of source zone impacts in both the saturated zone and capillary fringe. Remediation expected within a year. Should "rebound" occur, it can be managed by re-activation of the system at minimal cost.	Permanent removal of source zone impacts, assuming daughter products are fully degraded. ISCO should be very effective in removing contaminant mass and reducing COC concentrations. This alternative assumes one-time injection. Remediation expected within a year, although "rebound" of groundwater impacts is possible over the long term.
Reliability	Bioremediation with biological substrate addition has been successful at other sites within Camp Lejeune.	Air sparging of VOCs using horizontal wells has been conducted successfully at other sites within Camp Lejeune. Blind end wells are not as common, and are more difficult to install.	Permanganate injections have been successful at other sites within Camp Lejeune.

TABLE 4-2
Comparative Analysis of Remedial Alternatives
SWMU 360 CMS
MCB Camp Lejeune, North Carolina

Evaluation Criteria	Alternative 1 Enhanced Reductive Dechlorination	Alternative 2 Air Sparging	Alternative 3 In-Situ Chemical Oxidation
Implementability	Readily implemented, with minimal impact to site operations. Direct push methods would be used for substrate injections.	Readily implemented, with minimal impact to site operations. Horizontal directional drilling techniques would be used to install the sparge well, used successfully at Site 73, 86, and 89. Shallow vapor probes would be installed to monitor sparge pressures and VOC off-gas concentrations	Readily implemented, with minimal impact to site operations. Direct push methods would be used for substrate injections.
Safety	Limited health and safety issues other than usual drilling safety, utility clearance, etc	Limited health and safety issues other than usual drilling safety, utility clearance, etc. If not combined with a surface cover and vapor collection system, vapor intrusion can be an issue.	Limited health and safety issues other than usual drilling safety, utility clearance, etc
Relative Cost	$261,000 (capital)	$441,000 (capital)	$278,000 (capital)
	$75,000 (one year O&M)	$137,000 (one year O&M)	$69,000 (one year O&M)
	(subsequent MNA expected to be slightly less)	(subsequent MNA expected to be less than $50,000 per year)	(subsequent MNA expected to be slightly less)

SECTION 5

Conclusions

The main conclusions of the CMS for SWMU 360 are as follows:

- The area of the groundwater plume exceeding risk based (Industrial worker exposure scenario) groundwater criteria is approximately 18,000 ft^2.
- Each of the groundwater remediation alternatives meet the threshold performance standards of protection of human health and the environment and attainment of cleanup objectives with MNA of the off-site plume. Alternative 1—Enhanced Reductive Dechlorination achieves cleanup objectives by in-situ degradation of PCE. Institutional controls preventing installation of new groundwater drinking wells are implemented through a site-specific LUCIP. Alternative 2—Air Sparging achieves objectives by mass transfer (stripping) of PCE from groundwater to the atmosphere, with remediation of the capillary fringe over time. Alternative 3— In-Situ Chemical Oxidation achieves objectives by injecting permanganate into the aquifer, oxidizing contaminants into carbon dioxide or converted into innocuous compounds
- Field evaluations of each of the three alternatives described in this CMS have been conducted at Camp Lejeune. Of the three, air sparging achieved the most consistent performance, in terms of uniform treatment and mass removal; at Site 86 and Site 89. ERD at Site 82 and Site 89 has also performed well (to date), although distribution of the substrate has been somewhat erratic in the dense silty sands. Performance of chemical oxidation at Site 35 was mixed. Persistence of chemical oxidation reagents, including permanganate was relatively poor. "Rebound" is considered more likely to be a long term problem with chemical oxidation, and, to a lesser extent, ERD.
- Total costs associated with ERD and chemical oxidation are similar. However, both methods are one time injection approaches, with associated increased risk of contaminant "rebound" over time. Air sparging, while more expensive, tends to penetrate the formation more uniformly, and, in the event rebound occurs, the system can be reactivated at low cost. Sparging will also purge VOCs from the capillary fringe, and, to a lesser extent, the vadose zone (depending on air conductivity). Sparging may effect vapor intrusion at Buildings 1817 or 1855. The total cost of air sparging is approximately 60% greater than the other two alternatives, because of increased capital and operations expenditures; operations cost for Alternatives 1 and 3 is limited to monitoring only.
- Each of these alternatives involve MNA for the remainder of the plume that exceeds NC 2L standards. Monitoring for the effectiveness of either of the groundwater alternatives would be included with monitoring the lower level contamination areas.

SECTION 6

References

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APPENDIX A

Detailed Cost Tables

APPENDIX A
DETAILED COST ESTIMATE - ERD
SWMU 360, CAMP LEJEUNE

Assumptions:
One time application of 50/50 emulsified oil and ethyl lactate at 20 direct push locations from 20 to 40 feet bgs, plus monitoring for one year

CAPITAL COSTS

Description	Qty	Unit	Unit Cost	Cost	Comments
Injection Set-Up and Performance					
Submittals, Work Plan, HASP	1	LS	$7,500	$7,500	Engineer's Estimate
Installation of New Monitoring Wells (flush mount w/ concrete pads)	4	wells	$2,900	$11,600	Engineer's Estimate
Utility Location	1	LS	$2,000	$2,000	Engineer's Estimate
Materials - Ethyl Lactate, incl shipping	13,700	lbs	$1.45	$19,865	Dosage is 685# per location, 20 locations, assumes 15' ROI
Materials - Emulsified Soybean Oil, incl shipping	7,340	lbs	$1.80	$13,212	Dosage is 367# per location, 20 locations, assumes 15' ROI (50% by wt solution)
Injection Labor (Direct Push, 20 Borings)	14	days	$7,000	$98,000	Budgetary Estimate, assume 14 days to complete injections*
Injection Oversight Labor					
Engineer/Hydrogeologist	140	hr	$85.00	$11,900	1 Staff, 10 Hour days
Per Diem	14	Days	$150	$2,100	1 Staff + Rental Truck
As Built Survey	1	LS	$2,500	$2,500	Engineer's Estimate
Subtotal *Injection Set-Up and Performance*				$168,677	
Professional Services					
Project Management			10%	$16,868	
Remedial Design			5%	$8,434	
Construction Management and Procurement			5%	$8,434	
G&A			10%	$16,868	
Profit			10%	$16,868	
Contingency			15%	$25,302	
Subtotal *Professional Services*				$92,772	
TOTAL CAPITAL COST				**$261,449**	

YEAR 1 MONITORING

Item/Activity	Qty	Unit	Unit Cost	Cost	Comments
Groundwater Sampling (Quarterly)					
Sample Labor, Travel, Perdiem	4	events	$3,600	$14,400	
Sample Analysis - Subcontractor	36	samples	$100	$3,600	9 samples/round TCL Volatiles
Sample Analysis - Subcontractor	24	samples	$220	$5,280	6 samples/round MNA Parameters
GW Sampling Equipment Rental	4	rounds	$600	$2,400	
Subtotal *Groundwater Sampling*				$25,680	
Reporting (4 Quarterly Reports and Detailed Study)					
Reporting Labor (quarterly reports)	4	rpts	$5,000	$20,000	
Reporting Labor (detailed study)	1	rpt	$10,000	$10,000	
Subtotal *Reporting*				$30,000	
Subtotal				$55,680	
Project Management			10%	$5,568	
Engineering Support			10%	$5,568	
Contingency			15%	$8,352	
TOTAL YEAR 1 OPERATIONS AND MAINTENANCE COST				**$75,168**	
TOTAL COST				**$336,617**	

Costs are considered "order-of-magnitude" estimates, with an expected accuracy of -30% to +50%.
* Assumes 8 gpm injection rate (minimum) at each location, single injection rig

APPENDIX A
DETAILED COST ESTIMATE - Air Sparge
SWMU 360, CAMP LEJEUNE

Assumptions:
Installation of blind end HDD sparge well to 55 feet bgs with 200 feet of slotted pipe (fiberglass) and operation for one year

CAPITAL COSTS

Description	Qty	Unit	Unit Cost	Cost	Comments
*Subcontractor Construction Services**					
Mobilization and Site Setup	1	EA	$12,000	$12,000	Engineers estimate
Utility Location	1	LS	$7,500	$7,500	Engineer's Estimate
Installation of New Monitoring Wells (flush mount w/ concrete pads)	4	wells	$2,900	$11,600	Engineer's Estimate
Installation of Vapor Collection Points (Direct Push) Adjacent to Building 1817	8	points	$850	$6,800	Engineer's Estimate
Installation of HDD air sparge well to 55 feet bgs (one well, blind end construction, 470 feet total length)	470	LF	$250	$117,500	Based on verbal estimate by DTD (including decon, IDW contanerization, and well development)
HDPE Casing (4") + freight	270	LF	$6.00	$1,620	Based on verbal estimate by PQ Products
Custom Slotted Fiberglass Well Screen (0.010" slot) + freight	200	LF	$46.00	$9,200	Based on verbal estimate by PQ Products
HDPE Conveyance Piping Materials, Trenching, and Installation (Incl Vapor Collection Points)	300	LF	$50.00	$15,000	Engineer's Estimate
Transport & Disposal of Soil Cuttings	1	LS	$4,800	$4,800	(2) 20CY rolloffs with transport & disposal
30 HP Screw Air Compressor, 200 gallon receiver, condensate system, etc	1	ea	$16,000	$16,000	Based on verbal estimate by Onion Equipment
3 HP Regenerative Blower for Vapor Collection w/ Knock-Out Tank and Controls	1	ea	$12,000	$12,000	Based on verbal estimate by Onion Equipment
8' x 20' Shipping Container and Interior Manifold	1	ea	$22,000	$22,000	Based on verbal estimate by Onion Equipment
Electrical Power Drop, 460 V/3 ph/200 A Service, Transformers, Poles	1	LS	$25,000	$25,000	Engineer's Estimate, based on Site 86
Final Electrical Connections, Installation of Service Panel and Disconnect	1	LS	$8,000	$8,000	Engineer's Estimate, based on Site 86
Equipment Delivery	1	LS	$8,000	$8,000	Engineer's Estimate
Site Restoration	1	LS	$2,500	$2,500	Engineer's Estimate
Misc Piping, Fittings, Materials	1	LS	$2,500	$2,500	Engineer's Estimate
As-Built Survey	1	LS	$2,500	$2,500	Engineer's Estimate
Subtotal *Subcontractor Construction Services*				$284,520	
CH2M Hill					
Project Management			10%	$28,452	
Remedial Design			5%	$14,226	
Construction Management and Procurement			5%	$14,226	
G&A			10%	$28,452	
Profit			10%	$28,452	
Contingency			15%	$42,678	
Subtotal *CH2M HILL*				$156,486	
TOTAL CAPITAL COST				**$441,006**	

YEAR 1 OPERATIONS AND MAINTENANCE

Description	Qty	Unit	Unit Cost	Cost	Comments
Groundwater Sampling (Quarterly)					
Sample Labor, Travel, Perdiem	4	events	$3,600	$14,400	
Sample Analysis - Subcontractor	36	samples	$100	$3,600	9 samples/round TCL Volatiles
GW Sampling Equipment Rental	4	rounds	$600	$2,400	
Subtotal *Groundwater Sampling*				$20,400	
Reporting					
Reporting Labor (quarterly reports)	4	rpts	$5,000	$20,000	
Subtotal *Reporting*				$20,000	
System Startup					
Labor	1	weeks	$7,200	$7,200	
Startup Equipment Rental	1	weeks	$450	$450	
Travel and Perdiem	1	weeks	$5,000	$5,000	
Subtotal *System Startup*				$12,650	

APPENDIX A
DETAILED COST ESTIMATE - Air Sparge
SWMU 360, CAMP LEJEUNE

Routine System O&M			
Monthly O&M Labor + Travel (Subcontractor)	12 events	$1,250	$15,000
Vapor Sample Analysis	12 events	$625	$7,500
Quarterly "Heavy" Maintenance	4 events	$1,800	$7,200
Travel and PerDiem	4 events	$500	$2,000
O&M Supplies	1 LS	$2,000	$2,000
Subtotal *Routine System O&M*			$33,700
Consumeables			
Electrical usage (30.hp total motor peak rating)	195348 kw-hr	$0.075	$14,651
Subtotal *Consumeables*			$14,651
Subtotal			$101,401
Project Management		10%	$10,140
Engineering Support		10%	$10,140
Contingency		15%	$15,210
TOTAL YEAR 1 OPERATIONS AND MAINTENANCE COST			**$136,891**
TOTAL COST			**$577,897**

Note: use of existing sparge equipment from the Site 89 pilot study would reduce capital costs by at least $38,000, with a corresponding total cost of $519,000
Costs are considered "order-of-magnitude" estimates, with an expected accuracy of -30% to +50%.

APPENDIX A
DETAILED COST ESTIMATE - ISCO
SWMU 360, CAMP LEJEUNE

Assumptions:
One time application of potassium permanganate solution (5% in water) at 20 direct push locations from 20 to 40 feet bgs, plus monitoring for one year

CAPITAL COSTS

Description	Qty	Unit	Unit Cost	Cost	Comments
Injection Set-Up and Performance					
Submittals, Work Plan, HASP	1	LS	$7,500	$7,500	Engineer's Estimate
Installation of New Monitoring Wells (flush mount w/ concrete pads)	4	wells	$2,900	$11,600	Engineer's Estimate
Utility Location	1	LS	$2,000	$2,000	Engineer's Estimate
Materials - Potassium Permanganate	15,280	lbs	$2.01	$30,713	Dosage is 764# per location at 4%, 20 locations
Injection Labor (Direct Push, 20 Borings)	14	days	$7,000	$98,000	Budgetary estimate, assume 15 days to complete injections*
Injection Oversight Labor					
Engineer/Hydrogeologist	140	hr	$60	$8,400	1 Staff, 10 Hour days
Per Diem	14	Days	$150	$2,100	1 Staff + Rental Truck
As Built Survey	1	LS	$2,500	$2,500	Engineer's Estimate
Subtotal *Injection Set-Up and Performance*				$162,813	
Professional Services					
Project Management			10%	$16,281	
Remedial Design			5%	$8,141	
Construction Management and Procurement			15%	$24,422	
G&A			11%	$17,909	
Profit			10%	$16,281	
Contingency			20%	$32,563	
Subtotal *Professional Services*				$115,597	
TOTAL CAPITAL COST				**$278,410**	

YEAR 1 MONITORING

Item/Activity	Qty	Unit	Unit Cost	Cost	Comments
Groundwater Sampling (Quarterly)					
Sample Labor, Travel, Perdiem	4	events	$3,600	$14,400	
Sample Analysis - Subcontractor	64	samples	$100	$6,400	16 samples/round TCL Volatiles
GW Sampling Equipment Rental	4	rounds	$600	$2,400	
Subtotal *Groundwater Sampling*				$23,200	
Reporting (4 Quarterly Reports and Detailed Study)					
Reporting Labor (quarterly reports)	4	rpts	$5,000	$20,000	
Reporting Labor (detailed study)	1	rpt	$10,000	$10,000	
Subtotal *Reporting*				$30,000	
Subtotal				$53,200	
Contingency			20%	$10,640	
Project Management			10%	$5,320	
TOTAL YEAR 1 OPERATIONS AND MAINTENANCE COST				**$69,160**	
TOTAL COST				**$347,570**	

Costs are considered "order-of-magnitude" estimates, with an expected accuracy of -30% to +50%.
* Assumes 5 gpm injection rate (minimum) at each location, 2 rigs, simultaneous injection at 4 injection poiints

APPENDIX B

ERD Dosage Calculation

APPENDIX B
ENHANCED REDUCTIVE DECHLORINATION DOSAGE CALCULATIONS
SWMU 360, CAMP LEJEUNE

Parameter	Concentration (mg/L)	Molecular Weight (g/mol)	(mmol/L)	Initial Oxidation state	Final Oxidation state	Number of electrons transferred/mol	Millieqiuvalents
DO (O_2)[1]	1	32	0.031	0	-2	4	0.13
Sulfate (SO_4^{2-})*	23	96	0.240	6	-2	8	1.92
Nitrate (NO^{3-})*	0.44	62	0.007	5	0	5	0.04
Ferrous Iron (Fe^{2+})*	6.5	55.9	0.116	3	2	1	0.12
Manganese (Mn^{2+})*	2	54.9	0.036	4	2	2	0.07
TCE (C_2HCl_3)	0.3	131	0.002	6	0	6	0.01
cis-1,2-DCE ($C_2H_2Cl_2$)	0.5	97	0.005	4	0	4	0.02
Total Electron Donor Demand =						Total mequivs	2.30

Ethyl Lactate Molecular Weight (g/mol) =	118	
Mass of Lactate Required (mg/L water) =	67.87	
Minimum Lactate Concentration (10X demand) =	679	mg/L

Ethyl Lactate Density (99%) =	8.7	lbs/gal		
Calculation of Ethyl Lactate Dosage	Imperial		SI	
ROI (Radius of Influence)	15	ft	4.6	m
Area	707	ft^2	65.7	m^2
Injection Zone Interval	20	ft	6.1	m
Total Volume (including solids)	14,130	ft^3	400.4	m^3
Assume 8% effective porosity	1,130	ft^3	60.1	m^3
	8,455	gals	60,055	liters
Lactate Volume per Injection Well at 0.5% concentration	42	gals	600.5	liters
Lactate Mass per Injection Well at 0.5% concentration	367	lbs	166646644	mg
Field Lactate Dosage			2775	mg/L
Emulsified Soybean Oil Solution Density (50%) =	8.1	lbs/gal		
Calculation of Emulsified Oil Dosage	Imperial		SI	
ROI (Radius of Influence)	15	ft	4.6	m
Area	707	ft^2	65.7	m^2
Injection Zone Interval	20	ft	6.1	m
Total Volume (including solids)	14,130	ft^3	400.4	m^3
Assume 8% effective porosity	1,130	ft^3	60.1	m^3
	8,455	gals	60,055	liters
Product Volume per Injection Well at 1% concentration	85	gals	0.6	liters
Emulsified Oil Volume per Injection Well at 0.5% concentration	42	gals	600.5	liters
Product Mass per Injection Well at 1% concentration	685	lbs	310664631	mg
Number of 275 gal totes per injection location	0.31	totes		

Total Number of Injections	20	
Total Volume of Ethyl Lactate	846	gallons
Total Mass of Ethyl Lactate	7348	lbs
Total Volume of Emulsified Oil Product	1691	gallons
Total Mass of Emulsified Oil Product	13698	lbs

APPENDIX C

Permanganate Dosage Calculation

APPENDIX C
POTASSIUM PERMANGANATE DOSAGE CALCULATION (PER LOCATION)
DIRECT PUSH INJECTION, 30 FOOT SPACING
SWMU 360, CAMP LEJEUNE

Parameters	Units	Estimates
*** Site Description ***		
ROI	Ft.	15
Area	Sq. Ft.	706.8582
Thickness	Ft.	15
Total Volume	Cu. Yd.	393
Porosity	%	8
Pore Volume	Gal.	31
Avg. Contaminant Conc.	ppm	0.3
Mass of Contaminant	lb.	7.86533E-05
PSOD	g/kg	6.55
Effective PSOD %	10	0.655
PSOD	lb/yd3	1.94535
PSOD Oxidant Demand	lb	763.94
Avg. Stoichiometric Demand	lb/lb	1
Contaminant Oxidant Demand	lb.	7.86533E-05
Theoritical Oxidant Demand	lb.	763.94
Confidence Factor		1
Calculated Oxidant Demand		763.94
*** Injection Design ***		KMnO4
Radius of Influence	Ft.	15
Number of Injection Points		1.00
Injection Concentration	% wt/wt	5.00%
Flow Rate - Per Injection Point	GPM	5.00
Number of Wells per Phase		n/a
Total Injection Flow Rate	GPM	30.00
Estimated Injection Pressure	PSIG	
Injection Volume/Hole	Gal	1,740.38
*** Injection Schedule ***		
Hours per Day	Hrs	8.00
Days Per Week	Days	5.00
Number of Inj. Days	Days	0.12
Number of Inj. Weeks	Weeks	0.02

Dry KMnO4 Injection Options

Pounds of KMnO4 (Dry Crystals)	Number of Pails	Number of Drums	Number of Totes	Price per Lb (Dry)	Total Cost of Chemical
764	13.89	2.31	0.23		$0.00

Total Gallons of Dillution Water Required	Dillution Water Flow Rate - GPM	OR	Dillution Water Gals per Pail	Dillution Water Gals per Drum	Dillution Water Gals per Tote
1,740	30.00		125.30	751.80	7,517.99

Instructions: Fill in all white colored blanks. Leave all shaded cells - these calculate themselves.
Please call Carus at 800/435-6856 for current chemical pricing.

				assumed density		Result
g KMnO4	lb KMnO4	kg soil	454 g soil	110 lb soil	27 ft^3 soil	2.97
kg soil	454 g KMnO4	1000 g soil	lb soil	ft^3	yd^3 soil	