

**CORRECTIVE MEASURES STUDY REPORT  
SWMU 39**

**NAVAL SUPPORT ACTIVITY MID-SOUTH  
MILLINGTON, TENNESSEE**

**Revision: 2**

**Comprehensive Long-Term Environmental Action Navy  
Contract Number: N62467-89-D-0318  
CTO-0146**

**Prepared for:**



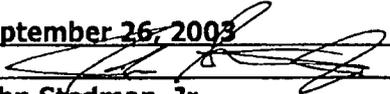
**Department of the Navy  
Southern Division  
Naval Facilities Engineering Command  
North Charleston, South Carolina**

**Prepared by:**

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**The Contractor, EnSafe Inc., certifies that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. N62467-89-D-0318 are complete, accurate, and comply with all requirements of the contract.**

**Date:** September 26, 2003  
**Signature:**   
**Name:** John Stedman, Jr.  
**Title:** Task Order Manager



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September 26, 2003

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Sincerely,

EnSafe Inc.

By: John Stedman, Jr.  
Task Order Manager

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## List of Acronyms

1,1-DCE	1,1-dichloroethylene
1,2-DCE	1,2-dichloroethylene
A-A	anaerobic-aerobic
APC	air pollution control
BCT	BRAC Cleanup Team
bls	below land surface
BRAC	Base Realignment and Closure
BTEX	benzene, toluene, ethylbenzene, and xylene
CMS	Corrective Measures Study
CO <sub>2</sub>	carbon dioxide
COC	chemical of concern
CRP	Community Relations Plan
CSI	Confirmatory Sampling Investigation
DO	dissolved oxygen
DPT	direct-push technology
gpm	gallon per minute
ICs	institutional controls
LS	lump sum
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNA	monitored natural attenuation
mV	millivolt
NA	not applicable
ND	not detected
NS	not sampled
NSA	Naval Support Activity
nM	nanoMolar
O&M	operation and maintenance
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
PCE	tetrachloroethylene
PPE	personal protective equipment
PRG	preliminary remedial goal
POTW	publicly-owned treatment works

RAB	Restoration Advisory Board
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
RGO	remedial goal option
SOB	Statement of Basis
SOUTHDIV	Southern Division Naval Facilities Engineering Command
SSL	soil screening level
SWMU	solid waste management unit
TCA	trichloroethane
TCE	trichloroethylene
TDEC	Tennessee Department of Environment and Conservation
TN-EPH	Tennessee Extractable Petroleum Hydrocarbons
TOC	total organic carbon
TPH	total petroleum hydrocarbons
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VC	vinyl chloride
VOC	volatile organic compound
yd <sup>3</sup>	cubic yards

## 1.0 INTRODUCTION

This Corrective Measures Study (CMS) report identifies, screens, develops, evaluates, and compares remedial action alternatives to mitigate hazards and threats to human health and the environment from groundwater contamination at solid waste management unit (SWMU) 39, located on the Southside of Naval Support Activity (NSA) Mid-South (formerly Naval Air Station [NAS] Memphis), Millington, Tennessee. As recommended in the CMS work plan (EnSafe, 2001), a streamlined approach for corrective measures at SWMU 39 has been taken.

The CMS is being performed under the Resource Conservation and Recovery Act (RCRA) of 1976. As required by RCRA, the NSA Mid-South Restoration Advisory Board (RAB) provides a focus for community input to the remedial decision-making process. The RAB, which regularly holds open public meetings, consists of community members, state and federal regulators, Southern Division Naval Facilities Engineering Command (SOUTHDIV), and other NSA Mid-South project team representatives.

When the CMS is complete, a Statement of Basis (SOB) will be written to document the CMS process and present the preferred alternative for site remediation. The SOB will be made available for public comment to ensure that decision-makers are aware of public concerns. The selection of the final remedy for the site could be affected by public input. The primary NSA Mid-South decision-makers are SOUTHDIV, the Tennessee Department of Environment and Conservation (TDEC), and the United States Environmental Protection Agency (USEPA).

The CMS report has been organized according to the format in the Office of Solid Waste and Emergency Response (OSWER) Directive 9902.3-2A, *RCRA Corrective Action Plan* (Final, May 1994), as outlined below.

- **Section 1, Introduction:** This section presents the purpose of the report and summarizes the project.

- **Section 2, Site Description:** This section presents history and background of SWMU 39 and the results of previous investigations, including the RCRA Facility Investigation (RFI) and supplemental CMS sampling.
- **Section 3, Remedial Objectives:** To maintain the CMS focus, this section summarizes the chemicals of concern (COCs) to be directly addressed by this CMS and their remedial objectives. In some cases, this section justifies the inclusion or removal of COCs identified in the RFI based on the contribution of a particular chemical or lack thereof to significant risks, hazards, or other regulatory standards applicable to this site.
- **Section 4, Identification and Screening of Technologies:** This section identifies and screens the remedial technologies that may be used to achieve remedial action objectives.
- **Section 5, Development and Evaluation of Alternatives:** This section develops and evaluates the potential remedial alternatives according to the nine evaluation criteria identified in OSWER Directive 9902.3-2A, RCRA *Corrective Action Plan* (Final, May 1994).
- **Section 6, Recommendations:** The section assesses the relative performance of the alternatives and presents recommendations for selection of a final remedy.
- **Section 7, Public Involvement Plan:** This section summarizes the public involvement plan as it relates to the CMS.
- **Section 8, References:** This section lists applicable references used to prepare the CMS report.
- **Section 9, Signatory Requirement:** This section provides the applicable signatory requirements for the CMS report.

## **2.0 SITE DESCRIPTION AND ENVIRONMENTAL SETTING**

### **2.1 Site Description**

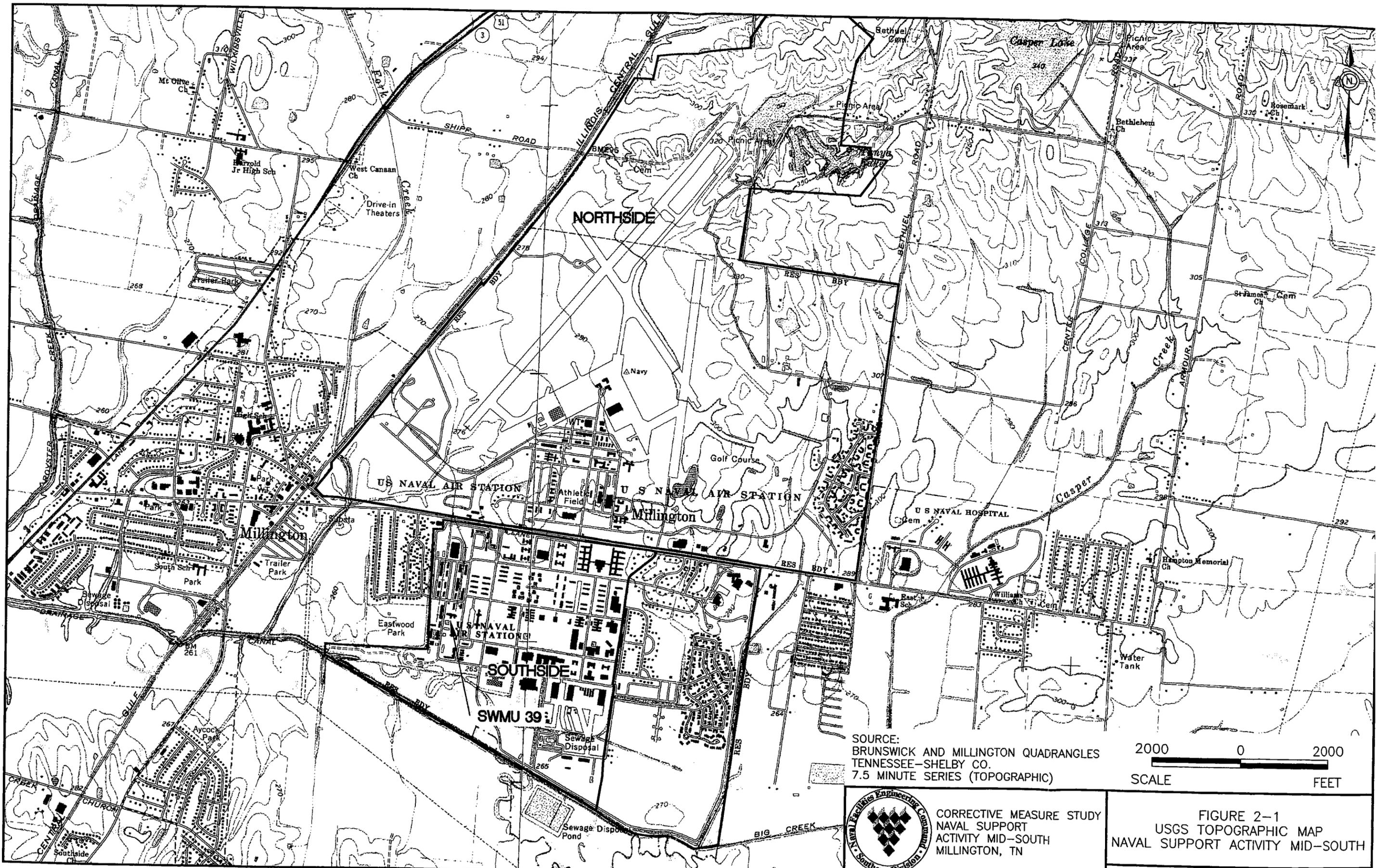
SWMU 39 is located approximately 150 feet east of Kearsarge Avenue across from and east of the boiler plant (former Building S-75) on the NSA Mid-South Southside. Figure 2-1, a topographic map of the facility and the surrounding area, shows the NSA Mid-South Northside and Southside base boundaries that were in place at the time of the Base Closure and Realignment Act (BRAC) in January 2000. SWMU 39 consists of the area in the vicinity of Building S-203, the concrete slab remaining from former Building S-74, and the area of former Building S-212. Building S-74 was built in 1943 and operated as a laundry and dry cleaning facility until 1981. It was demolished in 1995. The remaining Building S-74 concrete foundation is surrounded by grassy areas. PCB transformers were formerly stored on the south end of the Building S-74 concrete slab. In May 1996, a UST located approximately 100 feet south of the Building S-74 concrete slab was removed by a Navy subcontractor. Former Building S-212 was used to store dry cleaning solvent; the area is now covered with grass. Surface drainage flows south and west across the site.

Figure 2-2 indicates where fluvial deposits groundwater data have been collected from monitoring wells as part of the earlier RFI or Confirmatory Sampling Investigations (CSIs) at NSA Mid-South SWMU 39.

### **2.2 Site Geology and Hydrogeology**

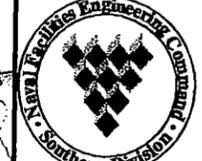
The geology of SWMU 39 consists of three major lithologic units, which are listed in descending order (youngest to oldest) (Carmichael et al., 1997):

- Pleistocene-age loess
- Pleistocene- to possibly Pliocene-age fluvial deposits
- Eocene-age Cockfield and Cook Mountain formations (upper units of the Claiborne Group), which overlie the Memphis Sand of Eocene-age and serve as the upper Claiborne confining unit for the Memphis aquifer



SOURCE:  
BRUNSWICK AND MILLINGTON QUADRANGLES  
TENNESSEE-SHELBY CO.  
7.5 MINUTE SERIES (TOPOGRAPHIC)

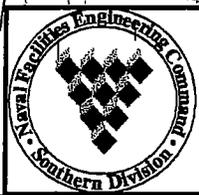
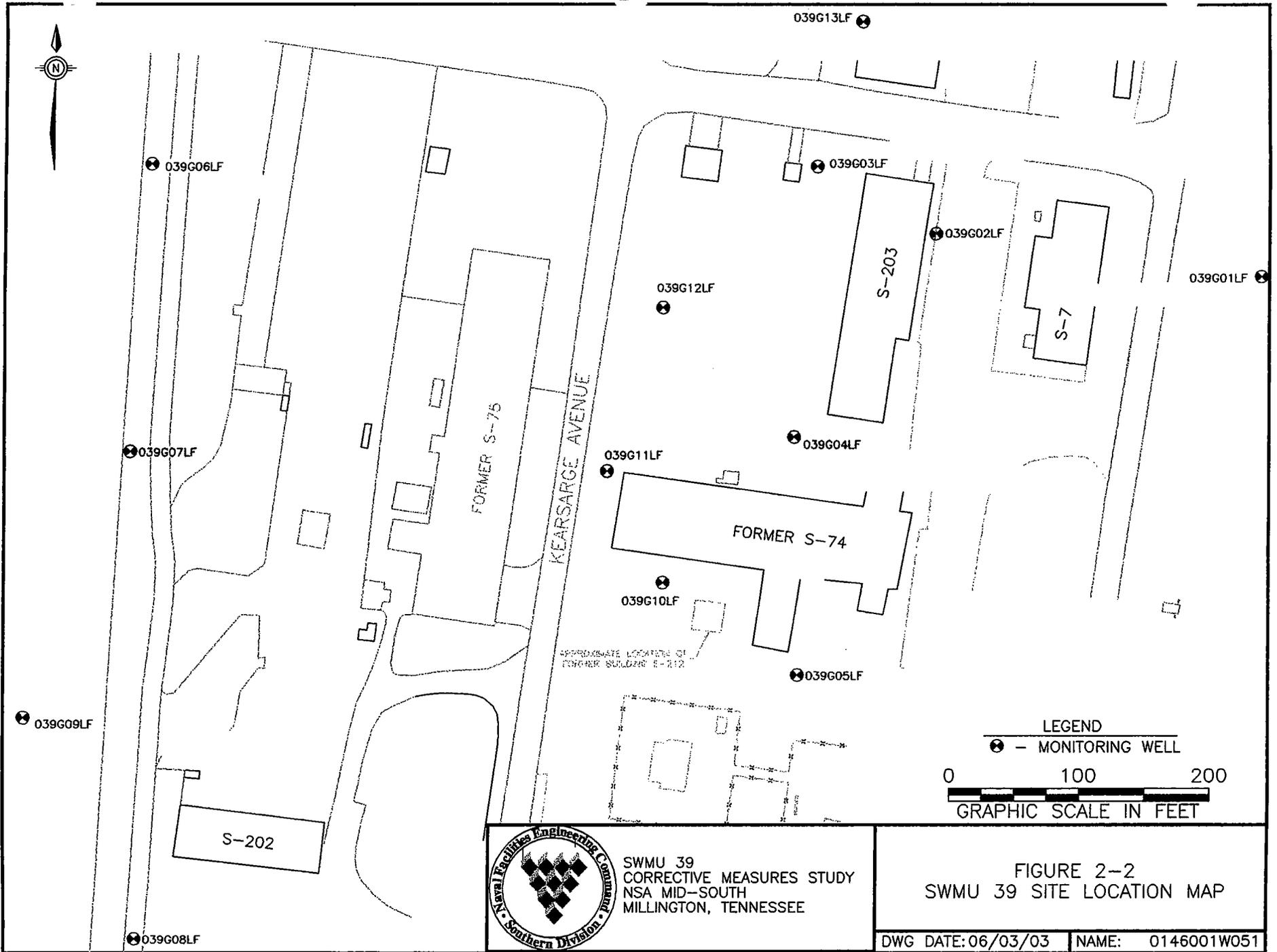
2000 0 2000  
SCALE FEET



CORRECTIVE MEASURE STUDY  
NAVAL SUPPORT  
ACTIVITY MID-SOUTH  
MILLINGTON, TN

FIGURE 2-1  
USGS TOPOGRAPHIC MAP  
NAVAL SUPPORT ACTIVITY MID-SOUTH

DWG DATE: 06/03/03 NAME: 0146001W049



SWMU 39  
CORRECTIVE MEASURES STUDY  
NSA MID-SOUTH  
MILLINGTON, TENNESSEE

LEGEND  
 ⊕ - MONITORING WELL

0 100 200  
 GRAPHIC SCALE IN FEET

FIGURE 2-2  
 SWMU 39 SITE LOCATION MAP

Two principal groundwater units have been the focus of investigations at NSA Mid-South: the alluvial-fluvial deposits aquifer, which is the most prominent surficial aquifer, and the Memphis aquifer, which is the primary drinking water source in the Memphis area. These aquifers are hydraulically separated by the Cockfield and Cook Mountain Formations.

Loess is the surficial unit that occurs outside the stream valleys throughout Memphis, including the NSA Mid-South area. The loess consists of a clayey silt or silty clay, with varying amounts of silt and clay and occasional fine sand. The loess behaves as an overlying semiconfining unit to the fluvial deposits aquifer. Thickness of the loess ranges from approximately 32 to 46 feet at SWMU 39. Color of the loess ranges from varying shades of brown, orange-brown and gray-brown, to gray. Some gray mottling and iron staining were observed during drilling of monitoring wells at SWMU 39. Saturated horizons in the loess are common and typically are encountered around 10 to 15 feet below land surface (bls).

The fluvial deposits are a fine-to coarse-grained, poorly sorted sand and gravel unit, that were encountered beneath the loess at depths between 32 and 41.5 feet at SWMU 39, with an overall thickness ranging from 11.5 to 42 feet. The entire thickness of the fluvial deposits at SWMU 39 is saturated. The rounded to sub-angular gravel coarsens downward, with individual cobbles typically ranging from less than 0.25 to 1 inch in longest dimension. Color of the fluvial deposits at SWMU 39 ranges from varying shades of orange-brown and gray to olive gray.

The contact between the fluvial deposits and the underlying Cockfield Formation ranges from 50.5 to 75.5 feet bls at SWMU 39. The upper part of the Cockfield Formation consists of a discontinuous sand zone overlying a clayey zone. This upper part consists of very-fine to fine-grained sand, ranging in color from very light gray to light yellow gray. Where present at SWMU 39, the sand thickness ranges from 16.5 to 28 feet.

Clay horizons in the Cockfield Formation behave as a lower semiconfining unit for the fluvial deposits aquifer and, where present at SWMU 39, sandy zones underlying the fluvial deposits

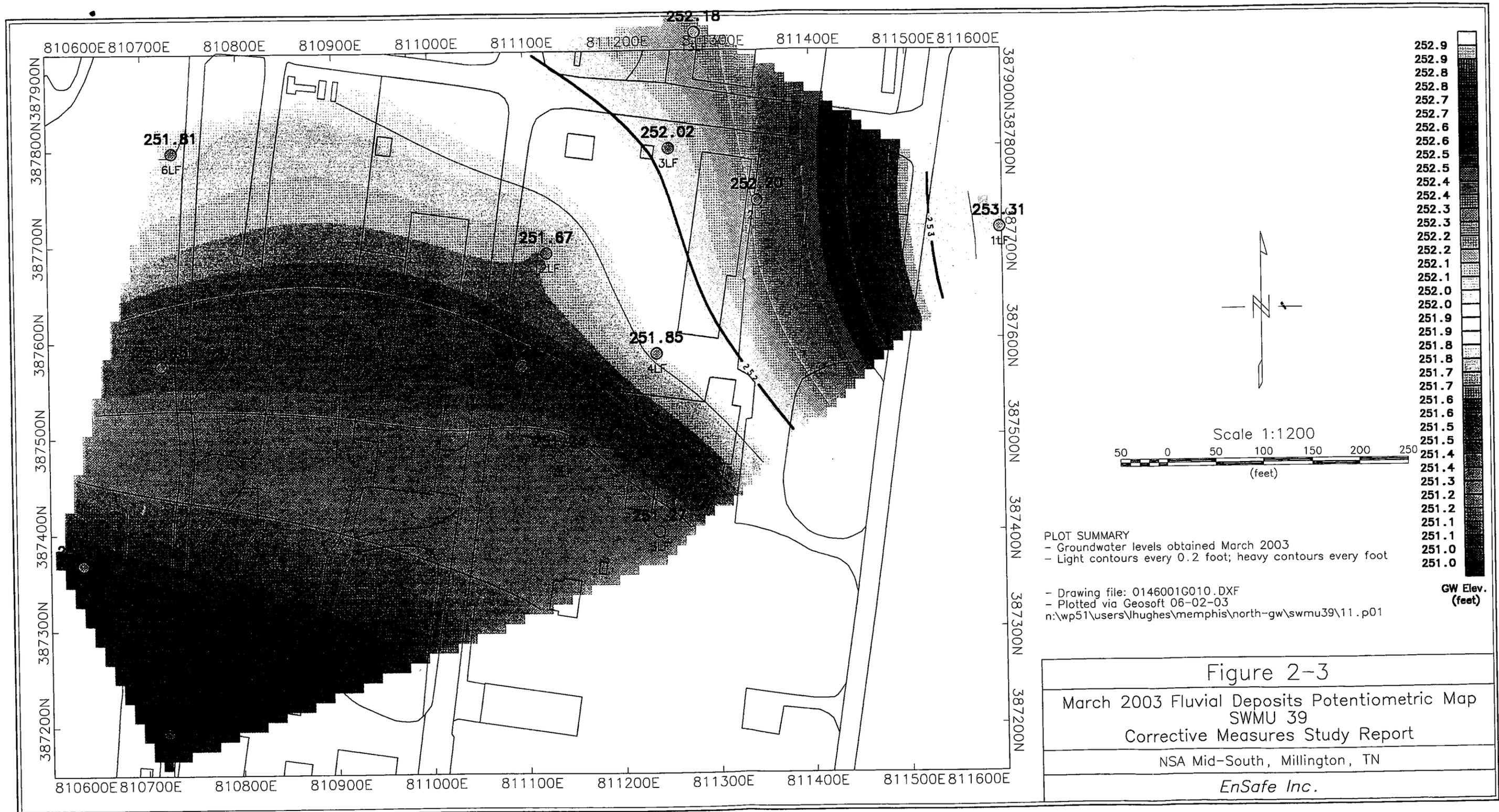
in the upper part of the Cockfield Formation. The contact between sands in the upper part of the Cockfield Formation to clays in the upper to middle part of the formation is distinct at SWMU 39. The clay zones in the upper to middle part of the Cockfield Formation consist of dark charcoal-gray or dark olive-gray clay which is dense and very stiff. Fine sand was noted within the clay at some drilling locations at SWMU 39.

The Cook Mountain Formation underlies the Cockfield Formation and contains the most areally extensive clay in the upper Claiborne confining unit in Memphis and Shelby County. The Cook Mountain Formation serves as the primary component of the lower confining unit to the fluvial deposits aquifer and the upper confining unit to the Memphis aquifer. The Cook Mountain Formation at NSA Mid-South primarily consists of clay and silt, though minor fine silty sand lenses also may be present locally. Geophysical logs from public-supply wells indicate the Cook Mountain Formation ranges from 10 to 60 feet thick in the NSA Mid-South Area (Carmichael et al., 1997).

As shown in Figure 2-3, groundwater elevations in SWMU 39 monitoring wells, which were screened across the lower part of the fluvial deposits and the sandy interval in the upper part of the Cockfield formation, measured in March 2003 were used to generate a computer-contoured potentiometric-surface map for SWMU39. The figure indicates that groundwater in the shallow aquifer beneath SWMU 39 generally flows southwest.

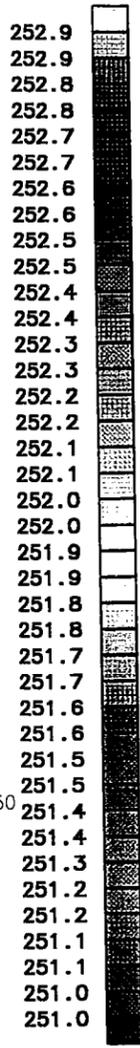
### **2.3 Aquifer Characterization**

On December 15, 1999, specific capacity tests were performed on monitoring wells 039G02LF, 039G03LF, and 039G08LF to provide estimates of hydraulic conductivity and transmissivity. Field measurements of yield, time, and drawdown were collected during the specific-capacity testing. These values were then used as input values in a commercially available



PLOT SUMMARY  
 - Groundwater levels obtained March 2003  
 - Light contours every 0.2 foot; heavy contours every foot

- Drawing file: 0146001G010.DXF  
 - Plotted via Geosoft 06-02-03  
 n:\wp51\users\hughes\memphis\north-gw\swmu39\11.p01



GW Elev.  
(feet)

Figure 2-3  
 March 2003 Fluvial Deposits Potentiometric Map  
 SWMU 39  
 Corrective Measures Study Report  
 NSA Mid-South, Millington, TN  
 EnSafe Inc.

software program, Q/s (Kasenow and Pare, 1995), designed to calculate transmissivity using specific-capacity test results. The Southern Division Monitoring Well Design, Installation, Construction, and Development Guidelines (1997) may be consulted for details regarding the theoretical considerations of these calculations.

Table 2-1 presents the results of the specific capacity testing and analysis of the data. Since each well fully penetrated the fluvial deposits and the sandy interval in the upper part of the Cockfield Formation, hydraulic conductivity (K) was calculated from the resulting transmissivity by dividing by the total aquifer thickness. A K value is provided for each well; since hydrologic data is typically log-normally distributed, a geometric mean K was calculated as a value representative of the central tendency. This value was then used in calculating the average horizontal groundwater velocity.

<b>Table 2-1 Specific Capacity Test Results</b>					
<b>Monitoring Well</b>	<b>Lithologic Unit</b>	<b>Specific Capacity (gpm/ft)</b>	<b>Transmissivity T (ft<sup>2</sup>/day)</b>	<b>Aquifer Thickness (ft)</b>	<b>Hydraulic Conductivity, K (ft/day)</b>
039G02LF	Entire Fluvial Deposits and Upper Part of Cockfield Formation	0.6	156	64	2.4
039G03LF	Entire Fluvial Deposits and Upper Part of Cockfield Formation	2.4	555	68	8.2
039G08LF	Entire Fluvial Deposits and Upper Part of Cockfield Formation	3.5	848	53	16.0
<b>Geometric Mean</b>					<b>6.8</b>

**Notes:**  
 gpm/ft — gallons per minute per foot  
 ft/day — feet per day  
 ft<sup>2</sup>/day — feet squared per day

The calculated average horizontal velocity of the groundwater was determined using the following equation (a derivation of the Darcy equation):

$$v = \frac{K * I}{n}$$

**where:**

- $v$  = calculated average horizontal velocity (ft/day)
- $K$  = geometric average hydraulic conductivity (ft/day)
- $I$  = average hydraulic gradient (ft/ft)
- $n$  = effective porosity

The hydraulic conductivity used for this calculation was 6.8 ft/day. The effective porosity used was 0.25, a value typical for silty sand (Freeze and Cherry, 1979). Based upon potentiometric maps for SWMU 39, an average hydraulic gradient of 0.0036 ft/ft was used. Using the equation above, the calculated average horizontal groundwater velocity is 0.10 ft/day (36.5 ft/yr).

## **2.4 RFI/CMS Sampling Results**

During December 1995, a preliminary screening investigation using direct-push technology (DPT) was conducted at SWMU 39 as part of the RFI Characterization. Based on the anticipated site contaminants from dry cleaning operations, volatile organic compounds (VOCs) were chosen as the indicator parameter. The results of the DPT investigation were then used to define the nature and extent of contamination. In May 1996, tank number S-212 was removed by the Corps of Engineers. Obvious soil contamination was observed during the removal and confirmed by soil samples. In 1998 and 1999, groundwater samples were collected at 55 locations as part of the RFI. Results from this sampling event indicated that past operations in the SWMU 39 area may have impacted the soil and groundwater. The RFI report recommended that further delineation of chlorinated solvents in soil beneath the Building S-74 foundation and in loess and fluvial deposits/Cockfield Formation was needed to complete a CMS evaluation

(EnSafe, 2000). In October 2000, supplemental RFI sampling was conducted for soil, loess groundwater, and fluvial deposits groundwater.

#### **2.4.1 Soil Sampling Results**

During the RFI, soil samples were collected from six locations at SWMU 39. Surface soil samples (0 to 1 foot bls) were collected from five locations beneath the foundation of former Building S-74. Subsurface soil samples were collected south of Building S-74 from depths of 9 to 11 feet and 11 to 13 feet bls. Analytical results indicated a release of chlorinated solvents and petroleum-related compounds. None of the compounds exceeded their Preliminary Remedial Goals (PRGs).

The second SWMU 39 DPT investigation, conducted in October 2000 as part of a supplement to the RFI, yielded 15 subsurface soil samples from beneath and around the concrete slab of former Building S-74 and also from the area of former Building S-212. The samples were analyzed for VOCs and total petroleum hydrocarbons (TPH). Only trichloroethene (TCE) was detected at a concentration of 11  $\mu\text{g}/\text{kg}$ , which exceeded its Soil Screening Level (SSL) of 0.77  $\mu\text{g}/\text{kg}$  in one soil sample.

Because minimal contamination was found in the surface soils and subsurface soils beneath the Building S-74 concrete slab, the potential impact of removing the slab was considered negligible. The CMS work plan recommended no further action for surface and subsurface soils at SWMU 39. TDEC and USEPA concurred with this recommendation in letters dated August 24, 2001, and January 28, 2002, respectively. Therefore, the CMS does not evaluate alternatives for soil.

#### **2.4.2 Groundwater Sampling Results**

During the RFI, groundwater samples were collected from loess temporary wells. VOCs were detected in only one loess groundwater sample collected south of Building S-74. As recommended by the RFI, supplemental groundwater sampling was also conducted in October and December 2000 of all SWMU 39 loess temporary and fluvial deposits/Cockfield Formation

groundwater monitoring wells. TCE exceeded its maximum contaminant level (MCL) in samples from three fluvial deposits wells (039G03LF, 039G04LF, and 039G06LF). No VOCs were detected in the loess groundwater exceeding their PRGs and/or MCLs.

The USEPA does not have a PRG or MCL for TPH (same as Tennessee Extractable Petroleum Hydrocarbons , TN-EPH). Because loess groundwater likely will never be used as a potable water source at NSA Mid-South because of the low yield and poor aesthetic water quality in this unit, detected concentrations of TPH in samples collected from loess temporary wells were compared to the TDEC groundwater cleanup level of 1,000 µg/L for non-drinking water aquifers. TPH concentrations found in fluvial deposits/Cockfield Formation monitoring wells were compared to TDEC's most stringent groundwater cleanup level of 100 µg/L for drinking water aquifers. None of the samples from the loess monitoring wells exceeded the 1,000 µg/L standard; a sample from one fluvial deposits well (039G09LF) had a concentration of 487 µg/kg, which exceeded the 100 µg/L standard. Groundwater sample results are presented in Tables 2-2 and 2-3.

VOCs detected in groundwater samples collected from loess monitoring wells did not exceed PRGs or MCLs. Therefore, no further action was recommended for loess groundwater. TDEC and USEPA concurred with this recommendation in letters dated August 24, 2001, and January 28, 2002, respectively. The temporary loess monitoring wells have since been abandoned.

Because the contamination in groundwater in the fluvial deposits/Cockfield Formation is present at low concentrations and presents minimal exposure concern, it was concluded in the CMS Work Plan that the groundwater in these units should be addressed in a streamlined CMS for TCE and petroleum-related hydrocarbons.

<b>Table 2-2</b>					
<b>RFI Groundwater Sample Exceedances (µg/L)</b>					
<b>Location</b>	<b>Date</b>	<b>Sample Depth<sup>a</sup></b>	<b>Parameter</b>	<b>Detection</b>	<b>MCL<sup>c</sup></b>
<b>Loess DPT Samples</b>					
039G0014	5/22/98	12	benzene	2	5
			1,2-DCE (total)	<b>26</b>	5
<b>Fluvial Deposits DPT Samples</b>					
039G0020	5/20/1998	40	chloromethane	<b>6</b>	1.5 <sup>b</sup>
039G0026	11/18/1998	40	TCE	<b>11</b>	5
039G0032	11/21/1998	50	TCE	3	5
039G0033	11/22/1998	40	TCE	<b>37</b>	5
039G0041	12/07/1998	50	TCE	<b>91.30</b>	5
039G0045	12/18/1998	50	TCE	<b>160</b>	5
039G0046	12/11/1998	50	1,2-DCA	1.71	5
039G0048	01/13/1999	50	1,2-DCA	1.52	5
039G0049	01/13/1999	40	1,2-DCA	4.46	5
039G0050	01/14/1999	40	TCE	<b>8.21</b>	5
039G0059	01/18/1999	40	TCE	2.01	5
<b>Fluvial Deposits Monitoring Well Samples</b>					
039G03LF	6/22/1999	43	1,2-DCE (total)	<b>23</b>	5
		43	TCE	<b>67</b>	5
		73	TCE	<b>57</b>	5
		99	TCE	<b>66</b>	5
039G04LF	6/22/1999	47	TCE	<b>50</b>	5
		57	1,2-DCE (total)	<b>10</b>	5
		57	TCE	<b>73</b>	5
		60	chloromethane	<b>8.9</b>	1.5 <sup>b</sup>
		60	TCE	<b>55</b>	5
		61	TCE	<b>73</b>	5
		69	TCE	<b>83</b>	5

**Notes:**

- a — feet below land surface
- b — When MCL values were unavailable, the USEPA Region 9 Preliminary Remedial Goal values were used in their place.
- c — MCL values are from the USEPA Summer 2000 *Drinking Water Standards and Health Advisories*.
- Bold** — Detection exceeds screening value
- µg/L — micrograms per liter

Table 2-3 Supplemental Groundwater Data (October 2000) Exceedances Only (µg/L)					
Well Location	Sample Date	Depth (ft bls)	Parameter	Detection	MCL <sup>a</sup>
<b>Fluvial Deposits</b>					
039G03LF	10/00	98	TCE	<b>30</b>	5
039G04LF	10/00	98	TCE	<b>180</b>	5
039G06LF	10/00	65	TCE	<b>11</b>	5
039G09LF	10/00	88	TN-EPH	<b>487 J</b>	100 <sup>b</sup>

**Notes:**

- a — MCL values are from the USEPA Summer 2000 *Drinking Water Standards and Health Advisories*
- b — TDEC TPH remediation goal
- J — estimated
- Bold** — Detection exceeds screening level
- µg/L — micrograms per liter

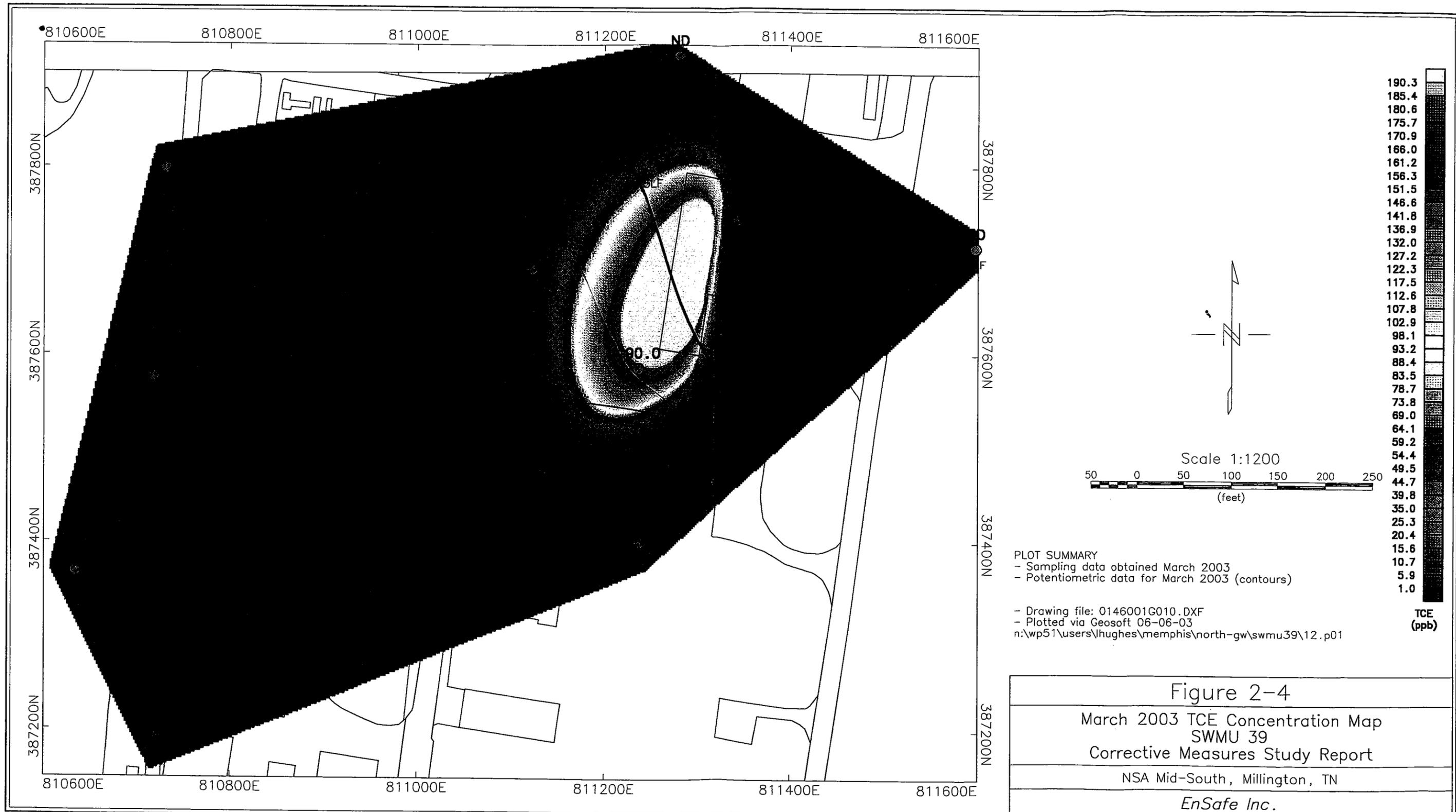
Samples from wells 039G01LF, 039G02LF, 039G05LF, 039G07LF, and 039G08LF were either non-detect or detections were below the PRGs and/or MCLs. All wells were sampled from the bottom five feet of the well screen.

## 2.5 Treatability Study

The CMS work plan (EnSafe, 2001) concluded that monitored natural attenuation (MNA) would most likely be the best alternative to achieve the remedial goals for SWMU 39. Based on this conclusion, a MNA Treatability Study work plan was developed that implemented quarterly monitoring at SWMU 39 (EnSafe, 2001). This monitoring program was developed to monitor the area over time and to verify that natural attenuation is occurring at rates sufficient to attain site-specific remedial goal options (RGOs). The monitoring program included the installation of three additional wells to monitor the migration and attenuation of TCE and its daughter products. The monitoring program included quarterly groundwater sampling of the three new wells and the ten other existing fluvial deposits/Cockfield Formation wells at SWMU 39 for one year. The samples were analyzed for VOCs and petroleum-related contaminants. Quarterly monitoring was conducted in June, August, and November of 2002, and March of 2003. Results from these sampling events are presented in Table 2-4.

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Table 2-4 Quarterly Monitoring Results (µg/L)							
Well ID	Date	Contaminants					
		PCE	TCE	cis-1,2-DCE	trans-1,2-DCE	vinyl chloride	TN-EPH (mg/L)
039G01LF	June 2002	1U	1U	1U	1U	1U	0.1U
	August 2002	1U	1U	1U	1U	1U	0.1U
	November 2002	1U	1U	1U	1U	1U	0.1U
	March 2003	1U	1U	1U	1U	1U	0.1U
039G02LF	June 2002	1U	0.31J	1U	1U	1U	0.1U
	August 2002	1U	0.52 J	1U	1U	1U	0.1U
	November 2002	1U	0.76 J	1U	1U	1U	0.1U
	March 2003	1U	0.72 J	1U	1U	1U	0.1U
039G03LF	June 2002	1U	<b>68</b>	12	15	1U	0.1U
	August 2002	1U	<b>72</b>	12	17	1U	0.1U
	November 2002	1U	<b>72</b>	14	18	0.34 J	0.1U
	March 2003	1U	<b>70</b>	16	22	0.28 J	0.1U
039G04LF	June 2002	1U	<b>180</b>	3.7	1U	1U	0.1U
	August 2002	1U	<b>180</b>	3.7	1U	1U	0.1U
	November 2002	1U	<b>200 D</b>	4.8	1U	1U	0.1U
	March 2003	2 U	<b>190</b>	6.1	2U	2U	0.1U
039G05LF	June 2002	1U	1U	0.75 J	1U	1U	0.1U
	August 2002	1U	1U	1U	1U	1U	0.1U
	November 2002	1U	1U	1U	1U	1U	0.1U
	March 2003	1U	1U	1U	1U	1U	0.1U
039G06LF	June 2002	1U	1U	1U	1U	1U	0.1U
	August 2002	1U	1U	1U	1U	1U	0.1U
	November 2002	1U	1U	1U	1U	1U	0.1U
	March 2003	1U	1U	1U	1U	1U	0.1U
039G07LF	June 2002	1U	1U	1U	1U	1U	0.1U
	August 2002	1U	1U	1U	1U	1U	0.1U
	November 2002	1U	1U	1U	1U	1U	0.1U
	March 2003	1U	1U	1U	1U	1U	0.1U



### **3.0 REMEDIAL OBJECTIVES**

This section summarizes COC(s) in the SWMU 39 fluvial deposits/Cockfield formation groundwater COC(s) that will be directly addressed by this CMS and their remedial objectives.

#### **3.1 Groundwater Chemicals of Concern**

As discussed in Section 2.4, the RFI identified two analyte types as COCs for SWMU 39, TCE and petroleum-related hydrocarbons. TCE will be addressed as the "primary" COC in this CMS because it is the most prevalent contaminant in fluvial deposits/Cockfield Formation.

Though TPH will continue to be monitored during cleanup activities, to streamline technology identification and screening as well as remedial alternative development, only TCE reduction/removal treatment systems have been considered. These systems will also address the other chlorinated solvents.

#### **3.2 Groundwater Remedial Goal Options**

Based on previous discussions and decisions, the remedial goals for SWMU 39 fluvial deposits/Cockfield Formation groundwater are MCLs. The technology evaluation includes the potential for achieving the 5 µg/L MCL for TCE, which is the only compound that exceeded its MCL in the quarterly monitoring.

## **4.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES**

This section describes the initial steps toward remedy selection: identification and screening of applicable technologies, followed by reviewing based on site-specific conditions and waste constraints. From the retained technologies, SWMU 39 remedial action technologies will be developed and further evaluated in Section 5.

### **4.1 Potential Response Actions**

Remedial action technologies can be broadly categorized into general response actions for consideration in the CMS. From these general categories, which are summarized below, potentially applicable technologies will be selected. Three technologies were retained for further consideration: institutional controls, monitored natural attenuation, and enhanced biodegradation.

- **Institutional Controls (ICs):** ICs often supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. ICs should not substitute for active response measures as the sole remedy, unless active measures are determined to be impractical.
  
- **MNA:** This term refers to monitoring of decreases in contaminant concentrations via natural processes; such as, biotic and abiotic degradation, contaminant dilution, dispersion, and/or advection. Monitoring must be conducted throughout the process to confirm that degradation proceeds at rates consistent with remedial objectives and to ensure that receptors are not threatened.
  
- **Treatment:** Where practical, treatment can be used to reduce the toxicity, mobility, or volume of the principal contaminants at a site. It can also be used to treat sources or hot spots as the initial step followed by other response actions such as MNA.

- **Combination:** Appropriate methods can be combined to protect human health and the environment.

#### **4.1.1 Institutional Controls**

ICs are required for industrial reuse scenarios and typically include:

- Governmental controls such as zoning restrictions, ordinances, statutes, building permits, or other provisions that restrict land or resource use at a site.
- Proprietary controls, which involve legal instruments placed in the chain-of-title of the site or property (e.g., easements or covenants).
- Enforcement and permit tools with IC components in which orders can be issued or negotiated to compel the land owner (usually the potentially responsible party) to limit certain site activities at both federal and private sites.
- Informational devices, such as state registries of contaminated properties, deed notices, and advisories, which provide information or notification that residual or capped contamination may remain onsite.

Because of federal ownership, ICs are applied differently at federal facilities. Some proprietary or governmental controls cannot be applied on active federal facilities. However, for properties being transferred as part of a base closure, the Department of Defense has the authority to restrict property use by retaining a property interest (i.e., easement to ensure the protectiveness of the remedy). For active bases, ICs are commonly addressed through remedy selection documents, base master plans, and separate memorandums of understanding (Fields, 2000). ICs were retained for further evaluation.

#### **4.1.2 Monitored Natural Attenuation**

MNA of contaminants in groundwater relies on natural processes to reduce concentrations to less than cleanup goals (e.g., MCLs). This technology involves extensive monitoring of site conditions to evaluate the potential for natural processes to achieve cleanup goals. This technology can be applied alone or as a polishing step that accompanies more aggressive technologies. Because it has reduced VOCs, specifically chlorinated hydrocarbons, to detection limits at other sites (USEPA, 1998a), MNA was retained for further evaluation.

#### **4.1.3 In situ Biological Treatment Technologies**

Chlorinated solvents are known to break down to less chlorinated daughter products under proper environmental conditions. Proper environmental conditions may be attained via a variety of engineering means as explained below.

Some forms of enhanced biodegradation use injected materials such as air, nutrients, primary substrates, or cometabolites to stimulate natural degradation of contaminants within the aquifer. In this case, an injected material is generally applied in a grid covering the entire zone targeted for remediation. Applications can be scheduled at different time intervals using different innocuous materials if both anaerobic and aerobic environments are required. This technology can reduce medium to low VOC concentrations to less than cleanup goals. In situ biological treatment or enhanced biodegradation is particularly useful to remediate localized areas of high chlorinated solvent contamination, before initiating actions such as MNA and institutional controls. Furthermore, passive injection of innocuous substrates, an extremely economical and simple application, is all that is required for some sites. Therefore, because of its demonstrated effectiveness at VOC-contaminated sites, enhanced biodegradation was retained for further evaluation.

## **5.0 DEVELOPMENT AND EVALUATION OF ALTERNATIVES**

The purpose of the detailed analysis of the alternatives is to provide decision-makers with the information needed to evaluate the proposed SWMU 39 site remedy. During the detailed analysis, each alternative is assessed against the evaluation criteria described in USEPA OSWER Directive Number 9902.3-2A.

### **5.1 Evaluation Process**

The evaluation process provides decision-makers with the information they need to adequately evaluate each alternative and satisfy RCRA requirements for selecting the remedial action.

#### **Primary Criteria**

Four primary evaluation criteria have been developed to address the RCRA requirements and their additional technical and policy considerations. The evaluation criteria with the associated statutory considerations that must be met are:

- Primary Criteria 1: Protection of human health and the environment
- Primary Criteria 2: Attainment of cleanup standards
- Primary Criteria 3: Source control
- Primary Criteria 4: Compliance with applicable waste management standards

#### **Secondary Criteria**

Five other general factors are considered. These factors combine technical measures and management controls to address the environmental problems at SWMU 39. The remedial alternative is evaluated with respect to these criteria, as described in the following sections.

- Secondary Criteria 1: Long-term reliability and effectiveness
- Secondary Criteria 2: Reduction in waste toxicity, mobility, or volume
- Secondary Criteria 3: Short-term effectiveness

- Secondary Criteria 4: Implementability
- Secondary Criteria 5: Cost

### **5.1.1 Protection of Human Health and the Environment**

Corrective action remedies must be protective of human health and the environment. The remedial alternative must satisfy this criterion to be eligible for selection. Evaluation of this criterion should provide a final measure to assess whether each alternative adequately protects human health and the environment. The overall assessment of protection draws on the assessments conducted under other evaluation criteria, especially long-term reliability and effectiveness, short-term effectiveness, and compliance with applicable waste management standards.

Evaluation of the overall protectiveness of a remedial alternative should gauge whether an alternative achieves adequate protection by eliminating, reducing, or controlling the risks each pathway poses through treatment, engineering, or ICs. This evaluation considers whether an alternative poses any unacceptable short-term or cross-media impacts.

### **5.1.2 Attainment of Cleanup Standards**

Remedies will be required to attain media cleanup standards set by the implementing agency, which may be derived from existing state or federal regulations (e.g., groundwater standards) or other standards. The media cleanup standards for a remedy will often play a large role in determining the extent of the remedy and technical approaches to it. In some cases, certain technical aspects of the remedy, such as the practical capabilities of remedial technologies, may influence to some degree the media cleanup standards that are established.

In addition, this CMS evaluates whether the potential remedial technology will achieve the remediation objective identified by the implementing agency. The estimated time for the alternative to meet these standards will also be discussed.

### **5.1.3 Source Control**

A critical objective of any remedy must be to stop further environmental degradation by controlling or eliminating further releases that may threaten human health and the environment. Unless source control measures are taken, efforts to clean up releases may be ineffective or, at best, will essentially involve a perpetual cleanup. Therefore, an effective source control program is essential to ensure the long-term effectiveness and protectiveness of the corrective action program.

This CMS report also evaluates whether source control measures are necessary, and if so, the type of actions that would be appropriate. For any proposed source control measure, estimated effectiveness is discussed based on site conditions and the history of the specific technology.

### **5.1.4 Compliance with Applicable Waste Management Standards**

Corrective action remedies must comply with applicable waste management standards. To be eligible for selection, the alternative must satisfy this criterion, which is used to evaluate whether the alternative will meet federal and state waste management standards identified in previous stages of the remedial process.

### **5.1.5 Long-Term Reliability and Effectiveness**

The evaluation of the alternatives under this secondary criterion addresses the results of a remedial action in terms of the risk remaining at the site after response objectives have been met. The primary focus of this evaluation is the extent and effectiveness of the controls that may be required to manage the risk posed by treatment residuals and/or untreated wastes. Two factors should be addressed for the alternative:

*Magnitude of Residual Risk:* This factor assesses the residual risk from untreated waste or treatment residuals at the conclusion of remedial activities. This risk may be measured by numerical standards such as cancer risk levels or the volume or concentration of constituents in waste, media, or treatment residuals remaining onsite.

*Adequacy and Reliability of Controls:* This factor assesses the adequacy and suitability of any controls used to manage treatment residuals or untreated wastes remaining onsite. It may include an assessment of containment systems and ICs to determine if they are sufficient to ensure that any exposure to human and environmental receptors is within protective levels.

### **5.1.6 Reduction in Waste Toxicity, Mobility, or Volume**

This criterion addresses the preference for remedial actions employing treatment technologies that permanently and significantly reduce the toxicity, mobility, or volume of hazardous substances. The evaluation should consider the following specific factors:

- The treatment processes, the remedies they will use, and the materials they will treat
- The amount of hazardous materials that will be destroyed or treated
- How principal threat(s) will be addressed
- The degree of expected reduction in toxicity, mobility, or volume, measured as a percentage of reduction (or order of magnitude), when possible
- The degree to which the treatment will be irreversible
- The type and quantity of treatment residuals that will remain following treatment

### **5.1.7 Short-Term Effectiveness**

The short-term effectiveness of a remedial alternative is evaluated relative to its effect on human health and the environment during implementation. Short-term effectiveness is based on four key factors:

- Risks to the community during implementation
- Risks to workers during implementation
- Potential for adverse environmental impact as a result of implementation
- Time until remedial response objectives are achieved

### **5.1.8 Implementability**

This criterion addresses the technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during its implementation. It involves analysis of the following factors:

#### **Technical Feasibility**

- Technical difficulties and unknowns associated with construction and operation.
- Potential technical problems during implementation that may lead to schedule delays.
- Ease of remedial action and potential future activities based on technology performance.
- Ability and ease of monitoring the remedy's effectiveness, including an evaluation of the risks of exposure if monitoring does not detect a system failure.

#### **Administrative Feasibility**

Activities needed to coordinate with other offices and agencies.

#### **Availability of Services and Materials**

- Availability of adequate offsite treatment, storage capacity, and disposal services.
- Availability of necessary equipment, specialists, and provisions to ensure any necessary additional resources.
- Potential to obtain competitive bids, which may be particularly important for innovative technologies.

- Availability of prospective technologies.

### **5.1.9 Cost**

A detailed cost estimate for the remedial alternative is based on engineering analyses, suppliers' estimates of necessary technology, and costs for similar actions (such as excavation) at other RCRA sites. The cost estimate for a remedial alternative typically consists of four principal elements: capital cost, annual operation and maintenance (O&M) costs, costs for evaluation reports, and present-worth analysis. Costs are expressed in 2003 dollars.

#### **Capital Costs**

- *Direct costs* for equipment, labor, and materials used to develop, construct, and implement a remedial action.
- *Indirect costs* for engineering, financial, and other services that are not actually part of construction, but are required to implement a remedial alternative. The percentage applied to the direct cost varies with the degree of difficulty associated with construction and/or implementation of the alternative. In this CMS, the indirect costs include health and safety items, permitting and legal fees, bid and scope contingencies, engineering design and services, and miscellaneous supplies or costs.

#### **Annual O&M Costs**

These are post-construction costs necessary to ensure the continued effectiveness of a remedial action, i.e., long-term power and material (such as the operation of a water treatment facility), equipment replacement, and long-term monitoring.

#### **Evaluation Reports**

These costs are associated with reports that evaluate the results of the selected alternative.

### **Present-Worth Analysis**

This analysis makes it possible to estimate the cost of a remedial alternative on the basis of a single cost representing an amount that would be sufficient to cover all costs associated with the remedial action during its planned life, if invested in the base year and disbursed as needed. A performance period appropriate to an alternative is assumed for present-worth analyses. Discount rates of 6% are assumed for base calculations. An increase in the discount rate decreases the present worth of the alternative.

The cost elements for the remedial alternative are summarized in the cost analysis section. The study estimate cost provided for the alternative is intended to reflect actual costs with an accuracy of minus 30% to plus 50%, in accordance with USEPA guidelines.

## **5.2 Development and Evaluation of Groundwater Remedial Alternatives**

Depending on the potential to achieve remedial objectives and property reuse considerations, the treatment alternative will include some level of ICs and monitoring. Two alternatives have been developed from the technologies described in Section 4.

- Alternative 1: MNA
- Alternative 2: Enhanced Biodegradation with MNA

### **5.2.1 Alternative 1: MNA**

MNA is a site management strategy used where contaminant degradation rates are fast enough to protect human health and the environment under natural conditions.

#### **5.2.1.1 Technology Description**

Natural attenuation or monitored natural attenuation (MNA) is best described as the use of natural biological, physical, and chemical processes to contain the spread of COCs at hazardous waste release sites, reduce their concentrations in the subsurface, and transform them into nontoxic or less toxic end products. It applies to organic wastes such as

petroleum compounds and chlorinated solvents, as well as inorganic materials such as metal wastes. MNA is increasingly being used as a remedial alternative at sites contaminated with chlorinated VOCs such as TCE.

Once thought to be persistent in the environment, chlorinated VOCs have been the subject of much research since the mid-1990s. Numerous studies evaluated the degradation mechanisms for chlorinated VOCs under natural conditions. The most common mechanism, described in the USEPA's protocol for MNA (USEPA, 1998a), is reductive dechlorination for sequential anaerobic pathways (such as iron reduction, sulfate reduction, and methanogenesis). Other natural attenuation mechanisms include contaminant dispersion, dilution, adsorption, volatilization, and chemical or biological stabilization. However, if contaminant biodegradation (destruction) is not occurring, these nondestructive mechanisms may require supplemental active remedial technologies to protect human health and the environment.

### **Common Destructive Pathways**

Natural biological attenuation uses naturally occurring microorganisms to break down or degrade hazardous substances into less toxic or nontoxic ones. Degradation can occur via several metabolic pathways depending on the chemistry and geochemistry of the site groundwater. These pathways can be broadly classified as being anaerobic, aerobic, or cometabolic. The most common metabolic pathways for chlorinated solvent degradation are summarized below.

#### ***Reductive Dechlorination***

Reductive dechlorination is the most important process in chlorinated solvent biodegradation. This process occurs when chlorine atoms in compounds such as perchloroethane (PCE), TCE, and trichloroethane (TCA) are substituted with hydrogen to successively transform these compounds into daughter products such as *cis*-1,2-DCE and vinyl chloride (VC). In this pathway, the chlorinated solvent is the electron acceptor. Reductive dechlorination generally occurs only under reducing conditions, i.e., the aquifer must be reduced or anaerobic in nature (low in dissolved oxygen). An electron donor (carbon source) also is required. Geochemical analysis is

generally required to demonstrate reducing conditions. The reductive dechlorination process could proceed beyond VC to eventually produce innocuous gaseous end products such as ethene. Though highly reducing conditions are required for complete dechlorination to occur, *cis*-1,2-DCE has been found to degrade to VC under slightly anaerobic conditions. Often, because of the natural reductive dechlorination process, intermediate biological breakdown products (*cis*-1,2-DCE and VC) are formed which could also then degrade via different metabolic pathways, such as aerobic cometabolism or direct oxidation.

### ***Direct Oxidation***

Oxidation also is an important mechanism for the degradation of daughter products such as DCE and VC. In this process, the chlorinated solvents can be used as an electron donor. Direct oxidation can proceed either aerobically (in the presence of oxygen) or anaerobically, where iron or nitrate serve as the electron acceptor to complete the metabolic process. Direct oxidation is often an important step in downgradient sections of a chlorinated VOC plume, which tend to be more oxygenated or contain higher nitrate and oxidized iron concentrations.

The ability of an aquifer to naturally oxidize *cis*-1,2-DCE and VC is particularly important at sites where in situ bioremediation is being implemented to promote reductive dechlorination of TCE. In such a situation, the daughter products DCE and VC could either further dechlorinate, accumulate, or oxidize under the appropriate natural conditions. These conditions include an aerobic environment (oxygen); or the presence of nitrate or oxidized iron in an anaerobic environment that facilitates direct bacterial oxidation of *cis*-1,2-DCE and VC.

### ***Anaerobic Cometabolism***

Anaerobic cometabolism of parent chlorinated compounds (PCE, TCE, and TCA) generally occurs when natural methanogenic, acetogenic, and sulfate reducer microorganisms mediate the fortuitous degradation of these compounds. These microorganisms have been found to possess metal-porphyrin-containing co-factors that can mediate the slow, incomplete reductive dechlorination of PCE and TCE to DCE (Gossett and Zinder, 1996). The process is cometabolic in

that it happens more or less incidentally as the organisms carry on their normal metabolic functions; that is, they derive no growth or energy-linked benefits from the reductive dechlorination itself. Generally, the microorganisms that mediate such processes are ubiquitous. However, the process is much slower than reductive dechlorination (Gossett and Zinder, 1996) and is hard to distinguish from direct reductive dechlorination at most sites.

### ***Aerobic Cometabolism***

Aerobic cometabolism is similar to anaerobic cometabolism, but occurs in oxygenated conditions. It is a much faster process and is applicable to most chlorinated solvents with the exception of PCE (USEPA, 1998). Under conditions that support aerobic metabolism, the lesser chlorinated solvents (*cis*-1,2-DCE and VC in particular) are degraded by cometabolism. Certain aerobic microorganisms generate oxygenase enzymes of broad substrate specificity that oxidize chlorinated solvents (USEPA, 1998). Microorganisms derive no growth-linked or energy-conserving benefit from this fortuitous degradation. Several types of microorganisms are capable of carrying on the process. During the cometabolism of chlorinated solvents, other microorganisms derive their energy from organic compounds such as methane, propane, phenol, toluene.

### ***Chemical Degradation***

This process includes hydrolysis and chemical elimination. It is a much slower process than the reductive/oxidative processes, but may be found to occur when a contaminant exists for long periods of time at a site. The two parent chlorinated solvents which most commonly undergo chemical transformation are 1,1,1-TCA and 1,2-DCA. Generally, the presence of 1,1-DCE at a site is indicative of its chemical breakdown via elimination from 1,1,1-TCA (USEPA, 1998a). Therefore, chemical breakdown mechanisms merit consideration at sites where MNA is being evaluated.

### **Common Nondestructive Pathways**

Other natural attenuation mechanisms commonly include contaminant advection, dispersion, dilution, volatilization, and adsorption.

- Advection — Movement of solute by bulk groundwater movement.
- Dispersion — Fluid mixing due to groundwater movement and aquifer heterogeneity.
- Diffusion — Described by Fick's Law, diffusion refers to the spreading and dilution of a contaminant as it migrates from zones of higher concentrations to those of lower concentrations.
- Dilution — Movement of uncontaminated water into a contaminated zone.
- Volatilization — Partitioning of dissolved contaminants from the dissolved phase to air.
- Adsorption — Reaction between aquifer matrix and solute whereby relatively hydrophobic compounds become sorbed to organic carbon or clay minerals.

The rates of nondestructive mechanisms are relatively slow relative to the biodegradation rates. Nevertheless, these abiotic mechanisms do contribute to overall contaminant reduction, particularly when aquifer geochemistry does not favor biodegradation (e.g., low availability of electron donor or carbon sources).

### **Geochemistry**

Direct evidence of natural attenuation typically involves evaluation of analytical data from the site to determine the relative presence of parent compounds (e.g., TCE) as opposed to degradation (or daughter) products such as 1,2-DCE and VC. If daughter products are identified, some degree of natural attenuation is occurring. If complete degradation is observed between the source area and the downgradient compliance point, natural attenuation may be effective at degrading site contaminants. Appropriate supporting evidence is necessary to conclude the efficacy of natural attenuation.

The most important factor that governs the potential or feasibility of natural attenuation is the aquifer geochemistry. The USEPA has suggested a list of geochemical parameters for groundwater MNA evaluation (USEPA, 1998a). This data can either be quantified in screening tables or analyzed quantitatively to provide the strength of evidence for MNA occurrence and feasibility. Each parameter bears its own significance in the determination of MNA occurrence. The following outlines the chemical and geochemical parameters and their significance in MNA evaluation of chlorinated solvents.

All of these data combined with the geochemical interpretation can be used to infer whether MNA may be the sole remedy, part of a remedy, or whether biological enhancement is the preferred option.

### ***Dissolved Oxygen***

The dissolved oxygen (DO) content of water in an aquifer indicates whether the aquifer is aerobic or anaerobic. Oxygen provides the most thermodynamically favorable respiratory pathway (or electron acceptor) used by microorganisms for biodegradation. DO concentrations are very critical to natural attenuation of chlorinated solvents. Because anaerobic bacteria generally cannot function at DO concentrations greater than 0.5 milligrams per liter (mg/L), reductive dechlorination generally does not proceed effectively when DO concentrations exceed this level. The oxygen needs to be depleted before the bacteria begin utilizing other electron acceptors because most microorganisms prefer to use oxygen for respiration (USEPA, 1998a). Generally, the sequence of electronic acceptor use proceeds from DO to nitrate, followed by ferric iron (Fe [III]), sulfate, and finally carbon dioxide (methanogenesis). Each sequential microbial reaction or geochemical condition renders the aquifer more anaerobic, creating favorable conditions for complete reductive dechlorination. These biochemical mechanisms can also occur simultaneously, particularly under strongly anaerobic conditions.

As the parent compound is reduced to less chlorinated compounds, aerobic conditions can play a more significant role to further degrade daughter products. This often occurs at the downgradient

or leading edge of a plume, resulting in cometabolic or oxidative destruction of compounds such as *cis*-1,2-DCE or VC (USEPA, 1998a).

### ***Oxidation-Reduction Potential***

The ORP indicates the relative oxidized or reduced state of groundwater in an aquifer. Biological processes generally occur within a prescribed ORP range (USEPA, 1998a). For instance, an ORP of less than 50 millivolts (mV) indicates reducing conditions (groundwater depleted of DO). ORP levels greater than 50 mV indicate aerobic groundwater conditions that will tend to hinder reductive dechlorination but promote aerobic degradation of lesser chlorinated daughter product such as DCE and VC. ORP levels below -100 mV are ideal for reductive dechlorination.

Though ORP is a useful parameter in MNA evaluation, it is difficult to measure in the field. Groundwater often contains constituents in ionic pairs that are not in a state of equilibrium. Each ionic electrode is sensitive to a specific ion pair. Unless the groundwater is at equilibrium, ORP measurement remains questionable in certain aquifers. Therefore, field-measured ORPs should be used with discretion for evaluation purposes.

### ***Nitrate***

Nitrate is the next favored electron acceptor for anaerobic degradation of chlorinated solvents after DO has been used by microorganisms. Nitrate concentrations greater than 1.0 mg/L in the contaminated portion of the aquifer could inhibit natural reductive dechlorination. However, nitrate can also facilitate the anaerobic oxidation of lesser chlorinated compounds such as *cis*-1,2-DCE and VC, particularly at the fringes of plumes.

### ***Total Organic Carbon***

TOC concentrations in the aquifer are used to assess the amount and distribution of electron donors that microorganisms require to degrade chlorinated solvents metabolically. TOC may be natural organic carbon or anthropogenic carbon (e.g., BTEX and other petroleum constituents). The USEPA has specified that 20 mg/L is a desirable TOC concentration

for biodegradation (USEPA, 1998a). However, 20 mg/L is relative to the amount of chlorinated solvents in the aquifer and the type of TOC present. Additionally, the chemical nature of natural organic carbon could also influence its usefulness. Therefore, TOC utilization involves a qualitative understanding of site degradation characteristics in addition to the USEPA-stipulated criteria. At some sites, TOC at low concentrations of 2 to 5 mg/L could be sufficient to carry out the reductive dechlorination of chlorinated solvents.

### ***Ferrous Iron***

Fe(II) can be produced from ferric iron (Fe[III]) by microbial activity. Reduction from Fe(III) to Fe(II) can occur during anaerobic degradation of natural or anthropogenic carbon, or during reductive dechlorination of the lesser chlorinated by-products of PCE and TCE, namely DCE and VC. As such, Fe(II) concentrations in the aquifer indicate the possibility of chlorinated solvent degradation (particularly VC). In addition to Fe(II) measurements, total iron measurements can provide an indication of the amount of iron that is available for iron-mediated biological oxidation.

### ***Sulfate and Sulfide***

After microbes have depleted DO, nitrate, and iron, sulfate is likely to be the next preferred electron acceptor. Sulfate reduction results in the production of sulfide. Sulfate concentrations greater than 20 mg/L can reduce the efficiency of reductive dechlorination because sulfate can compete with chlorinated solvents as the preferred electron acceptor. The presence of sulfide in the aquifer indicates that conditions are conducive to the reductive dechlorination process. Sulfide is often hard to detect in groundwater because of its tendency to precipitate with iron and other metals in reduced environments.

### ***Methane***

During methanogenesis, carbon dioxide is used as an electron acceptor and is converted to methane. Methanogenesis generally occurs after microorganisms have used the available oxygen, nitrate, and sulfate. The presence of methane in the aquifer indicates strongly reducing conditions (commonly ORP is less than -250 mV). Methane is particularly useful as the groundwater

transitions from anaerobic conditions to an aerobic environment and still carries relatively high concentrations of methane to facilitate cometabolic degradation of chlorinated solvents.

### ***Dissolved Hydrogen***

Dissolved hydrogen in groundwater is the most reliable parameter for evaluating redox processes in natural attenuation. Nitrate-, ferric-, sulfate-, and carbon dioxide-reducing microorganisms exhibit different efficiencies in utilizing hydrogen in groundwater (USEPA, 1998a). The first two (nitrate and ferric iron) are very efficient hydrogen utilizers, and therefore maintain lower hydrogen concentrations in groundwater. The latter two (sulfate and carbon dioxide) are less efficient and maintain relatively higher hydrogen concentrations in groundwater. TCE degradation occurs best under sulfate-reducing or carbon dioxide-reducing conditions (methanogenesis). Therefore, groundwater hydrogen measurements can be used very effectively to distinguish among the various redox zones or within plumes in a contaminated aquifer, and indirectly the potential efficacy of MNA. Hydrogen concentrations of 3 nanoMolar (nM), or higher typically indicate conditions more conducive to complete reductive dechlorination of chlorinated solvents.

### ***Alkalinity***

Alkalinity commonly increases when chlorinated VOCs are completely degraded. Therefore, groundwater alkalinity in a plume, relative to background concentrations, could indicate the level of microbial activity and serve as an indirect indicator of chlorinated solvent biodegradation.

### ***Chloride***

Chloride produced by reductive dechlorination is generally inert and can serve as a conservative indicator of chlorinated solvent degradation in an aquifer. Reductive dechlorination generally results in chloride concentrations greater than background levels in the contaminated portion of the aquifer, and could therefore be an indirect estimator of microbial activity.

### ***Carbon Dioxide***

Carbon dioxide concentrations in groundwater can be used to distinguish between zones of heightened bioactivity in the subsurface. Often, contaminated areas that contain carbon dioxide concentrations considerably higher than background indicate greater biological activity.

### ***pH and Temperature***

pH and temperature are common environmental factors that affect microbial activity. Microorganisms capable of degrading chlorinated solvents generally prefer a pH between 6 and 8 standard units. Groundwater temperature also affects microbial activity, which tends to increase with temperature up to a certain level. Below certain temperatures (generally 10°C), microbial activity decreases until it is negligible at freezing temperatures.

### ***VOCs***

Analyses of VOCs are used to determine the type, concentration, and distribution of contaminants and daughter products in the aquifer. The presence and distribution of certain daughter products can indicate the extent of parent-compound degradation. VOC data can be used to infer whether the concentrations of the contaminant or its daughter products are decreasing in the direction of groundwater flow. VOC data collected over time can be used to estimate trends and plan long-term monitoring approaches for MNA verification.

#### **5.2.1.2 MNA Application at SWMU 39**

Four MNA sampling events have been conducted at SWMU 39 since June 2002. Geochemical and VOC data collected from targeted wells for each of the four sampling events are summarized in Appendix A, Tables A-2, A-4, A-6, and A-8. The data were then used to estimate the potential for natural biodegradation and evaluate whether this alternative would be reliable and effective. The scored evaluations for each of the four sampling events are also summarized in Appendix A, Tables A-3, A-5, A-7, and A-9, respectively.

Based on the USEPA protocol, SWMU 39 monitoring well data indicate that some natural bioattenuation is occurring in the aquifer. In addition to bioattenuation, other mechanisms, such as dispersion and dilution, could also contribute to reduction in contaminants. However, natural attenuation at the rate at which it is perceived to be occurring, could take a very prolonged period of time before it reduces contaminants to the required levels. While one or two wells (02LF and 04LF) did show adequate evidence for MNA during one sampling event, many of the wells show inadequate or limited evidence of natural biological reductive dechlorination of chlorinated solvents. Specific findings are described below.

- DO appears to fluctuate to some extent at the site, particularly in areas where higher TCE concentrations exist. DO data indicate a slightly aerobic environment which could support limited reductive dechlorination of TCE, but should be conducive to direct bio-oxidation of daughter products *cis*-1,2-DCE and VC.
- Low TOC concentrations may be limiting microbial activity. For reductive dechlorination to occur naturally, sufficient TOC must be present in the groundwater. At this site, it appears that the TOC may not be sufficient to sustain reductive dechlorination of TOC.
- The presence of isolated *cis*-1,2-DCE detections suggests some natural chlorinated solvent degradation. Isolated *cis*-1,2-DCE could also indicate that only a small fraction of the TCE is reductively dechlorinating under natural conditions. Except for an isolated occurrence, VC concentrations remain less than detection limits. This suggests that any *cis*-1,2-DCE and VC that is being formed could be undergoing either aerobic or iron-mediated oxidation.
- Ferrous iron is generally present in relatively high concentrations and usually exceeds 1.0 mg/L in aquifers that are reducing. One-half of SWMU 39 wells had ferrous iron concentrations exceeding 1.0 mg/L. The presence of ferrous iron highlights an important aspect of natural biodegradation. Its presence indicates that daughter products such as *cis*-1,2-DCE and VC could be degrading, with

native microorganisms using iron as the electron acceptor (forming ferrous iron in the process) and the contaminant (DCE or VC) as the energy source.

In summary, the above discussion indicates that some natural TCE bioattenuation (MNA) is occurring in the aquifer. However, geochemical inadequacies (DO, TOC, etc.), may limit the rate of degradation. Because the aquifer contains relatively high concentrations of ferrous-iron and is slightly aerobic, it is more conducive to direct oxidation of the lesser-chlorinated daughter products, i.e. *cis*-1,2-DCE and VC. Therefore, the aquifer is very likely to support natural attenuation of these daughter products.

To overcome the limitations noted during MNA evaluation, groundwater will likely have to be amended with an organic compound (which it is now lacking) to sustain rapid reductive dechlorination. In other words, the observed natural attenuation can be enhanced by modifying the environment to increase TCE degradation rates and reduce remediation and monitoring time. A pilot study that was conducted at a selected location within Area of Concern A (AOC A) on the Northside of NSA Mid-South proved that enhanced biodegradation was feasible and effective at treating TCE-contaminated groundwater in the fluvial deposits aquifer. An organic food source was added during the study to create an anaerobic environment, which supported the reductive dechlorination of TCE. Reducing conditions (low DO) were created and a 50% reduction in TCE mass in the area was achieved during the pilot study. Enhanced biodegradation is now being implemented at AOC A. A similar approach could be effective to treat TCE in groundwater at SWMU 39. Due to the pilot study success, MNA coupled with enhanced biodegradation could be an effective remedial approach.

### **Institutional Controls**

One or more of the following ICs would be required as part of the MNA alternative:

- Groundwater-use restriction — would likely include prohibitions on well drilling in the fluvial deposits/upper Cockfield Formation aquifer

- Easement — provisions in any subsequent property transfer agreements that would allow for continued access for groundwater monitoring activities
  
- Covenant — provisions in any subsequent property transfer agreements that would restrict groundwater use
  
- Reversionary interest — places a condition on a potential transferee's right to own and occupy the land; if violated (e.g., groundwater is used), the property could be returned to the Navy
  
- Informational devices — tools (e.g., deed notices, state registries of hazardous waste sites, and advisories), which often rely on property record systems, used to provide public information about risks from contamination
  
- Site access controls — would likely include fences, signs, gates, and additional site personnel

### **Monitoring**

Annual sampling would be required to gauge the efficacy of natural attenuation. Thirteen SWMU 39 wells would be sampled for the analytes/parameters listed below. Sampling would continue for 30 years or until VOC concentrations were consistently less than MCLs (i.e., three consecutive years).

#### Laboratory Parameters

- VOCs (method: SW8260B)
- methane, ethane, and ethene (8015MOD)
- nitrate (E300)
- TOC (SW9060)
- major cations (SW6010)

#### Field Parameters

- ferrous iron
- sulfate and sulfide
- DO
- ORP
- pH
- temperature
- alkalinity
- chloride

### 5.2.1.3 Evaluation of MNA Primary Criteria

#### Protection of Human Health and the Environment

MNA evaluation results indicate that chlorinated VOCs are not biodegrading at rates sufficient enough to attain MCLs. Therefore, this alternative by itself cannot ensure the protection of human health and the environment. However, MNA could be paired with an active (engineered) remedial technology to address VOC-contaminated groundwater. MNA would serve as the final polishing step for remedial treatment. Attenuation (as the final polishing step) would likely occur via aerobic biodegradation or iron-reducing of daughter products.

#### Attainment of Cleanup Standards

MNA does not appear to be attaining cleanup goals within the site boundary. Without another remedial alternative, contaminants would remain at concentrations greater than cleanup standards indefinitely.

#### Source Control

Based on extensive RFI sampling results, there is no defined VOC "source area" for the fluvial deposits/Cockfield Formation groundwater at SWMU 39. Nonetheless, there is insufficient natural attenuation to prevent contaminants from potentially migrating offsite. Lacking another active remedial technology, MNA would not be able to provide adequate source control.

### **Compliance with Applicable Waste Management Standards**

No waste would be managed under this alternative; therefore, waste management standards do not apply.

#### **5.2.1.4 Evaluation of MNA Secondary Criteria**

##### **Long-Term Reliability and Effectiveness**

As discussed in Section 5.2.1.2, geochemical data and the scoring/ranking system suggests that MNA is unlikely to be an effective long-term remedy by itself. Most SWMU 39 monitoring wells show inadequate or limited evidence of natural chlorinated VOC reductive dechlorination. Therefore, an active remedial alternative coupled with MNA could then be a polishing step following active or enhanced biodegradation. As such, an active remedial alternative, ICs, and long-term system monitoring would be required to implement this alternative.

##### **Reduction in Toxicity, Mobility, and Volume**

By itself, natural attenuation is not capable of reducing contaminant toxicity, mobility, and volume at SWMU 39. There is marginal evidence of chlorinated VOC biodegradation, which if working, would provide some mass reduction. If implemented as a secondary remedial alternative, MNA could be used to mitigate further VOC migration of daughter compounds DCE and VC produced from enhanced biodegradation of TCE. These compounds could attenuate via aerobic biodegradation or iron-mediated biological oxidation (dilution, dispersion, volatilization, etc.)

##### **Short-Term Effectiveness**

MNA implementation would not cause any short-term risks to workers. Appropriate personal protective equipment would be used during scheduled groundwater sampling events to minimize worker risk.

## **Implementability**

MNA is technically and administratively feasible and easily implemented. No construction, operation, or maintenance issues are initially involved with this alternative. MNA would not require offsite treatment services, materials, or innovative engineering technologies. Current access controls, including military security and limited personnel access, have been reliable at sites at NSA Mid-South in the past. ICs described in Section 5.2.1.2 could be implemented to restrict groundwater use in this area even if the property is transferred to another owner. Other than ICs, no administrative coordination would be required to implement MNA.

## **Cost**

As shown in Table 5-1, the total cost for this alternative is \$699,450. Capital costs are estimated to be \$96,000; annual costs would be \$43,840. As appropriate, the long-term monitoring program can be shortened with contaminant attenuation and regulatory approval.

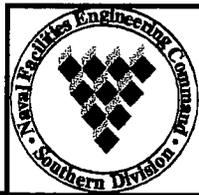
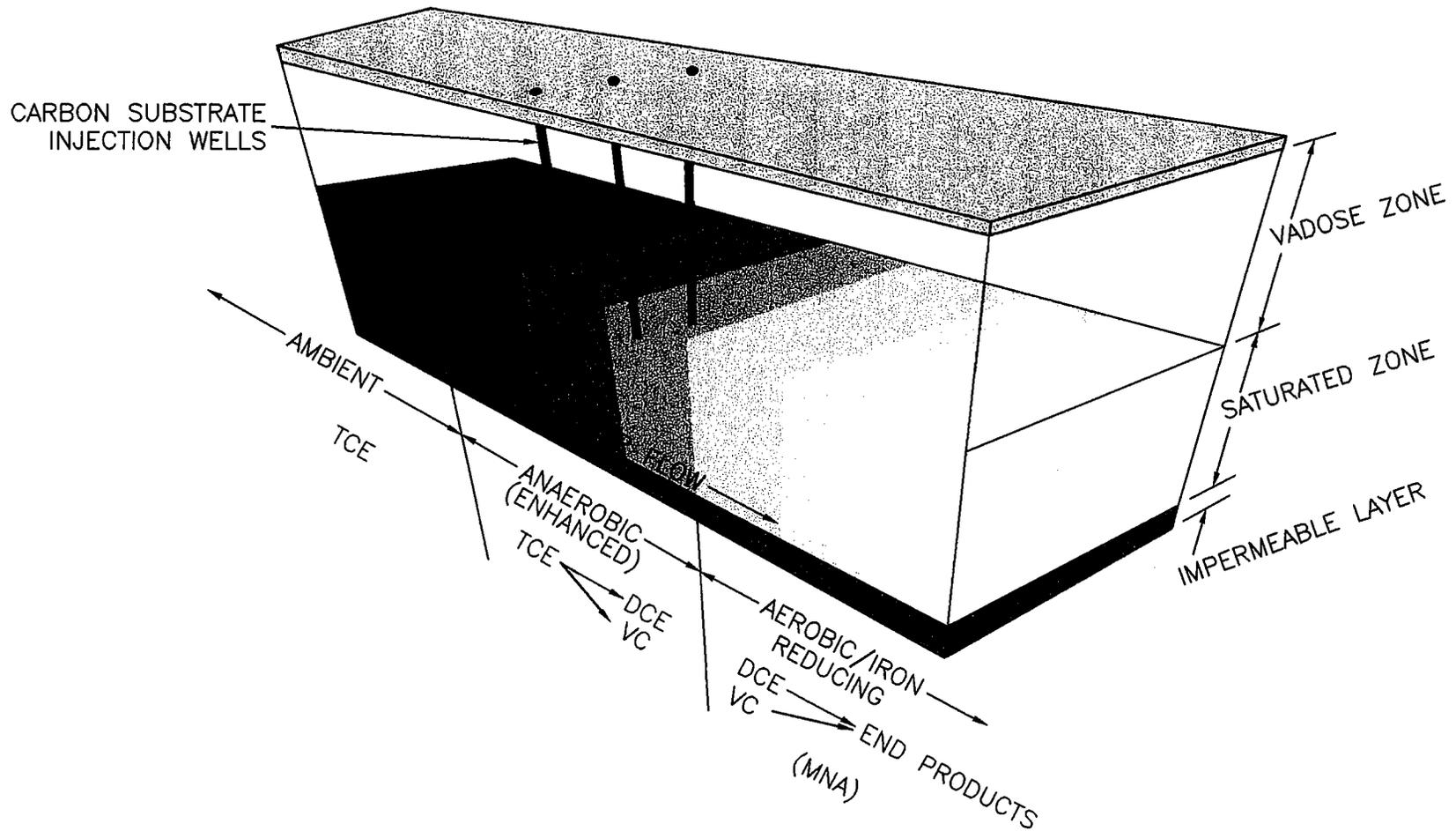
### **5.2.2 Alternative 2: Enhanced Biodegradation with MNA**

Enhanced biodegradation comprises subsurface zones where migrating contaminants, such as TCE, are intercepted and permanently immobilized or biodegraded into either lesser chlorinated daughter products, such as DCE or VC, or innocuous end products, such as ethane. Redox manipulation, if applied strategically in plume areas, would be a more aggressive remedial strategy than relying only on natural attenuation/reduction.

MNA, as described in Section 5.2.1, would be used to address the lesser chlorinated VOCs formed from the TCE reduction.

#### **5.2.2.1 Technology Description**

Enhanced biodegradation relies on groundwater flowing through created anaerobic zones (Figure 5-1), to treat TCE contamination. The anaerobic zone reduces the highly chlorinated VOCs (TCE) to lesser chlorinated VOCs (1,2-DCE and VC), which are subsequently degraded to innocuous end products via natural biodegradation.



CMS REPORT  
 SWMU 39  
 FLUVIAL DEPOSITS GROUNDWATER  
 NSA MID-SOUTH  
 MILLINGTON, TN

FIGURE 5-1  
 ENHANCED BIODEGRADATION WITH MNA  
 CONCEPTUAL DIAGRAM

DWG DATE: 09/18/03 | NAME: 0094001W027

Corrective Measures Study Report  
 Naval Support Activity Mid-South — SWMU 39  
 Section 5 — Development and Evaluation of Alternatives  
 September 26, 2003

<b>Table 5-1 MNA Costs</b>			
	<b>Quantity</b>	<b>Unit Cost</b>	<b>Total Cost</b>
<b>Capital Costs</b>			
Engineering design and planning	LS	\$25,000	\$25,000
Groundwater and solute transport modeling	LS	\$25,000	\$25,000
Institutional controls	LS	\$25,000	\$25,000
Sampling equipment	LS	\$5,000	\$5,000
		20% contingency	\$16,000
		<b>Total capital costs</b>	<b>\$96,000</b>
<b>Annual Costs</b>			
Field technicians	100 hours	\$100/hour	\$10,000
Laboratory sampling and analysis	15 samples	\$650/sample	\$9,750
Field sampling and analysis	LS	\$2,000	\$2,000
Sampling equipment	LS	\$5,000	\$5,000
Data review and reporting	100 hours	\$100/hour	\$10,000
Miscellaneous expenses and travel	LS	20% cost	\$7,090
		<b>Subtotal Annual Costs</b>	<b>\$43,840</b>
		<b>Present value subtotal at 6% for 30 years</b>	<b>\$603,450</b>
<b>Total</b>			
		<b>MNA Total</b>	<b>\$699,450</b>

**Note:**  
 LS — Lump Sum

Carbon (e.g., fructose or acetate) and nutrients (e.g., diammonium phosphate) are injected in designed amounts to the hot spot locations (i.e., locations of the highest concentrations of TCE). The carbon and nutrients provide a food source that stimulates microbial respiration, resulting in DO consumption. This will create an anaerobic zone in the hot spot area. As discussed previously, highly chlorinated solvents such as TCE are amenable to reductive dechlorination under anaerobic conditions.

Again, anaerobic reductive dechlorination forms lesser chlorinated daughter products, namely *cis*-1,2-DCE and VC. However, unlike TCE, these compounds can break down more readily

in an aerobic environment. Therefore, the lesser chlorinated daughter products should attenuate naturally in the current aerobic and iron-enriched SWMU 39 environment that is currently present at SWMU 39. In the unlikely event that it is needed, an aerobic zone may be created downgradient of the injection wells by injecting air into the aquifer using sparging wells connected to an aboveground blower. Sparging rates are based on groundwater DO concentrations in area monitoring wells, and sparging is generally performed intermittently and at low flow rates. Carbon and nutrients can also be added to the air-sparging wells to enhance the aerobic degradation of 1,2-DCE and VC. Aerobic degradation of VC forms innocuous end products such as CO<sub>2</sub> and water.

Without a known VOC source, full-scale treatment using enhanced biodegradation would be as simple as strategically injecting carbon into the lower part of the fluvial deposits aquifer to reductively dechlorinate VOCs. With slow groundwater velocities and low VOC concentrations, routine carbon-source injection (as distinguished from one-time applications, e.g., vegetable oil or hydrogen release compounds) using a line of wells would quickly address "hot spots," which could be used to create an aqueous biobarrier or an anaerobic zone perpendicular to groundwater flow (as shown in Figure 5-1).

#### **5.2.2.2 Enhanced Biodegradation with MNA: Application at SWMU 39**

At this time, it appears that a soluble (rather than an insoluble or slowly soluble) organic substrate would be more effective at enhancing aquifer geochemistry to promote relatively rapid biodegradation at SWMU 39. Soluble organic amendments would be injected into the lower part of the fluvial deposits aquifer or infiltrated into it to promote TCE biodegradation, under anaerobic conditions. TCE would be anaerobically biodegraded to *cis*-1,2-DCE and VC, which would degrade naturally to harmless end products in the downgradient aerobic and iron-reducing zone. Sparging wells could be installed to introduce additional DO to the second treatment zone if necessary to enhance aerobic degradation of *cis*-1,2-DCE and VC.

## **System Design**

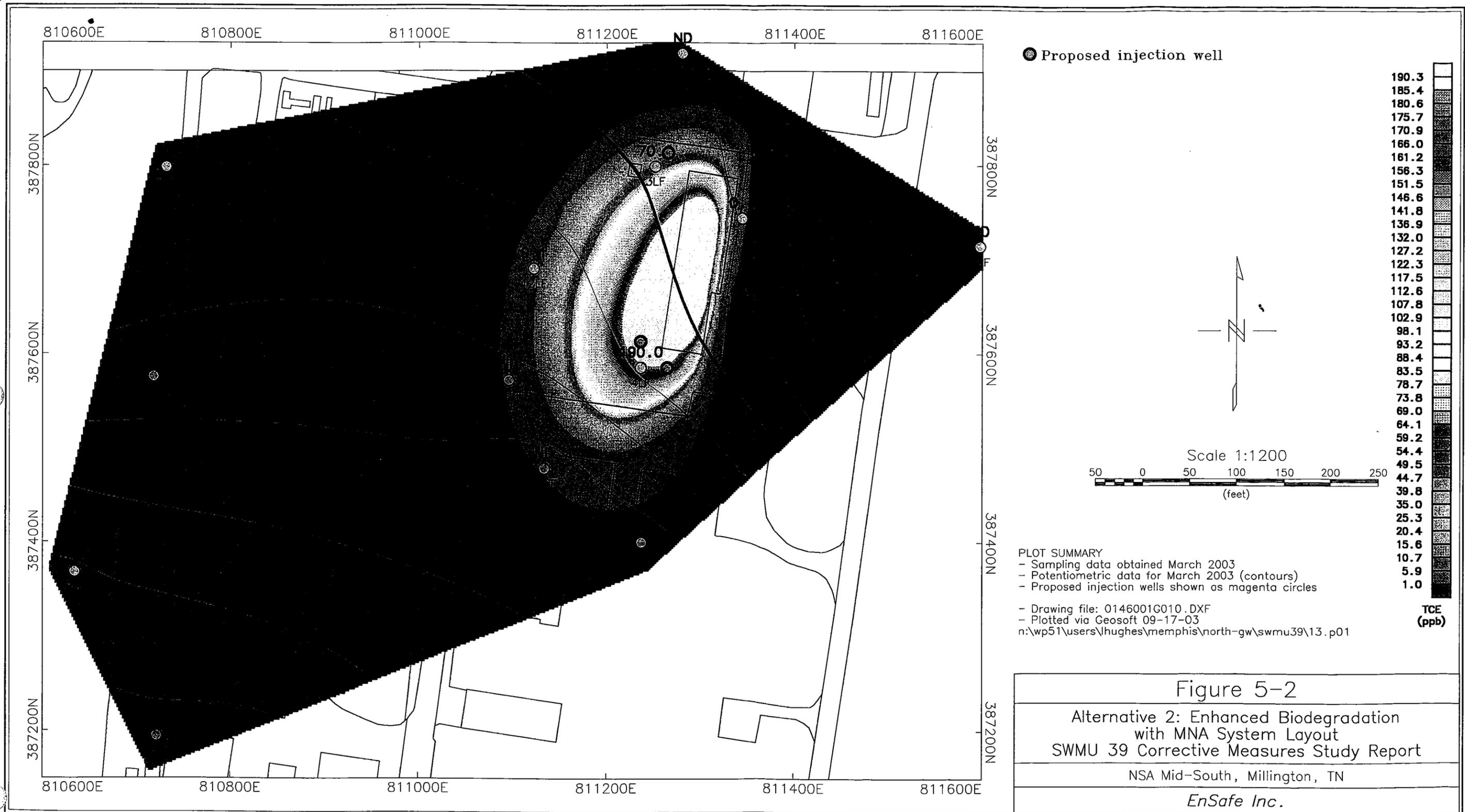
Wells would be strategically installed to infiltrate or inject a carbon source and nutrient solution in the two areas of highest TCE concentrations. The amendment solution would be applied quarterly during the treatment period.

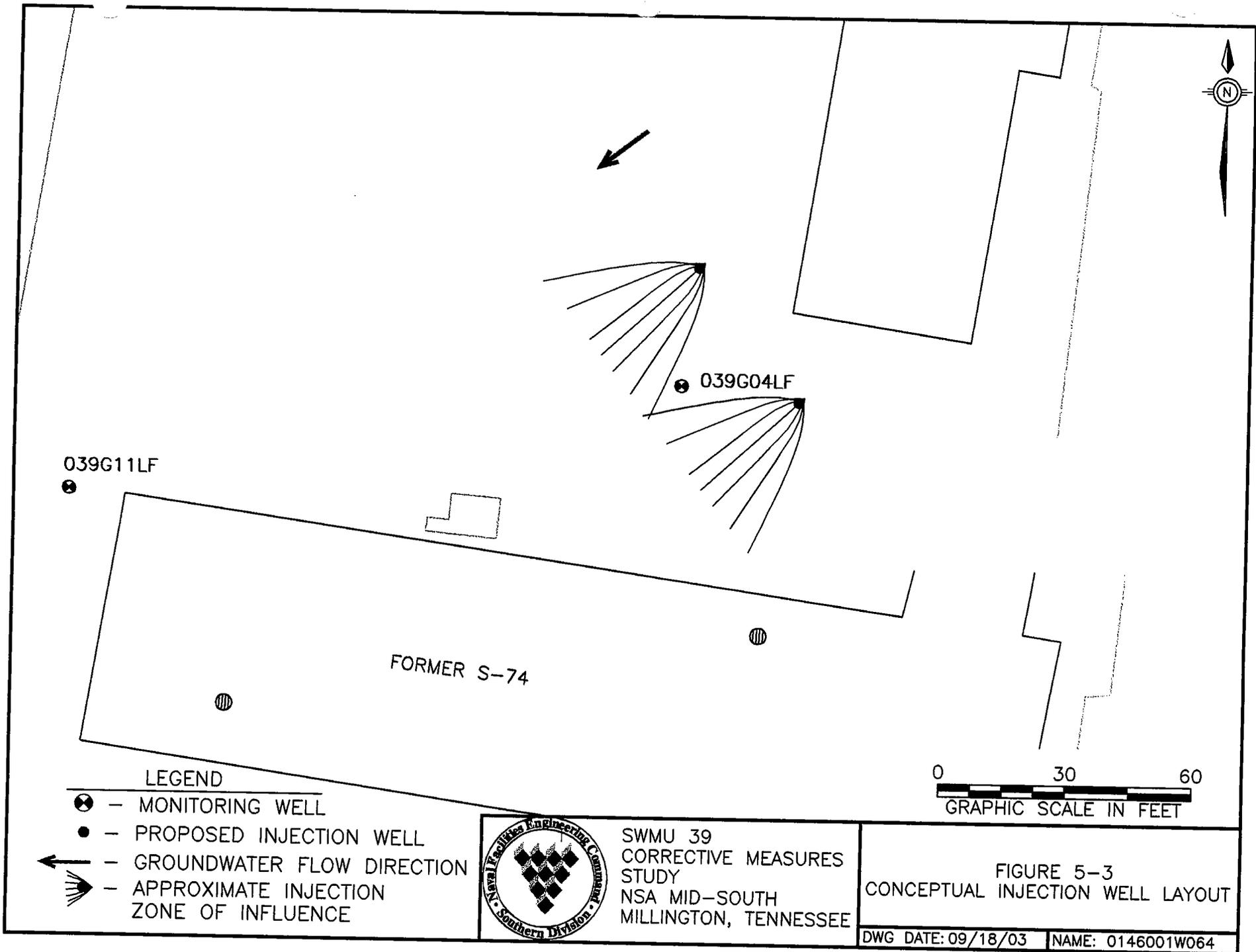
The carbon source would be delivered to the injection points via a mobile application unit (e.g., a truck with a large storage vessel and a pump). As shown on Figure 5-2, a total of three injection points would be strategically located in two separate rows, each row upgradient of the two areas showing the highest TCE concentrations, namely 03LF and 04LF.

Two injection wells would be spaced approximately 40 feet apart within a row, which would be approximately 15 to 25 feet upgradient of monitoring well 04LF and perpendicular to the direction of groundwater flow. One injection well would be approximately 15 to 25 feet directly upgradient of monitoring well 03LF. Using this approach, additional injection points could be easily added if effectiveness monitoring indicates that a portion of the plume was not being adequately affected by the amendments. Figure 5-2 shows the well locations with respect to the TCE plume. Figure 5-3 presents a conceptual injection well layout.

Based on the maximum concentration of 200 ppb for TCE at well 04LF and the biodegradation rate developed for the AOC A pilot study (*EnSafe, 2003*), the time frame for enhanced biodegradation is expected to be one to two years.

A sparging system (wells, blower, etc.) would be implemented if aerobic conditions are required to address residual *cis*-1,2-DCE or VC concentrations. However, it is likely that these will be addressed by *natural* aerobic degradation and other natural non-destructive attenuation mechanisms (such as dispersion). Therefore, MNA would be used to address residual VOCs downgradient of the treatment areas and along the perimeter of the plume. As such, in addition to groundwater monitoring, ICs would be included in the alternative to limit exposure pathways.





**System Monitoring**

Groundwater monitoring would be required to assess enhanced biodegradation with MNA. Onsite effectiveness monitoring would include routine chemical and geochemical sampling to gauge remediation effectiveness. Field and laboratory monitoring parameters are listed in Table 5-2. Ideally, wells would be monitored in the targeted area and downgradient of the application; background wells would also be sampled. Samples would be collected and analyzed quarterly using low-flow groundwater collection techniques. Five monitoring wells (03LF, 04LF, 10LF, 11LF, and 12LF) would be sampled for effectiveness monitoring.

As soon as biodegradation and geochemical trends have been established, the sampling frequency could be reduced to semiannually or annually. Sampling results would be used to estimate the TCE mass reduction and approximate VOC degradation rates. Reductant redosing rates would depend on the plume management strategy, site-specific biodegradation performance, remedial goal options (RGOs), and other technical or regulatory considerations.

**Institutional Controls**

Because MNA would be used for areas with relatively low VOC concentrations, one or more of the following ICs, which are detailed in Section 5.2.1.2, would be implemented as part of this alternative:

- Groundwater-use restriction
- Easement
- Covenant

<b>Table 5-2 Enhanced In Situ Bioremediation and MNA Sampling Analytes/Parameters</b>	
<b>Analyte</b>	<b>Method</b>
<b>Laboratory</b>	
VOCs	SW8260B
hydrogen	AM20GAX
methane, ethane, and ethene	8015MOD

<b>Table 5-2 Enhanced In Situ Bioremediation and MNA Sampling Analytes/Parameters</b>	
<b>Analyte</b>	<b>Method</b>
nitrate	353.3
TOC	SW9060
metabolic fatty acids	—
major cations	SW6010
<b>Field</b>	
ferrous iron	potable colorimeter
sulfate and sulfide	potable colorimeter
DO	YSI 55 DO meter calibrated prior to use per manufacturer's instructions
ORP	Orion 250A ORP meter or equivalent calibrated prior to use per manufacturer's instructions
pH	pH meter
temperature	temperature probe
alkalinity	potable colorimeter
chlorides	potable colorimeter
phosphorus and ammonia-nitrogen	potable colorimeter

- Reversionary interest
- Informational devices
- Site-access controls

**5.2.2.3 Enhanced Biodegradation with MNA: Primary Criteria**

**Protection of Human Health and the Environment**

Enhanced biodegradation with MNA (Alternative 2) protects human health and the environment by promoting the biodegradation of chlorinated VOCs to relatively harmless end products — ethene and ethane — or completely mineralizing them to carbon dioxide and water. Because enhanced biodegradation is expected to reduce VOCs to concentrations less than MCLs, risk to future site workers or residents and the environment would be greatly minimized. Short-term risks from inhalation and dermal contact during implementation would be minimal and would be

controlled using common engineering techniques and appropriate PPE. This alternative would comply with applicable waste management standards and chemical-specific regulations.

**Attainment of Cleanup Standards**

Alternative 2 would be expected to meet RGOs in targeted areas within one to two years based on groundwater flow rate and proposed well spacing (cleanup times could be accelerated by increasing the number of carbon-source injection points). As discussed in Section 5.2.2.2, areas with low chlorinated VOC concentrations would be addressed with natural attenuation, which would be monitored for 15 years or until VOC concentrations were consistently less than MCLs (i.e., three consecutive years).

**Source Control**

Though there is no defined VOC source at SWMU 39, Alternative 2 would address areas of highest contamination to minimize or limit continued VOC migration. As discussed in Section 5.2.2.2, the areas around monitoring well 03LF and 04LF would be targeted by the enhanced biodegradation system. The remainder of the VOC plume, which has relatively low concentrations, would be addressed via natural attenuation, groundwater monitoring, and ICs.

**Compliance with Applicable Waste Management Standards**

No waste would be managed under this alternative; therefore, waste management standards do not apply. However, several permits, which are summarized in Table 5-3, would be required to implement an enhanced biodegradation system.

<b>Table 5-3 Alternative 2 Permit Summary</b>		
<b>Task</b>	<b>Permit Required</b>	<b>Agency</b>
Well installation	Well construction permits	MSCHD
Groundwater injection	Injection well permit/variance	MSCHD
	Class V injection well authorization	TDEC, Division of Water Supply

**Note:**

- (1) — Per Section 13 of the Memphis/Shelby County Water Well Regulations, no injection wells of any type shall be allowed in Memphis and Shelby County for the injection of surface or groundwater, or chemically or thermally altered water, or any other fluids into the underground formations. Injection wells for the purpose of improving groundwater quality, however, may be considered under Section 14.02.

#### **5.2.2.4 Enhanced In Situ Biodegradation with MNA: Secondary Criteria**

##### **Long-Term Reliability and Effectiveness**

Alternative 2 offers long-term reliability and effectiveness once contaminants are biodegraded because this technology is a destructive process (as opposed to containment) and no dense nonaqueous phase liquid (DNAPL) has been detected at SWMU 39. Though it is still considered an innovative technology, enhanced biodegradation has already been successfully demonstrated during the pilot studies conducted at another location of NSA Mid-South. This suggests that a strategically implemented full-scale system would effectively address VOC contamination at SWMU 39 after treatment.

Based on preliminary estimates, the latest VOC concentrations, experience at other similar sites, and literature degradation rates, the remediation time frame would be one to two years. The time frame depends on injection well density, carbon-source injection rate, how well the aquifer reacts to the enhancement over a long period of time, and other technical or regulatory considerations.

##### **Reduction in Toxicity, Mobility, and Volume**

If implemented effectively, this alternative would quickly reduce the toxicity, mobility, and volume of groundwater contamination at SWMU 39 by enhancing or hastening biochemical reactions that may be occurring naturally, but at relatively slow rates. Alternative 2 protects human health and the environment by biologically and/or chemically transforming highly chlorinated VOCs to ethene and ethane, which are essentially harmless, or carbon dioxide and water. As discussed in Section 5.2.2.2, residual VOC contamination likely would attenuate naturally via biological and physical mechanisms.

##### **Short-Term Effectiveness**

Short-term effectiveness considerations include the health and safety of remediation personnel and site employees (current and/or future). Workers exposed to risks should be trained according to OSHA standards, as required by 29 CFR 1910.120, to protect and mitigate risks during

remedial construction. Appropriate PPE is necessary for handling all chemicals (i.e., carbon and nutrient amendments).

### **Implementability**

Implementation of an enhanced biodegradation system at SWMU 39 is relatively simple, only requiring the installation of injection wells in targeted areas and establishment of an amendment application plan/methodology. This technology is not connected with a specific vendor; therefore, there are no limitations or constraints based on vendor availability. Though there may be patent issues associated with this technology, the proposed approach has been widely applied by many consulting and remediation firms, and therefore does not violate any patents.

Regulatory acceptance of this alternative is likely. Obtaining the necessary permits (e.g., an underground injection permit) to implement this system on a long-term basis is expected to be possible.

### **Cost**

As shown in Table 5-4, the estimated total cost for Alternative 2 is \$646,500. Capital costs are estimated to be \$132,000; annual costs would be \$138,600 for the first two years and then \$38,700 for years three to fifteen. The site would be monitored for a total of fifteen years or until VOC concentrations were consistently less than MCLs (i.e., three consecutive years). As appropriate, the long-term monitoring program can be shortened with contaminant attenuation and regulatory approval, which would result in a significant cost reduction.

<b>Table 5-4</b>			
<b>Alternative 2: Enhanced Biodegradation with MNA Costs</b>			
	<b>Quantity</b>	<b>Unit Cost</b>	<b>Total Cost</b>
<b>Capital Costs</b>			
Additional aquifer characterization and groundwater and solute-transport modeling	lump sum	\$25,000	\$25,000
Engineering design and planning	lump sum	\$20,000	\$20,000
Injection well installation	3	\$5,000/well	\$15,000
Carbon Substrate Dispensing/Delivery Unit	1	\$10,000	\$10,000
Contractor oversight, engineering review, and reporting	1 week	\$10,000/week	\$10,000
Institutional controls	lump sum	\$25,000	\$25,000
Sampling equipment	lump sum	\$5,000	\$5,000
20% contingency			\$22,000
<b>Full-Scale Design and Implementation Subtotal</b>			<b>\$132,000</b>
<b>Annual In situ Bioremediation Costs</b>			
Carbon source (and nutrients) (1)	2 tons	\$1,500/ton	\$3,000
Field technicians (two people two days per quarter)	65 hours	\$100/hour	\$6,500
Laboratory sampling and analysis (2)	30 samples	\$650/sample	\$19,500
Field sampling and analysis	lump sum	\$4,000	\$4,000
Sampling equipment	lump sum	\$10,000	\$10,000
Engineering review and reporting	200 hours	\$100/hour	\$20,000
Miscellaneous expenses and travel	lump sum	20% cost	\$12,600
<b>Subtotal</b>			<b>\$75,600</b>
<b>Present value subtotal at 6% for 2 years</b>			<b>\$138,600</b>
<b>Annual MNA Costs</b>			
Field technicians	120 hours	\$100/hour	\$12,000
Laboratory sampling and analysis	5 samples	\$650/sample	\$3,250
Field sampling and analysis	lump sum	\$2,000	\$2,000
Sampling equipment	lump sum	\$5,000	\$5,000
Data review and reporting	100 hours	\$100/hour	\$10,000
Miscellaneous expenses and travel	lump sum	20% cost	\$6,450
<b>Subtotal</b>			<b>\$38,700</b>
<b>Present value subtotal at 6% for 15 years</b>			<b>\$375,900</b>
<b>Total</b>			
<b>In situ Enhanced Bioremediation Total</b>			<b>\$646,500</b>

**Notes:**

- (1) — approximately 100 pounds per quarter per injection well.
- (2) — Average number of samples per year over the two-year treatment period, which includes quarterly sampling of 5 wells for effectiveness monitoring.

## **6.0 GROUNDWATER REMEDIAL ALTERNATIVE RECOMMENDATION**

The recommendation for the SWMU 39 groundwater remedial alternative is outlined below. Selection of the recommended alternative was based on primary and secondary criteria evaluation and professional judgment. Based on the rationale and decision factors in the previous sections, enhanced biodegradation with MNA was identified as the corrective measures alternative that has the best potential to achieve the remedial goals for this site. The factors that were considered are summarized below:

- Demonstrated pilot-study success at AOC A
- Contaminants are destroyed rather than merely transferred to another medium
- Expected to be the most rapid remedial alternative at reaching RGOs
- Compatible with MNA
- Minimal O & M
- Flexible Technology: More injection points can easily be added if necessary and amendment addition amounts can be varied based on remediation strategy/success
- Cost effective

## **7.0 PUBLIC INVOLVEMENT PLAN**

### **7.1 General**

This Public Involvement Plan is included as part of this report in accordance with the USEPA guidance on RCRA CMS. This plan reflects and summarizes information prepared and presented in the Navy's Community Relations Plan (CRP), prepared for the NSA Mid-South in 1994 (EnSafe/Allan & Hoshall, 1994).

Under RCRA, there is no required interaction with the community during the CMS process. Public input is required to be solicited only at the beginning of the permitting process or during certain permit modifications. Therefore, the Navy has outlined a voluntary program of informing local communities throughout the entire RCRA corrective action process. Activities are detailed in the 1994 CRP for NSA Mid-South.

However, because the CMS process results in a modification to the facility's RCRA permit, certain provisions are made to solicit the public's input on the preferred alternative (as the reason for the modification). The requirements are identical to those for a draft permit.

Two primary objectives are stated in the CRP:

- To initiate and sustain community involvement
- To provide a mechanism for communicating to the public

### **7.2 RFI Public Involvement Plan**

To achieve these objectives, the CRP identifies public involvement and outreach activities at each step of the corrective action process. For example, the following activities have been designated for the completion of the RFI. All have been accomplished to date.

### **Public Outreach and Involvement Activities**

- Update and publicize the information repository
- Continue to publicize the point of contact
- Update the mailing list
- Distribute fact sheets and/or write articles to explain RFI findings
- Inform community leaders of the RFI's completion and results
- Update and continue to provide presentations for informal community groups
- Update the community on results of the RFI through public RAB meetings

### **7.3 CMS Public Involvement Plan**

During the CMS, the following activities will be carried out as part of the Navy's current and ongoing community involvement program.

- Distribute fact sheets or write articles for publications that report CMS recommendations
- Continue to update the mailing list
- Continue to respond to requests for speaking engagements
- Update the community on the CMS status through public RAB meetings

### **7.4 Statement of Basis Public Involvement Plan**

Upon completion of the CMS, the following activities are required if a modification to the RCRA permit is required. If a permit modification is not necessary, the Navy may choose to implement all, some, or none of the following actions, depending on the level of public interest or concern:

- A SOB will be prepared, explaining the proposed remedy and the method by which it was chosen.
- A 45-day comment period will be provided to allow community members the opportunity to review and comment on the preferred alternative. The comment period may be as

short as 30 days in cases where no permit modification is necessary, but a public comment period is warranted.

- The availability of the comment period and SOB will be announced in a public notice.
- The community will be provided an update on the proposed remedy through the informal and publicized RAB meeting.

In addition, the following activities will be carried out, as identified in the CRP:

- Update and publicize the information repository
- Publicize the environmental point of contact
- Continue to update the mailing list

### **7.5 Restoration Advisory Board**

The RAB is a key component of this community outreach program. It is through the RAB that the Navy has a regular, scheduled, and publicized forum for interfacing with community members on the progress of the environmental program, including the CMS. In addition, RAB members are instrumental in measuring community interest in specific issues and knowledge of them. A Community Relations Subcommittee to the RAB has been tasked with identifying issues and information to be addressed by the Navy.

## 8.0 REFERENCES

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## 9.0 SIGNATORY REQUIREMENTS

State of Tennessee Rule 1200-1-11.07(2)(a)8 states: All reports required by permits and other information requested by the Commissioner shall be signed by a person described in part 7 of this paragraph or by a duly authorized representative of that person. The certification reads as follows:

*I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.*

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Name  
NSA Mid-South  
Millington, Tennessee

---

Date

**Appendix A**

**Monitored Natural Attenuation Evaluation Tables**

<b>Table A-1c</b>	
<b>Interpretation of Points Awarded During Screening Step 1</b>	
<b>Score</b>	<b>Interpretation</b>
0 to 5	Inadequate evidence for anaerobic biodegradation* of chlorinated organics
6 to 14	Limited evidence for anaerobic biodegradation* of chlorinated organics
15 to 20	Adequate evidence for anaerobic biodegradation* of chlorinated organics
>20	Strong evidence for anaerobic biodegradation* of chlorinated organics

**Note:**

\* = *reductive dechlorination*

**Table A-1a**

**Soil, Soil Gas, and Groundwater Analytical Methods to Evaluate the Potential for Natural Attenuation of Chlorinated Solvents or Fuel Hydrocarbons in Groundwater**

<b>Analysis</b>	<b>Method/Reference</b>	<b>Comments</b>	<b>Data Use</b>	<b>Analysis Frequency</b>	<b>Sample Volume, Sample Container, Sample Preservation</b>	<b>Laboratory</b>
<b>Soil</b>						
Aromatic and chlorinated hydrocarbons (BTEX); chlorinated compounds	SW8260A		Data are used to determine the extent of soil contamination, the contamination mass present, and the potential for source removal.	Each soil sampling round	Sample volume approximately 100ml; subsample and extract in the field using methanol or appropriate solvent; cool to 4°C.	Fixed-base
Biologically Available Iron (III)	Under development	HCl extraction followed by quantification of released iron (III)	Optional method that should be used when fuel hydrocarbons or vinyl chloride are present in the groundwater to predict the possible extent of removal of fuel hydrocarbons and vinyl chloride via iron reduction.	One round of sampling in five borings, five cores from each boring	Minimum 1 inch diameter core samples collected into plastic liner. Cap and prevent aeration.	Laboratory
TOC	SW9060 modified for soil samples	Procedure must be accurate for the range of 0.1 to 5 percent TOC	The rate of migration of petroleum contaminants in ground water is depends on the amount of TOC in the aquifer matrix.	At initial sampling		Fixed-base
<b>Soil Gas</b>						
Fuel and Chlorinated VOCs	EPA Method TO-14		Useful for determining chlorinated and BTEX compounds in soil.	At initial sampling	1-liter Summa Canister	Fixed-base
Methane, Oxygen, Carbon dioxide	Field Soil Gas Analyzer		Useful for determining bioactivity in vadose zone.	At initial sampling and respiration testing	3-liters in a Tedlar bag, bags are reusable for analysis of methane, oxygen, or carbon dioxide.	Field
<b>Water</b>						
alkalinity	Hach Alkalinity test kit model AL AP MG-L	Phenol-phthalein method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same ground-water system an (2) to measure the buffering capacity of groundwater.	Each sampling round	Collect 100 mL of water in glass container.	Field

**Table A-1a**  
**Soil, Soil Gas, and Groundwater Analytical Methods to Evaluate the Potential for Natural Attenuation of Chlorinated Solvents or Fuel Hydrocarbons in Groundwater**

Analysis	Method/ Reference	Comments	Data Use	Analysis Frequency	Sample Volume, Sample Container, Sample Preservation	Laboratory
<b>Water (continued)</b>						
Aromatic and chlorinated hydrocarbons (BTEX, trimethylbenzene isomers, chlorinated compounds)	SW8260A	Analysis may be extended to higher molecular weight alkyl benzenes	Method of analysis for BTEX and chlorinated solvents/byproducts, which are the primary target analytes for monitoring natural attenuation; method can be extended to higher molecular weight alkyl benzenes; trimethylbenzenes are used to monitor plume dilution if degradation is primarily anaerobic.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2.	Fixed-base
Arsenic	EPA 200.7 or EPA 200.9		To determine if anaerobic biological activity is solubilizing arsenic from the aquifer matrix material.	One round of sampling	Collect 100 mL in a glass or plastic container that is rinsed in the field with the groundwater to be sampled. Unfiltered samples obtained using low flow sampling methods are preferred for analysis of dissolved metals. Adjust pH to 2 with nitric acid. Do not insert pH paper or an electrode into the sample.	Laboratory
Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field.	Each sampling round	Collect 100 mL of water in a glass container	Field
Chloride	Mercuric nitrate titration A4500-Cl <sup>-</sup> C	Ion chromatography (IC) method E300 or method SW9050 may also be used	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system. Final product of chlorinated solvent reduction.	Each sampling round	Collect 250 mL of water in a glass container.	Fixed-based
Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field	Each sampling round	Collect 100 mL of water in a glass container.	Field
Conductivity	E120.1/SW9050, direct reading meter		General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Each sampling round	Collect 100 to 250 mL of water in a glass or plastic container.	Field
Iron (II) (Fe <sup>2+</sup> )	Colorimetric Hach Method #8146	Filter if turbid.	May indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese.	Each sampling round	Collect from a flow-through or over-flow cell/analyze at the well head.	Field

**Table A-1a**

**Soil, Soil Gas, and Groundwater Analytical Methods to Evaluate the Potential for Natural Attenuation of Chlorinated Solvents or Fuel Hydrocarbons in Groundwater**

Analysis	Method/ Reference	Comments	Data Use	Analysis Frequency	Sample Volume, Sample Container, Sample Preservation	Laboratory
<b>Water (continued)</b>						
Hydrogen (H <sub>2</sub> )	Equilibration with gas in the field. Determined with a reducing gas detector.	Optional specialized analysis	Determined terminal electron accepting process. Predicts the possibility for reductive dechlorination.	One round of sampling on selected wells.	Sampled at the well head requires the production of 300 mL per minute of water for 30 minutes.	Field
Manganese	EPA 200.7 or EPA 200.9		To determine if anaerobic biological activity is solubilizing manganese from the aquifer matrix material.	One round of sampling	Collect 200 mL in a glass or plastic container that is rinsed in the field with the groundwater to be sampled. Unfiltered samples obtained using low flow sampling methods are preferred for analysis of dissolved metal. Adjust pH to 2 with nitric acid. Do not insert pH paper or an electrode into the sample.	Laboratory
Methane, ethane, and ethene	Kampbell <i>et al.</i> , 1989 and 1998 or SW3810 Modified	Method published by researchers at the USEPA. Limited to few commercial labs.	The presence of CH <sub>4</sub> suggests BTEX degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing biological transformation.	Each sampling round	Collect water samples in 50 mL glass serum bottles with gray butyl/Teflon-faced septa and crimp caps; add H <sub>2</sub> SO <sub>4</sub> to pH less than 2, cool to 4°C	Fixed-base
Nitrate	IC method E300		Substrate for microbial respiration if oxygen is depleted.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H <sub>2</sub> SO <sub>4</sub> to pH less than 2, cool to 4°C	Fixed-base
ORP	A2580B	Measurements made with electrodes; results are displayed on a meter; protect samples from exposure to oxygen. Report results against a silver/silver chloride reference electrode. (Eh) is calculated by adding a correction factor specific to the electrode used.	The ORP of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the ORP (expressed as Eh) of groundwater may range from more than 800 mV to less than -400 mV.	Each sampling round	Measure in a flow through cell or an over-flowing container filled from the bottom to prevent exposure of the groundwater to the atmosphere.	Field

Table A-1a Soil, Soil Gas, and Groundwater Analytical Methods to Evaluate the Potential for Natural Attenuation of Chlorinated Solvents or Fuel Hydrocarbons in Groundwater						
Analysis	Method/ Reference	Comments	Data Use	Analysis Frequency	Sample Volume, Sample Container, Sample Preservation	Laboratory
<b>Water (continued)</b>						
Oxygen	Dissolved oxygen meter calibrated between each well according to the supplier's specifications	Refer to method A4500 for a comparable laboratory procedure.	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1mg/L generally indicate an anaerobic pathway.	Each sampling round	Measure dissolved oxygen on site using a flow-through cell or over-flow cell.	Field
pH	Field probe with direct reading meter calibrated in the field according to the supplier's specifications.	Field	Aerobic and anaerobic biological processes are pH-sensitive.	Each sampling round	Measure dissolved oxygen on site using a flow-through cell or over-flow cell.	Field
Sulfate (SO <sub>4</sub> <sup>-2</sup> )	IC method E300	If this method is used for sulfate analysis, do not use the field method.	Substrate for anaerobic microbial respiration.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base
Sulfate (SO <sub>4</sub> <sup>-2</sup> )	Hach method # 8051	Colorimetric, if this method is used for sulfate analysis, do not use the fixed-base laboratory method.	Same as above.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Field
Temperature	Field probe with direct reading meter.	Field only	To determine if a well is adequately purged for sampling.	Each sampling round	Read from oxygen meter.	Field
TOC	SW9060	Laboratory	Used to classify plume and to determine if reductive dechlorination is possible in the absence of anthropogenic carbon.	Each sampling round	Measure using a flow-through cell or over-flow cell.	Laboratory

**Notes:**

Analyses other than those listed in this table may be required for regulatory compliance.

"Hach" refers to the Hach Company catalog, 1990.

"A" refers to *Standard Methods for the Examination of Water and Wastewater*, 18<sup>th</sup> edition, 1992.

"E" refers to *Methods for Chemical Analysis of Water and Wastes*, U.S. EPA, 1983.

"SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods*, SW-846, U.S. EPA, 3<sup>rd</sup> edition, 1986.

**Table A-1b**  
**Analytical Parameters and Weighting for Preliminary Screening for Anaerobic Biodegradation Processes\*\***

<b>Analysis</b>	<b>Concentration in Most Contaminated Zone</b>	<b>Interpretation</b>	<b>Value</b>
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	3
Oxygen*	>1 mg/L	Not tolerated; however, VC may be oxidized aerobically	-3
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	2
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe (III)-reducing conditions	3
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	2
Sulfide*	>1 mg/L	Reductive pathway possible	3
Methane*	<0.5 mg/L	VC oxidizes	0
	>0.5 mg/L	Ultimate reductive daughter product, VC accumulates	3
ORP using Ag/AgCl electrode*	<50 millivolts (mV)	Reductive pathway possible	1
	<-100 mV	Reductive pathway likely	2
pH*	5<pH<9	Optimal range for reductive pathway	0
	5>pH>9	Outside optimal range for reductive pathway	-2
TOC	>20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2
Temperature*	>20°C	At T >20°C biochemical process is accelerated	1
Carbon dioxide	>2x background	Ultimate oxidative daughter product	1
Alkalinity	>2x background	Results from interaction between CO <sub>2</sub> and aquifer minerals	1
Chloride*	>2x background	Daughter product of organic chlorine	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	3
	<1 nM	VC oxidized	0
Volatile fatty acids	>0.1 mg/L	Intermediates resulting from biodegradation of more complex compounds; carbon and energy source	2
BTEX*	>0.1 mg/L	Carbon and energy source; drives dechlorination	2
PCE	—	Material released	0

**Table A-1b  
Analytical Parameters and Weighting for Preliminary Screening for Anaerobic Biodegradation Processes\*\***

<b>Analysis</b>	<b>Concentration in Most Contaminated Zone</b>	<b>Interpretation</b>	<b>Value</b>
TCE*	—	Material released	0
		Daughter product of PCE	2**
DCE*	—	Material released	0
		Daughter product of TCE If <i>cis</i> is >80% of total DCE it is likely a daughter product. 1,1-DCE can be chemical reaction product of TCA	2**
VC*	—	Material released	0
		Daughter product of DCE	2**
1,1,1-TCA*	—	Material released	0
DCA	—	Daughter product of TCA under reducing conditions	2
Carbon tetrachloride	—	Material released	0
Chloroethane*	—	Daughter product of DCA or VC under reducing conditions	2
Ethene/ethane	>0.01 mg/L	Daughter product of VC/ethene	2
	>0.1 mg.L		3
Chloroform	—	Material released	0
		Daughter product of carbon tetrachloride	2
Dichloromethane	—	Material released	0
		Daughter product of chloroform	2

**Notes:**

\* = Required analysis.

\*\* = Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

**Table A-2  
MNA Chemical and Geochemical Data  
June 2002**

Parameters	Units	01LF	02LF	03LF	04LF	05LF	06LF	07LF	08LF	09LF	10LF	11LF	12LF	13LF
Dissolved Oxygen (DO)*	mg/L	0.28	0.06	1.16	0.76	0.93	0.97	1.41	1.13	1.44	0.49	0.0	0.98	0.04
Temperature*	°C	19.5	23.5	21.5	21.1	20.9	18.4	21.5	20.7	20.0	22.6	21.4	21.0	21.4
pH*	pH units	6.35	6.46	6.7	6.33	6.3	6.28	6.28	6.19	6.16	6.77	6.31	6.34	6.48
Oxidation-Reduction Potential (ORP)*	mV	67.1	57.1	51.6	52.1	74.2	91.9	222.6	237.8	225.1	74.8	3.2	61.0	-154
Chloride*	mg/L	8.4	24	43	20	68	5.3	22	6	24	11	9.2	12	5
Alkalinity*	mg/L	130	320	450	410	210	250	230	140	190	180	110	120	140
Ferrous Iron (Iron II)*	mg/L	0.33	NA	0.00	2.4	3.29	0.41	0.2	0.44	0.03	3.15	3.17	1.87	3.12
Nitrate	mg/L	0.077	ND	ND	ND	ND	ND	0.13	0.3	0.38	ND	ND	0.3	ND
Sulfate*	mg/L	1.4	10	5.4	13	1.5	27	7.3	3.4	2.1	180	4.2	3.9	1.3
Sulfide*	mg/L	0.068	ND	ND	0.024	0.033	ND	0.045	0.048	0.047	ND	ND	ND	0.027
Methane	mg/L	0.001	0.005	0.007	0.026	0.006	0.0	0.0	0.0	0.0	0.005	0.0	0.0	0.001
Total Organic Carbon	mg/L	ND	ND	ND	ND	0.718	ND	ND	ND	ND	4.3	ND	ND	1.6
PCE	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TCE	mg/L	ND	0.31	68	180	ND	ND	ND	ND	0.34	ND	ND	2.4	ND
cis-1,2-DCE	mg/L	ND	ND	12	3.7	0.75	ND	ND	ND	ND	ND	ND	ND	ND
Vinyl Chloride (VC)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

**Notes:**

\*These parameters were measured in the field. The remaining were measured by laboratory analysis.

NA — Not Available  
 ND — Not Detected  
 mg/L — micrograms/Liter  
 mg/L — milligrams/Liter

**Table A-3  
MNA Screening and Ranking Evaluation  
June 2002**

Parameters	01LF	02LF	03LF	04LF	05LF	06LF	07LF	08LF	09LF	10LF	11LF	12LF	13LF
Dissolved Oxygen (DO)	3	3	-3	0	-2	-2	-3	-3	-3	3	3	-2	3
Temperature	1	1	1	1	1	0	1	1	1	1	1	1	1
pH	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxidation Reduction Potential	0	1	1	1	0	0	0	0	0	1	1	0	2
Chloride	0	2	2	2	2	0	2	0	2	2	0	2	0
Alkalinity	0	1	1	1	0	0	0	0	0	0	0	0	0
Ferrous Iron (Iron II)	0	NA	0	3	3	0	0	0	0	3	3	3	3
Nitrate	2	2	2	2	2	2	2	2	2	2	2	2	2
Sulfate	2	2	2	2	2	0	2	2	2	0	2	2	2
Sulfide	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Organic Carbon (TOC)	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-DCE	0	0	2	2	0	0	0	0	0	0	0	0	0
Vinyl Chloride (VC)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	8	12	8	14	8	0	4	2	4	12	12	8	13
Ranking	L	L	L	L	L	I	I	I	I	L	L	L	L

**Notes:**

- NA — Not Available
- I — Inadequate evidence for biodegradation of chlorinated organics
- L — Limited evidence for biodegradation of chlorinated organics
- A — Adequate evidence for biodegradation of chlorinated organics
- S — Strong evidence for biodegradation of chlorinated organics

**Table A-4  
MNA Chemical and Geochemical Data  
August 2002**

<b>Parameters</b>	<b>Units</b>	<b>01LF</b>	<b>02LF</b>	<b>03LF</b>	<b>04LF</b>	<b>05LF</b>	<b>06LF</b>	<b>07LF</b>	<b>08LF</b>	<b>09LF</b>	<b>10LF</b>	<b>11LF</b>	<b>12LF</b>	<b>13LF</b>
Dissolved Oxygen (DO)*	mg/L	0.98	0.39	0.93	0.48	0.71	NA	0.84	0.92	2.38	0.75	0.43	0.58	0.28
Temperature*	°C	20.9	22.9	20.8	21.7	21.5	19.5	19.9	21.5	20.3	24.1	21.6	22.5	22.3
pH*	pH units	6.17	6.35	6.5	6.28	6.18	6.18	6.23	6.15	6.16	6.61	5.76	5.97	7.22
Oxidation Reduction Potential (ORP)*	mv	88.1	-89.6	169.1	-62.2	-20.6	54.0	-21.0	220	386	-127	24	190.6	-98
Chloride*	mg/L	7.0	15	47	12	62	4.7	24	5.3	19	4.8	3.7	9.2	5.6
Alkalinity*	mg/L	130	330	440	390	190	250	210	130	180	190	110	140	130
Ferrous Iron (Iron II)*	mg/L	0.76	8.75D	0.04	8.85D	7.2D	0.64	0.61	0.99	0.12	5.6D	1.9	0.28	0.01
Nitrate	mg/L	0.077	ND	ND	ND	0.017	ND	0.19	0.091	0.38	0.12	0.11	0.99	ND
Sulfate*	mg/L	1.5	11	5.5	14	1.7	28	7.4	4.2	1.8	41	5.3	3.6	2.5
Sulfide*	mg/L	0.068	0.945	0.003	0.103	0.027	0.049	0.033	0.015	0.011	0.037	0.114	0.017	0.61D
Methane	mg/L	0.001	0.015	0.008	0.024	0.016	0.000	0.04.3	0.000	0.000	0.018	0.008	0.008	0.017
Total Organic Carbon	mg/L	ND	ND	ND	1.3	ND	4.1							
PCE	mg/L	ND												
TCE	mg/L	ND	0.52	72	180	ND	ND	ND	ND	0.33	ND	0.28	6.0	ND
cis-1,2-DCE	mg/L	ND	ND	12	3.7	ND	1.0	ND						
Vinyl Chloride (VC)	mg/L	ND												

**Notes:**

\*These parameters were measured in the field. The remaining were measured by laboratory analysis.

- ND — Not Detected
- NA — Not Available
- mg/L — milligrams/Liter
- mg/L — micrograms/Liter

**Table A-1a**

**Soil, Soil Gas, and Groundwater Analytical Methods to Evaluate the Potential for Natural Attenuation of Chlorinated Solvents or Fuel Hydrocarbons in Groundwater**

Analysis	Method/ Reference	Comments	Data Use	Analysis Frequency	Sample Volume, Sample Container, Sample Preservation	Laboratory
<b>Soil</b>						
Aromatic and chlorinated hydrocarbons (BTEX); chlorinated compounds	SW8260A		Data are used to determine the extent of soil contamination, the contamination mass present, and the potential for source removal.	Each soil sampling round	Sample volume approximately 100ml; subsample and extract in the field using methanol or appropriate solvent; cool to 4°C.	Fixed-base
Biologically Available Iron (III)	Under development	HCI extraction followed by quantification of released iron (III)	Optional method that should be used when fuel hydrocarbons or vinyl chloride are present in the groundwater to predict the possible extent of removal of fuel hydrocarbons and vinyl chloride via iron reduction.	One round of sampling in five borings, five cores from each boring	Minimum 1 inch diameter core samples collected into plastic liner. Cap and prevent aeration.	Laboratory
TOC	SW9060 modified for soil samples	Procedure must be accurate for the range of 0.1 to 5 percent TOC	The rate of migration of petroleum contaminants in ground water is depends on the amount of TOC in the aquifer matrix.	At initial sampling		Fixed-base
<b>Soil Gas</b>						
Fuel and Chlorinated VOCs	EPA Method TO-14		Useful for determining chlorinated and BTEX compounds in soil.	At initial sampling	1-liter Summa Canister	Fixed-base
Methane, Oxygen, Carbon dioxide	Field Soil Gas Analyzer		Useful for determining bioactivity in vadose zone.	At initial sampling and respiration testing	3-liters in a Tedlar bag, bags are reusable for analysis of methane, oxygen, or carbon dioxide.	Field
<b>Water</b>						
alkalinity	Hach Alkalinity test kit model AL AP MG-L	Phenol-phthalein method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same ground-water system an (2) to measure the buffering capacity of groundwater.	Each sampling round	Collect 100 mL of water in glass container.	Field

**Table A-1a**  
**Soil, Soil Gas, and Groundwater Analytical Methods to Evaluate the Potential for Natural Attenuation of Chlorinated Solvents or Fuel Hydrocarbons in Groundwater**

Analysis	Method/ Reference	Comments	Data Use	Analysis Frequency	Sample Volume, Sample Container, Sample Preservation	Laboratory
<b>Water (continued)</b>						
Aromatic and chlorinated hydrocarbons (BTEX, trimethylbenzene isomers, chlorinated compounds)	SW8260A	Analysis may be extended to higher molecular weight alkyl benzenes	Method of analysis for BTEX and chlorinated solvents/byproducts, which are the primary target analytes for monitoring natural attenuation; method can be extended to higher molecular weight alkyl benzenes; trimethylbenzenes are used to monitor plume dilution if degradation is primarily anaerobic.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2.	Fixed-base
Arsenic	EPA 200.7 or EPA 200.9		To determine if anaerobic biological activity is solubilizing arsenic from the aquifer matrix material.	One round of sampling	Collect 100 mL in a glass or plastic container that is rinsed in the field with the groundwater to be sampled. Unfiltered samples obtained using low flow sampling methods are preferred for analysis of dissolved metals. Adjust pH to 2 with nitric acid. Do not insert pH paper or an electrode into the sample.	Laboratory
Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field.	Each sampling round	Collect 100 mL of water in a glass container	Field
Chloride	Mercuric nitrate titration A4500-Cl <sup>-</sup> C	Ion chromatography (IC) method E300 or method SW9050 may also be used	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system. Final product of chlorinated solvent reduction.	Each sampling round	Collect 250 mL of water in a glass container.	Fixed-based
Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field	Each sampling round	Collect 100 mL of water in a glass container.	Field
Conductivity	E120.1/SW9050, direct reading meter		General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Each sampling round	Collect 100 to 250 mL of water in a glass or plastic container.	Field
Iron (II) (Fe <sup>2+</sup> )	Colorimetric Hach Method #8146	Filter if turbid.	May indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese.	Each sampling round	Collect from a flow-through or over-flow cell/analyze at the well head.	Field

**Table A-1a**

**Soil, Soil Gas, and Groundwater Analytical Methods to Evaluate the Potential for Natural Attenuation of Chlorinated Solvents or Fuel Hydrocarbons in Groundwater**

Analysis	Method/ Reference	Comments	Data Use	Analysis Frequency	Sample Volume, Sample Container, Sample Preservation	Laboratory
<b>Water (continued)</b>						
Hydrogen (H <sub>2</sub> )	Equilibration with gas in the field. Determined with a reducing gas detector.	Optional specialized analysis	Determined terminal electron accepting process. Predicts the possibility for reductive dechlorination.	One round of sampling on selected wells.	Sampled at the well head requires the production of 300 mL per minute of water for 30 minutes.	Field
Manganese	EPA 200.7 or EPA 200.9		To determine if anaerobic biological activity is solubilizing manganese from the aquifer matrix material.	One round of sampling	Collect 200 mL in a glass or plastic container that is rinsed in the field with the groundwater to be sampled. Unfiltered samples obtained using low flow sampling methods are preferred for analysis of dissolved metal. Adjust pH to 2 with nitric acid. Do not insert pH paper or an electrode into the sample.	Laboratory
Methane, ethane, and ethene	Kampbell <i>et al.</i> , 1989 and 1998 or SW3810 Modified	Method published by researchers at the USEPA. Limited to few commercial labs.	The presence of CH <sub>4</sub> suggests BTEX degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing biological transformation.	Each sampling round	Collect water samples in 50 mL glass serum bottles with gray butyl/Teflon-faced septa and crimp caps; add H <sub>2</sub> SO <sub>4</sub> to pH less than 2, cool to 4°C	Fixed-base
Nitrate	IC method E300		Substrate for microbial respiration if oxygen is depleted.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H <sub>2</sub> SO <sub>4</sub> to pH less than 2, cool to 4°C	Fixed-base
ORP	A2580B	Measurements made with electrodes; results are displayed on a meter; protect samples from exposure to oxygen. Report results against a silver/silver chloride reference electrode. (Eh) is calculated by adding a correction factor specific to the electrode used.	The ORP of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the ORP (expressed as Eh) of groundwater may range from more than 800 mV to less than -400 mV.	Each sampling round	Measure in a flow through cell or an over-flowing container filled from the bottom to prevent exposure of the groundwater to the atmosphere.	Field

Table A-1a Soil, Soil Gas, and Groundwater Analytical Methods to Evaluate the Potential for Natural Attenuation of Chlorinated Solvents or Fuel Hydrocarbons in Groundwater						
Analysis	Method/ Reference	Comments	Data Use	Analysis Frequency	Sample Volume, Sample Container, Sample Preservation	Laboratory
<b>Water (continued)</b>						
Oxygen	Dissolved oxygen meter calibrated between each well according to the supplier's specifications	Refer to method A4500 for a comparable laboratory procedure.	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1mg/L generally indicate an anaerobic pathway.	Each sampling round	Measure dissolved oxygen on site using a flow-through cell or over-flow cell.	Field
pH	Field probe with direct reading meter calibrated in the field according to the supplier's specifications.	Field	Aerobic and anaerobic biological processes are pH-sensitive.	Each sampling round	Measure dissolved oxygen on site using a flow-through cell or over-flow cell.	Field
Sulfate (SO <sub>4</sub> <sup>-2</sup> )	IC method E300	If this method is used for sulfate analysis, do not use the field method.	Substrate for anaerobic microbial respiration.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base
Sulfate (SO <sub>4</sub> <sup>-2</sup> )	Hach method # 8051	Colorimetric, if this method is used for sulfate analysis, do not use the fixed-base laboratory method.	Same as above.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Field
Temperature	Field probe with direct reading meter.	Field only	To determine if a well is adequately purged for sampling.	Each sampling round	Read from oxygen meter.	Field
TOC	SW9060	Laboratory	Used to classify plume and to determine if reductive dechlorination is possible in the absence of anthropogenic carbon.	Each sampling round	Measure using a flow-through cell or over-flow cell.	Laboratory

**Notes:**

Analyses other than those listed in this table may be required for regulatory compliance.

"Hach" refers to the Hach Company catalog, 1990.

"A" refers to *Standard Methods for the Examination of Water and Wastewater*, 18<sup>th</sup> edition, 1992.

"E" refers to *Methods for Chemical Analysis of Water and Wastes*, U.S. EPA, 1983.

"SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods*, SW-846, U.S. EPA, 3<sup>rd</sup> edition, 1986.

**Table A-1b**  
**Analytical Parameters and Weighting for Preliminary Screening for Anaerobic Biodegradation Processes\*\***

<b>Analysis</b>	<b>Concentration in Most Contaminated Zone</b>	<b>Interpretation</b>	<b>Value</b>
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	3
Oxygen*	>1 mg/L	Not tolerated; however, VC may be oxidized aerobically	-3
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	2
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe (III)-reducing conditions	3
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	2
Sulfide*	>1 mg/L	Reductive pathway possible	3
Methane*	<0.5 mg/L	VC oxidizes	0
	>0.5 mg/L	Ultimate reductive daughter product, VC accumulates	3
ORP using Ag/AgCl electrode*	<50 millivolts (mV)	Reductive pathway possible	1
	<-100 mV	Reductive pathway likely	2
pH*	5<pH<9	Optimal range for reductive pathway	0
	5>pH>9	Outside optimal range for reductive pathway	-2
TOC	>20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2
Temperature*	>20°C	At T >20°C biochemical process is accelerated	1
Carbon dioxide	>2x background	Ultimate oxidative daughter product	1
Alkalinity	>2x background	Results from interaction between CO <sub>2</sub> and aquifer minerals	1
Chloride*	>2x background	Daughter product of organic chlorine	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	3
	<1 nM	VC oxidized	0
Volatile fatty acids	>0.1 mg/L	Intermediates resulting from biodegradation of more complex compounds; carbon and energy source	2
BTEX*	>0.1 mg/L	Carbon and energy source; drives dechlorination	2
PCE	—	Material released	0

**Table A-1b  
Analytical Parameters and Weighting for Preliminary Screening for Anaerobic Biodegradation Processes\*\***

<b>Analysis</b>	<b>Concentration in Most Contaminated Zone</b>	<b>Interpretation</b>	<b>Value</b>
TCE*	—	Material released	0
		Daughter product of PCE	2**
DCE*	—	Material released	0
		Daughter product of TCE If <i>cis</i> is >80% of total DCE it is likely a daughter product. 1,1-DCE can be chemical reaction product of TCA	2**
VC*	—	Material released	0
		Daughter product of DCE	2**
1,1,1-TCA*	—	Material released	0
DCA	—	Daughter product of TCA under reducing conditions	2
Carbon tetrachloride	—	Material released	0
Chloroethane*	—	Daughter product of DCA or VC under reducing conditions	2
Ethene/ethane	>0.01 mg/L	Daughter product of VC/ethene	2
	>0.1 mg.L		3
Chloroform	—	Material released	0
		Daughter product of carbon tetrachloride	2
Dichloromethane	—	Material released	0
		Daughter product of chloroform	2

**Notes:**

\* = Required analysis.

\*\* = Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

**Table A-2  
MNA Chemical and Geochemical Data  
June 2002**

Parameters	Units	01LF	02LF	03LF	04LF	05LF	06LF	07LF	08LF	09LF	10LF	11LF	12LF	13LF
Dissolved Oxygen (DO)*	mg/L	0.28	0.06	1.16	0.76	0.93	0.97	1.41	1.13	1.44	0.49	0.0	0.98	0.04
Temperature*	°C	19.5	23.5	21.5	21.1	20.9	18.4	21.5	20.7	20.0	22.6	21.4	21.0	21.4
pH*	pH units	6.35	6.46	6.7	6.33	6.3	6.28	6.28	6.19	6.16	6.77	6.31	6.34	6.48
Oxidation-Reduction Potential (ORP)*	mV	67.1	57.1	51.6	52.1	74.2	91.9	222.6	237.8	225.1	74.8	3.2	61.0	-154
Chloride*	mg/L	8.4	24	43	20	68	5.3	22	6	24	11	9.2	12	5
Alkalinity*	mg/L	130	320	450	410	210	250	230	140	190	180	110	120	140
Ferrous Iron (Iron II)*	mg/L	0.33	NA	0.00	2.4	3.29	0.41	0.2	0.44	0.03	3.15	3.17	1.87	3.12
Nitrate	mg/L	0.077	ND	ND	ND	ND	ND	0.13	0.3	0.38	ND	ND	0.3	ND
Sulfate*	mg/L	1.4	10	5.4	13	1.5	27	7.3	3.4	2.1	180	4.2	3.9	1.3
Sulfide*	mg/L	0.068	ND	ND	0.024	0.033	ND	0.045	0.048	0.047	ND	ND	ND	0.027
Methane	mg/L	0.001	0.005	0.007	0.026	0.006	0.0	0.0	0.0	0.0	0.005	0.0	0.0	0.001
Total Organic Carbon	mg/L	ND	ND	ND	ND	0.718	ND	ND	ND	ND	4.3	ND	ND	1.6
PCE	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TCE	mg/L	ND	0.31	68	180	ND	ND	ND	ND	0.34	ND	ND	2.4	ND
cis-1,2-DCE	mg/L	ND	ND	12	3.7	0.75	ND	ND	ND	ND	ND	ND	ND	ND
Vinyl Chloride (VC)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

**Notes:**

\*These parameters were measured in the field. The remaining were measured by laboratory analysis.

- NA — Not Available
- ND — Not Detected
- mg/L — micrograms/Liter
- mg/L — milligrams/Liter

**Table A-3  
MNA Screening and Ranking Evaluation  
June 2002**

Parameters	01LF	02LF	03LF	04LF	05LF	06LF	07LF	08LF	09LF	10LF	11LF	12LF	13LF
Dissolved Oxygen (DO)	3	3	-3	0	-2	-2	-3	-3	-3	3	3	-2	3
Temperature	1	1	1	1	1	0	1	1	1	1	1	1	1
pH	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxidation Reduction Potential	0	1	1	1	0	0	0	0	0	1	1	0	2
Chloride	0	2	2	2	2	0	2	0	2	2	0	2	0
Alkalinity	0	1	1	1	0	0	0	0	0	0	0	0	0
Ferrous Iron (Iron II)	0	NA	0	3	3	0	0	0	0	3	3	3	3
Nitrate	2	2	2	2	2	2	2	2	2	2	2	2	2
Sulfate	2	2	2	2	2	0	2	2	2	0	2	2	2
Sulfide	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Organic Carbon (TOC)	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-DCE	0	0	2	2	0	0	0	0	0	0	0	0	0
Vinyl Chloride (VC)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	8	12	8	14	8	0	4	2	4	12	12	8	13
Ranking	L	L	L	L	L	I	I	I	I	L	L	L	L

**Notes:**

- NA — Not Available
- I — Inadequate evidence for biodegradation of chlorinated organics
- L — Limited evidence for biodegradation of chlorinated organics
- A — Adequate evidence for biodegradation of chlorinated organics
- S — Strong evidence for biodegradation of chlorinated organics

**Table A-4  
MNA Chemical and Geochemical Data  
August 2002**

<b>Parameters</b>	<b>Units</b>	<b>01LF</b>	<b>02LF</b>	<b>03LF</b>	<b>04LF</b>	<b>05LF</b>	<b>06LF</b>	<b>07LF</b>	<b>08LF</b>	<b>09LF</b>	<b>10LF</b>	<b>11LF</b>	<b>12LF</b>	<b>13LF</b>
Dissolved Oxygen (DO)*	mg/L	0.98	0.39	0.93	0.48	0.71	NA	0.84	0.92	2.38	0.75	0.43	0.58	0.28
Temperature*	°C	20.9	22.9	20.8	21.7	21.5	19.5	19.9	21.5	20.3	24.1	21.6	22.5	22.3
pH*	pH units	6.17	6.35	6.5	6.28	6.18	6.18	6.23	6.15	6.16	6.61	5.76	5.97	7.22
Oxidation Reduction Potential (ORP)*	mv	88.1	-89.6	169.1	-62.2	-20.6	54.0	-21.0	220	386	-127	24	190.6	-98
Chloride*	mg/L	7.0	15	47	12	62	4.7	24	5.3	19	4.8	3.7	9.2	5.6
Alkalinity*	mg/L	130	330	440	390	190	250	210	130	180	190	110	140	130
Ferrous Iron (Iron II)*	mg/L	0.76	8.75D	0.04	8.85D	7.2D	0.64	0.61	0.99	0.12	5.6D	1.9	0.28	0.01
Nitrate	mg/L	0.077	ND	ND	ND	0.017	ND	0.19	0.091	0.38	0.12	0.11	0.99	ND
Sulfate*	mg/L	1.5	11	5.5	14	1.7	28	7.4	4.2	1.8	41	5.3	3.6	2.5
Sulfide*	mg/L	0.068	0.945	0.003	0.103	0.027	0.049	0.033	0.015	0.011	0.037	0.114	0.017	0.61D
Methane	mg/L	0.001	0.015	0.008	0.024	0.016	0.000	0.04.3	0.000	0.000	0.018	0.008	0.008	0.017
Total Organic Carbon	mg/L	ND	ND	ND	1.3	ND	4.1							
PCE	mg/L	ND												
TCE	mg/L	ND	0.52	72	180	ND	ND	ND	ND	0.33	ND	0.28	6.0	ND
cis-1,2-DCE	mg/L	ND	ND	12	3.7	ND	1.0	ND						
Vinyl Chloride (VC)	mg/L	ND												

**Notes:**

\*These parameters were measured in the field. The remaining were measured by laboratory analysis.

- ND — Not Detected
- NA — Not Available
- mg/L — milligrams/Liter
- mg/L — micrograms/Liter

**Table A-5  
MNA Screening and Ranking Evaluation  
August 2002**

Parameters	01LF	02LF	03LF	04LF	05LF	06LF	07LF	08LF	09LF	10LF	11LF	12LF	13LF
Dissolved Oxygen (DO)	-2	3	-2	3	0	NA	-1	-2	-3	0	3	2	3
Temperature	1	1	1	1	1	1	1	1	1	1	1	1	1
pH	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxidation Reduction Potential	0	1	0	1	1	1	1	0	0	2	1	0	2
Chloride	0	2	2	2	2	0	2	0	2	0	0	0	0
Alkalinity	0	1	1	1	0	0	0	0	0	0	0	0	0
Ferrous Iron (Iron II)	0	3	0	3	3	0	0	3	0	3	3	0	0
Nitrate	2	2	2	2	2	2	2	2	2	2	2	2	2
Sulfate	2	2	2	2	2	0	2	2	2	2	2	2	2
Sulfide	0	1	0	1	0	0	0	0	0	0	1	0	0
Methane	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Organic Carbon (TOC)	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-DCE	0	0	2	2	0	0	0	0	0	0	0	2	0
Vinyl Chloride (VC)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	3	16	8	18	11	4	7	6	4	10	13	9	10
Ranking	I	A	L	A	L	I	L	L	I	L	L	L	L

**Notes:**

- NA — Not Available
- I — Inadequate evidence for biodegradation of chlorinated organics
- L — Limited evidence for biodegradation of chlorinated organics
- A — Adequate evidence for biodegradation of chlorinated organics
- S — Strong evidence for biodegradation of chlorinated organics

**Table A-5  
MNA Screening and Ranking Evaluation  
August 2002**

Parameters	01LF	02LF	03LF	04LF	05LF	06LF	07LF	08LF	09LF	10LF	11LF	12LF	13LF
Dissolved Oxygen (DO)	-2	3	-2	3	0	NA	-1	-2	-3	0	3	2	3
Temperature	1	1	1	1	1	1	1	1	1	1	1	1	1
pH	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxidation Reduction Potential	0	1	0	1	1	1	1	0	0	2	1	0	2
Chloride	0	2	2	2	2	0	2	0	2	0	0	0	0
Alkalinity	0	1	1	1	0	0	0	0	0	0	0	0	0
Ferrous Iron (Iron II)	0	3	0	3	3	0	0	3	0	3	3	0	0
Nitrate	2	2	2	2	2	2	2	2	2	2	2	2	2
Sulfate	2	2	2	2	2	0	2	2	2	2	2	2	2
Sulfide	0	1	0	1	0	0	0	0	0	0	1	0	0
Methane	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Organic Carbon (TOC)	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-DCE	0	0	2	2	0	0	0	0	0	0	0	2	0
Vinyl Chloride (VC)	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	3	16	8	18	11	4	7	6	4	10	13	9	10
Ranking	I	A	L	A	L	I	L	L	I	L	L	L	L

**Notes:**

- NA — Not Available
- I — Inadequate evidence for biodegradation of chlorinated organics
- L — Limited evidence for biodegradation of chlorinated organics
- A — Adequate evidence for biodegradation of chlorinated organics
- S — Strong evidence for biodegradation of chlorinated organics

**Table A-6  
MNA Chemical and Geochemical Data  
November 2002**

Parameters	Units	01LF	02LF	03LF	04LF	05LF	06LF	07LF	08LF	09LF	10LF	11LF	12LF	13LF
Dissolved Oxygen (DO)*	mg/L	0.93	1.04	0.9	0.83	2.19	1.14	2.45	0.66	1.6	1.6	1.35	1.3	1.56
Temperature*	°C	18.2	19.5	19.1	19.8	19.7	16.9	15.9	20.2	20.6	20.6	21.4	20.5	19.1
pH*	pH units	6.16	6.72	6.99	6.7	6.59	6.55	6.67	6.44	6.53	6.9	6.26	6.28	6.23
Oxidation-Reduction Potential (ORP)*	mV	220	-19.5	31.9	3.8	6.1	40.9	71.4	94.2	162.1	-98.8	71	204	288
Chloride*	mg/L	8.6	22	46	12	74	5.2	25	8.1	27	4.8	3.1	6.0	5.0
Alkalinity*	mg/L	160	340	410	430	230	260	240	140	190	190	120	120	120
Ferrous Iron (Iron II)*	mg/L	0.38	1.18	0.58	2.74	2.42	0.55	0.38	0.66	0.01	3.44	2.07	0.68	0.15
Nitrate	mg/L	0.023	ND	0.11	0.06	ND	ND	0.16	0.22	0.29	ND	ND	0.48	0.67
Sulfate*	mg/L	1.2	11	6.1	14	1.7	27	9.6	3.9	2.5	18	4.2	4.8	2.4
Sulfide*	mg/L	0.281	0.506	0.364	0.206	0.487	0.104	0.37	0.107	0.027	0.097	1.036	0.066	0.122
Methane	mg/L	0.001	0.015	0.013	0.016	0.013	0.000	0.000	0.000	0.000	0.040	0.009	0.001	0.036
Total Organic Carbon	mg/L	ND	ND	0.81	0.6	ND								
PCE	mg/L	ND												
TCE	mg/L	ND	0.76	72	200	ND	2.1	ND						
cis-1,2-DCE	mg/L	ND	ND	14	4.8	ND								
Vinyl Chloride (VC)	mg/L	ND	ND	0.34	ND									

**Notes:**

\*These parameters were measured in the field. The remaining were measured by laboratory analysis.

- ND — Not Detected
- NA — Not Available
- mg/L — milligrams/Liter
- µg/L — micrograms/Liter

**Table A-7  
MNA Screening and Ranking Evaluation  
November 2002**

<b>Parameters</b>	<b>01LF</b>	<b>02LF</b>	<b>03LF</b>	<b>04LF</b>	<b>05LF</b>	<b>06LF</b>	<b>07LF</b>	<b>08LF</b>	<b>09LF</b>	<b>10LF</b>	<b>11LF</b>	<b>12LF</b>	<b>13LF</b>
Dissolved Oxygen (DO)	-2	-3	-2	-1	-3	-3	-3	1	-3	-3	-3	-3	-3
Temperature	0	1	0	-1	1	0	0	1	1	1	1	1	0
pH	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxidation Reduction Potential	0	1	1	1	1	1	0	0	0	1	0	0	0
Chloride	0	2	2	2	2	0	2	0	2	0	0	0	0
Alkalinity	0	1	1	1	0	0	0	0	0	0	0	0	0
Ferrous Iron (Iron II)	0	3	0	3	3	0	0	0	0	3	3	0	0
Nitrate	2	2	2	2	2	2	2	2	2	2	2	2	2
Sulfate	2	2	2	2	2	0	2	2	2	2	2	2	2
Sulfide	1	1	1	1	1	1	0	1	0	0	3	0	1
Methane	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Organic Carbon (TOC)	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-DCE	0	0	2	2	0	0	0	0	0	0	0	0	0
Vinyl Chloride (VC)	0	0	2	0	0	0	0	0	0	0	0	0	0
<b>Total</b>	<b>3</b>	<b>10</b>	<b>11</b>	<b>14</b>	<b>9</b>	<b>1</b>	<b>3</b>	<b>7</b>	<b>4</b>	<b>6</b>	<b>8</b>	<b>2</b>	<b>2</b>
<b>Ranking</b>	<b>I</b>	<b>L</b>	<b>L</b>	<b>L</b>	<b>L</b>	<b>I</b>	<b>I</b>	<b>L</b>	<b>I</b>	<b>L</b>	<b>L</b>	<b>I</b>	<b>I</b>

**Notes:**

- I — Inadequate evidence for biodegradation of chlorinated organics
- L — Limited evidence for biodegradation of chlorinated organics
- A — Adequate evidence for biodegradation of chlorinated organics
- S — Strong evidence for biodegradation of chlorinated organics

**Table A-8  
MNA Chemical and Geochemical Data  
March 2003**

Parameters	Units	01LF	02LF	03LF	04LF	05LF	06LF	07LF	08LF	09LF	10LF	11LF	12LF	13LF
Dissolved Oxygen (DO)*	mg/L	0.9	0.68	1.01	0.98	1.83	0.65	1.12	0.52	1.51	1.3	0.65	0.63	0.89
Temperature*	°C	17.04	18.16	18.91	19.66	18.72	18.15	17.77	19.66	18.33	22.06	20.3	19.88	18.58
pH*	pH units	6.51	6.63	6.86	6.58	6.54	6.45	6.48	6.36	6.4	6.76	6.34	6.43	6.51
Oxidation-Reduction Potential (ORP)*	mV	24.1	20.7	34.7	-59	5.3	79.2	132.6	25	161	-55.6	11.4	23.9	54.0
Chloride*	mg/L	17	21	49	18	70	10	32	12	26	4.3	3.6	17	9.1
Alkalinity*	mg/L	150	330	100	150	210	250	59	140	180	170	110	130	120
Ferrous Iron (Iron II)*	mg/L	0.45	1.52	0.13	4.32	2.46	0.36	0.34	0.94	0.13	3.07	2.24	0.65	0.59
Nitrate	mg/L	ND	ND	ND	ND	ND	ND	0.095	0.25	0.42	0.09	0.04	0.89	0.78
Sulfate*	mg/L	1.5	11	5.8	13	1.7	26	8.2	3.4	2.0	6.3	4.3	3.7	2.3
Sulfide*	mg/L	0.417	0.906	0.278	0.244	0.614	0.037	0.4	0.23	0.065	0.502	0.123	0.047	0.281
Methane	mg/L	0.002	0.029	0.010	0.020	0.048	0.0	0.002	0.0	0.0	0.220	0.012	0.009	0.064
Total Organic Carbon	mg/L	ND												
PCE	mg/L	ND												
TCE	mg/L	ND	0.72	70	190	ND	ND	ND	ND	0.44	ND	ND	9.1	ND
cis-1,2-DCE	mg/L	ND	ND	16	6.1	ND	1.8	ND						
Vinyl Chloride (VC)	mg/L	ND	ND	0.28	ND									

**Notes:**

\*These parameters were measured in the field. The remaining were measured by laboratory analysis.

- ND — Not Detected
- NA — Not Available
- mg/L — milligrams/Liter
- µg/L — micrograms/Liter

**Table A-9  
MNA Screening and Ranking Evaluation  
March 2003**

Parameters	01LF	02LF	03LF	04LF	05LF	06LF	07LF	08LF	09LF	10LF	11LF	12LF	13LF
Dissolved Oxygen (DO)	-2	-1	-3	-2	-3	-1	-3	-2	-3	-3	1	1	-1
Temperature	0	0	0	0	0	0	0	0	0	1	1	1	0
pH	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxidation Reduction Potential	1	1	1	1	1	0	0	1	0	1	1	1	0
Chloride	2	2	1	2	2	2	2	2	2	0	0	2	0
Alkalinity	0	1	0	0	0	0	0	0	0	0	0	0	0
Ferrous Iron (Iron II)	0	3	0	3	3	0	0	0	0	3	3	0	0
Nitrate	2	2	2	2	2	2	2	2	2	2	2	2	2
Sulfate	2	2	2	2	2	0	2	2	2	2	2	2	2
Sulfide	0	2	1	1	2	0	1	0	0	2	1	0	1
Methane	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Organic Carbon (TOC)	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-DCE	0	0	2	2	0	0	0	0	0	0	0	2	0
Vinyl Chloride (VC)	0	0	2	0	0	0	0	0	0	0	0	0	0
Total	5	12	8	11	9	3	4	5	3	8	11	11	4
Ranking	I	L	L	L	L	I	I	I	I	L	L	L	I

**Notes:**

- I — Inadequate evidence for biodegradation of chlorinated organics
- L — Limited evidence for biodegradation of chlorinated organics
- A — Adequate evidence for biodegradation of chlorinated organics
- S — Strong evidence for biodegradation of chlorinated organics