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CORRECTIVE ACTION PLAN FOR SITE 11 NSB KINGS BAY GA
7/1/1998
BECHTEL ENVIRONMENTAL

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CORRECTIVE ACTION PLAN

**SITE 11, OLD CAMDEN COUNTY LANDFILL
NAVAL SUBMARINE BASE KINGS BAY, GEORGIA**

Prepared for

**DEPARTMENT OF THE NAVY
SOUTHERN DIVISION
NAVAL FACILITIES ENGINEERING COMMAND**

Under Contract No. N62467-93-D-0936

Prepared by

**BECHTEL ENVIRONMENTAL, INC.
OAK RIDGE, TENNESSEE**

JULY 1998

REVISION 1

Bechtel Job No. 22567

The work described and professional opinions rendered in this document, *Corrective Action Plan for Site 11, Old Camden County Landfill, Naval Submarine Base, Kings Bay, Georgia, Revision 1, July 1998*, were conducted and developed using commonly accepted procedures consistent with applicable standards of practice. The scope of services and options described in this document were developed under the supervision of a professional geologist registered in the State of Georgia.



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ACRONYMS

CAP	Corrective Action Plan
DCE	cis -1,2-dichloroethene
GEPD	Georgia Department of Natural Resources, Environmental Protection Division
H ₂ O ₂	hydrogen peroxide
IM	interim measure
LAS	Land Application System
MCL	Maximum Contaminant Level
Navy	U.S. Department of the Navy
NSB	Naval Submarine Base
O&M	operations and maintenance
PCE	tetrachloroethene
RAC	Remedial Action Contractor
RBC	rotating biological contactor
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
ROW	right-of-way
RW	recovery well
RWP	remediation work plan
SVE	soil vapor extraction
SVOC	semivolatile organic compound
TBD	to be determined
TCE	trichloroethene
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UV	ultraviolet
VC	vinyl chloride
VOC	volatile organic compound

UNITS OF MEASURE

bgs	below ground surface
ft	foot/feet
gal.	gallon
gals.	gallons
gpm	gallons per minute
mg/kg	milligram per kilogram
mg/l	milligram per liter
µg/l	microgram per liter
ppb	parts per billion

EXECUTIVE SUMMARY

Bechtel Environmental, Inc. (Bechtel) was contracted by the Department of the Navy, Naval Facilities Engineering Command, Southern Division, to provide remedial services as the Navy's Environmental Response Action Contractor. Bechtel prepared this Corrective Action Plan (CAP) in July, 1998 for remediation of contaminated Groundwater at Site 11, Old Camden County Landfill at the Naval Submarine Base (NSB) Kings Bay in accordance with the requirements of the Resource Conservation and Recovery Act (RCRA), and the Hazardous and Solid Waste Amendments (HSWA) of 1984. Naval Submarine Base, Kings Bay, Georgia, updated this CAP in July, 2001.

The CAP describes four alternatives, including the preferred alternative, for remediation of the contaminated groundwater at Site 11 to the United States Environmental Protection Agency and Georgia Department of Natural Resources (GDNR) Maximum Contaminant Levels. To achieve this objective, the preferred alternative specifies remediation of the source areas that were identified during the December 1997 direct-push sediment sampling event by the United States Geological Survey (USGS) utilizing in-situ chemical oxidation, containment of the dissolved groundwater plume utilizing pump and treat technologies, and discharge of treated groundwater to the NSB land application system and/or an on-site infiltration gallery. The active remedial measures proposed herein will be supplemented by monitored natural attenuation and risk reduction measures for the residents of the adjacent subdivision.

GDNR approved this CAP in 1998 and the preferred alternative was commenced. In-situ chemical oxidation was performed in three phases from 1998 through 2000, with another treatment proposed in 2001. Pump and treat operation was discontinued in 1999. Remediation work plans are approved by GDNR before work starts.

1.0 INTRODUCTION

Bechtel Environmental, Inc. (Bechtel) has been contracted by the Department of the Navy, Naval Facilities Command, Southern Division, to provide remedial services as the Navy's Environmental Response Action Contractor (RAC). Under Delivery Order 25, Task 1, of the Prime Contract N62467-93-D-0936, Bechtel has been contracted to prepare a Corrective Action Plan (CAP) for remediation of contaminated groundwater at Site 11 at Naval Submarine Base (NSB) Kings Bay, in accordance with the requirements of the Resource Conservation and Recovery Act (RCRA) and the Hazardous and Solid Waste Amendments (HSWA) of 1984. The CAP summarizes the plan for the corrective action that is designed to contain and remediate contaminated groundwater beneath and immediately downgradient of Site 11.

Included in the CAP is a brief chronology of previous activities, a summary of the results from past investigations; corrective action objectives for the proposed activities, a conceptual description, screening and evaluation of several corrective action alternatives, and a recommendation for corrective action.

1.1 PURPOSE

The purpose of this CAP is to document the results of the process completed to identify, screen, and evaluate remedial alternatives and recommend a corrective action to address volatile organic compound (VOC) contaminated groundwater at Site 11. This plan has been prepared to comply with the Georgia Department of Natural Resources, Environmental Protection Division (GEPD) Consent Order No. EPD-HW-1072, effective March 18, 1994, and Hazardous Waste Facility Permit No. HW-014(S)(2), issued September 29, 1989. Subsequent activities to this CAP will include design, implementation, and monitoring of the corrective action proposed herein, contingent upon approval by GEPD.

1.2 SCOPE

The scope of this report is to present corrective action objectives, evaluate corrective action alternatives, and propose a corrective action for implementation at Site 11. Physical and chemical data collected during several investigative initiatives at Site 11, including the RCRA Facility Investigation (RFI), the Interim Corrective Measure Screening Investigation, the Supplemental RFI, the Phase I and II Interim Measures, and several focused direct-push investigations led to the identification of contaminants of concern and media of concern. A chronology of the source documents for these studies is provided in Section 2.0, Investigation and Remediation. The results of these studies have been reported under separate cover.

1.3 OBJECTIVES

The objective of the corrective actions proposed in this CAP is to meet the cleanup goals set by GEPD for groundwater. Based on communication with GEPD, the contaminants of concern for Site 11 will be chlorinated VOCs, specifically tetrachloroethene (PCE), trichloroethene (TCE),

cis-1,2-dichloroethene (DCE), and vinyl chloride (VC), that exceed the GEPD Rules for Safe Drinking Water Maximum Contaminant Levels (MCLs). Table 1-1 lists the groundwater contaminants of concern, the GEPD MCLs, and the Federal MCLs.

Additionally, groundwater that is extracted from a recovery system, as part of alternatives developed under this plan, will be required to meet discharge criteria. The specific discharge requirements will be determined during the CAP implementation phase.

Table 1-1
Maximum Contaminant Levels for Contaminants of Concern

Corrective Action Plan
Site 11, Old Camden County Landfill
Naval Submarine Base
Kings Bay, Georgia

Constituent	GEPD MCL ($\mu\text{g/L}$) ¹	Federal MCL ($\mu\text{g/L}$) ²
Vinyl chloride	2	2
cis-1,2-Dichloroethene	70	70
Trichloroethene	5	5
Tetrachloroethene	5	5

¹ GEPD, 1997

² U.S. Environmental Protection Agency, 1996

Notes: $\mu\text{g/L}$ = micrograms per liter

GEPD = Georgia Department of Natural Resources, Environmental Protection Division

MCL = Maximum Contaminant Levels

1.4 REPORT ORGANIZATION

This report is organized into seven chapters plus two appendices. The contents of each chapter are described below.

Chapter 1.0, Introduction, identifies the scope and purpose of this report as well as the objectives for the corrective action proposed.

Chapter 2.0, Investigation and Remediation, provides a source document chronology of previous site investigations, interim measures implemented, and the contaminants of concern for corrective action.

Chapter 3.0, Development of Remedial Alternatives, presents the screening of technologies and subsequent development of three corrective action alternatives.

Chapter 4.0, Evaluation of Alternatives, presents the evaluation of each corrective action alternative against selected criteria.

Chapter 5.0, *Alternative Justification and Recommendation*, presents a comparative evaluation of the corrective action alternatives and proposes one alternative for implementation.

Chapter 6.0, *Proposed Implementation Schedule*, includes the schedule for implementation of the proposed activities

Chapter 7.0, *Contingencies and Exit Strategy Based Upon Long Term Monitoring Results*, presents criteria for contingency actions and deactivation of the remediation system.

2.0 INVESTIGATION AND REMEDIATION

2.1 PREVIOUS INVESTIGATIONS

The investigative process provides for the evaluation of the nature and extent of the releases of hazardous constituents and the collection of necessary data to support interim and final corrective action activities. RFI activities were initiated in January 1992 by ABB Environmental Services, Inc. (ABB-ES). The nature and extent of contamination at Site 11 has been characterized and areas affected by site releases have been identified. The RFI and subsequent investigations provided the physical and chemical data needed to support the corrective action proposed herein. Table 2-1 provides a summary of the investigations carried out to date and associated source documents.

A description of the site-specific hydrogeology, including a conceptual model, can be found in the RFI Interim Report for Site 11 (ABB-ES, 1993) and the report, Hydrology of the Shallow Aquifer System in the Vicinity of Site 11 (USGS, 1998).

2.2 REMEDIATION EFFORTS

A Groundwater extraction and treatment system was designed and installed as an interim measure (IM) to hydraulically control further migration of contaminated groundwater. However, in-situ oxidation proved to be a more effective treatment at this site. Repeated injections of oxidizers removed the most contaminated source areas, and another treatment is planned. Monitored natural attenuation continues. The Navy is proposing another chemical oxidation injection along with action to enhance attenuation in 2001.

Initial construction of the IM began in September 1993 with start-up activities occurring in March 1994. The first phase of the IM included the installation of five groundwater recovery wells and their associated conveyance system, a diffused aeration tank for groundwater treatment, and vapor-phase carbon drums for off-gas air treatment. The recovery wells were positioned in the areas with the highest known concentrations of contaminants along the western side of the landfill and right-of-way (ROW) of Spur 40. The second phase of the IM included the addition of a new recovery well, which was centrally located within the existing recovery well network. Four recovery wells operated (RW-1, -3, -4, and -6) at a combined flow rate of approximately 55 gallons per minute. The recovered groundwater was treated to below MCLs and discharged to the NSB Kings Bay Land Application System (LAS). Figure 2-1 shows the former IM system layout.

Recovery wells RW-7 and RW-8 were added to the IM system in February, 1999, but were shut down in March 1999 due to repeated fouling of the wells, pumps, and effluent piping. IM equipment remained inoperative and will be removed in 2001.

In-situ chemical oxidation treatment was performed from November 1998 to February 1999. It was repeated in June and July 1999 and in January, March, and April, 2000. A total of 34,850 gallons of 50% hydrogen peroxide and an equivalent amount of ferrous oxide were injected into the contaminate source area. This reduced the contaminant levels in the most contaminated area by more than ninety per cent and reduced the size of the contaminated area by more than ninety per cent. Details are in the Completion Report for Interim Measures (BEI, 2000). Chemical oxidation injection will be repeated in 2001 to remove residual contamination below the originally treated area.

After chemical oxidation treatment, vegetable oil may then be injected in the landfill area to enhance the reductive oxidation and electron donor conditions necessary to promote microbial reductive dechlorination of chlorinated solvents. This action will preclude further oxidation treatments. The Georgia Department of Natural Resources (GDNR) will review the work plan for the final in-situ chemical oxidation and the vegetable oil injection prior to these actions.

2.3 CONTAMINANTS AND AREAS OF REMEDIAL CONCERN

2.3.1 Plume/Source Area Delineation

The contaminants of concern for corrective action activities, as identified by GDNR, are PCE, TCE, DCE and VC. In order to define areas of remedial concern, groundwater data were compared to MCLs for the contaminants of concern. The data initially used included the September 1997 groundwater monitoring event (see Figure 2-2), two direct-push investigations performed in March and September 1997 by ABB-ES (see Figures 2-3 through 2-8), and a direct-push sediment sampling event performed by the USGS in December 1997 (see Figures 2-3 and 2-9).

In the anaerobic biodegradation process, PCE is reduced to TCE, then DCE and VC. For this reason, the areas of higher concentrations of PCE were sought out as source areas during the development of this CAP. The data presented on Figures 2-4 and 2-9 indicated the presence of two distinct source areas of PCE. The groundwater monitoring event and the direct-push efforts performed by ABB-ES (Figure 2-4) generally defined this source area, while the USGS direct-push sediment sampling event (Figure 2-9), which was performed utilizing the previous data as a starting point, further isolated the source areas to two distinct locations.

The data presented on Figures 2-4 through 2-8 indicated a dissolved groundwater plume, which extends downgradient from the two source areas in a narrow, cigar-like shape. In the areas closest to the source area, the highest chlorinated ethene constituent is PCE. In the areas downgradient from the source areas, the PCE concentrations decrease and the daughter products TCE, DCE and VC begin to appear due to biodegradation of the PCE. The highest chlorinated ethene concentrations appear to be limited to the areas directly downgradient from the source areas; therefore, dispersion of the plume appears to be minimal in the crossgradient directions.

The data shown on Figure 2-8 define the downgradient extent of the PCE plume, and also indicate the presence of low-level concentrations of the daughter products TCE, DCE and VC. Based upon the information provided in the report, *Selecting Remedial Goals by Assessing the Natural Attenuation Capacity of Ground-Water Systems* (USGS, 1998), natural attenuation can be utilized to effectively remediate these areas as part of an overall remediation strategy. A copy of this report is provided in Appendix A.

2.3.2 Crooked River Plantation Subdivision Private Well Survey/Groundwater Monitoring

Between the dates of June 1 and June 6, 1998, a private well survey was conducted in the Crooked River Plantation Subdivision, within the boundaries shown on Figure 2-10. A resident at each property location within the given boundary was contacted, either by phone or in person. In all, a total of 58 residents were contacted and 25 private wells were located within the survey boundaries. The wells ranged from 10 feet to 40 feet below ground surface. None of the wells were being utilized for drinking water purposes.

On June 5 and 6, 1998, a total of 21 of the located wells were sampled for analyses of the contaminants of concern. A sample could not be collected from four of the wells, due to problems with the irrigation pump or the well itself. Only one well, located at 223 Plantation Court, was found to contain concentrations of the contaminants of concern at or above Federal MCLs. The sample collected at 223 Plantation Court contained 2 ug/l (micrograms per liter) of VC, which is equal to the Federal MCL. This sample also contained 1 ug/l of DCE, which is below the Federal MCL. The well located at 209 Cottage Court contained 56 ug/l of DCE, and 1 ug/l vinyl chloride, both of which are below Federal MCLs. The well located at 203 Plantation Court contained 1 ug/l of TCE, which is also below the Federal MCL. None of the remaining samples contained concentrations of PCE, TCE, DCE, or VC above laboratory detection limits. The analytical results are summarized on Table 2-2. The irrigation wells at 203 Plantation Court, 223 Plantation Court, and 209 Cottage Court are currently being sampled monthly. Results are summarized in quarterly groundwater monitoring reports (JAJMS, 2001).

a 1
Site 11 Investigation, Chronology and Source Documents

Corrective Action Plan
Site 11, Old Camden County Landfill
Naval Submarine Base
Kings Bay, Georgia

Program and Activity	Dates Conducted	Activities	Source Documentation
RFI Field Program	January/February 1992	Soil borings Geophysical surveys Subsurface soil sampling Monitoring well installation Slug tests Groundwater Sampling Event No. 1	Technical Memorandum No. 1 ¹ Potential Source of Contamination Investigation/Site Investigation Solid Waste Management Unit RCRA Facility Investigation Work Plan ²
RFI Field Program	May 1992	Groundwater Sampling Event No. 2	Technical Memorandum No. 2 ³
Hazardous Ranking System (HRS) II Scoring	July 1992	HRS II Scoring	Documentation Support and HRS II Scoring ⁴
RFI Field Program	July 1992	Groundwater Sampling Event No. 3	Technical Memorandum No. 3 ⁵
Phase I Interim Investigation	August 1992	Piezocene penetrations Groundwater sampling	Phase I Interim Investigation Memorandum ⁶
RFI Field Program	September 1992	Groundwater Sampling Event No. 4	Technical Memorandum No. 4 ⁷
ICMS Investigation	October/November 1992	Records search Piezocone penetrations Air screening survey Groundwater sampling Soil vapor sampling Sediment sampling Surface water sampling Private Irrigation well sampling Screening risk evaluation	ICMS Investigation Report ⁸ Technical Work Plan ICMS Investigation ⁹
RFI Field Program	November 1992	Groundwater Sampling Event No. 5	Technical Memorandum No. 5 ¹⁰
RFI Field Program	January 1993	Groundwater Sampling Event No. 6	RFI Interim Report for Site 11 ¹¹
Supplemental RFI Field Program	October/November 1993	Soil borings Subsurface soil sampling Monitoring well installation	Supplemental RFI Work Plan ¹² Technical Memorandum, 1993 Field Program and January 1994 Groundwater Sampling Event ¹²
IM Phase I Start-up Activities	September through December 1993	Site construction Extraction system installation Initial pumping test Treatment system installation	Interim Measure Work Plan: Phase I Activities ¹⁴ Interim Measure, Phase I Activities: System Installation Technical Memorandum ¹⁵

**Table 2-1 (Continued)
Site 11 Investigation Chronology and Source Documents**

Corrective Action Plan
Site 11, Old Camden County Landfill
Naval Submarine Base
Kings Bay, Georgia

Program and Activity	Dates Conducted	Activities	Source Documentation
Supplemental RFI Field Program	January 1994	Groundwater sampling event	Technical Memorandum, 1993 Field Program and January 1994 Groundwater Sampling Event ¹²
IM Phase I	March through May 1994	Pumping tests Pilot-scale operation	Interim Measure Phase I Activities: Evaluation and Recommendation Report Addendum ¹⁴
Supplemental RFI Field Program	April 1994	Groundwater sampling event	Technical Memorandum, April 1994 Groundwater Sampling Event ¹⁷
IM Phase I Continuance	September 1994	Groundwater sampling event	
Supplemental RFI Field Program	November 1994	Surface soil sampling Surface water and sediment sampling Source characterization Air sampling	Technical Memorandum, November 1994 Field Program ¹⁸
IM Phase I Continuance	April 1995	Groundwater sampling event	Long-term Remedial Options Pre-Evaluation Plan ¹⁹
IM Phase I Continuance	April 1996	Groundwater sampling event	Letter Report, April 1996 Groundwater Data ²⁰
IM Phase I Continuance	October 1996	Groundwater sampling event	Letter Report, Summary of October 1996 Groundwater Data ²¹
IM Phase II Upgrades	December 1996	Installation of recovery well RW-6 Abandonment of recovery well RW-5	Letter Report, IM System Phase II Upgrades, Treatment System Evaluation ²²
Focused Groundwater Investigation	March 1997	Direct push groundwater sampling event	Letter Report, Summary of Analytical Results of March 1997 Groundwater Sampling Activities ²³
Focused Groundwater Investigation	September 1997	Direct push groundwater sampling event	Letter Report, Summary of 1997 Focused Groundwater Investigations ²⁴
IM Phase II Monitoring	September 1997	Groundwater sampling event	

Sources: ¹ABB-ES, June 1992 ⁴ABB-ES, September 1992 ¹¹ABB-ES, December 1993 ¹⁶ABB-ES, October 1995 ²¹ABB-ES, May 1997
²ABB-ES, October 1991 ⁷ABB-ES, December 1992 ¹²ABB-ES, August 1994 ¹⁷ABB-ES, September 1994 ²²ABB-ES, March 1997
³ABB-ES, July 1992 ⁸ABB-ES, August 1993 ¹³ABB-ES, July 1994 ¹⁸ABB-ES, May 1995 ²³ABB-ES, June 1997
⁶ABB-ES, July 1992 ⁹ABB-ES, March 1993 ¹⁴ABB-ES, March 1994 ¹⁹ABB-ES, September 1995 ²⁴ABB-ES, October 1997
⁵ABB-ES, September 1992 ¹⁰ABB-ES, March 1993 ¹⁵ABB-ES, July 1994 ²⁰ABB-ES, July 1992

Notes: RFI = Resource Conservation and Recovery Act (RCRA) Facility Investigation.
RCRA = Resource Conservation and Recovery Act.
IM = Interim measure.
ICMS = Interim Corrective Measures Study

Table 2-1 (Continued)
Site 11 Investigation, Chronology and Source Documents

Corrective Action Plan
Site 11, Old Camden County Landfill
Naval Submarine Base
Kings Bay, Georgia

Program and Activity	Dates Conducted	Activities	Source Documentation
Interim Measures	1 Feb 99 - 30 Apr 99	IM system operation and shutdown In-Situ Chemical Oxidation Groundwater sampling	IM Progress Report, February 1, 1999 - April 30, 1999 (Bechtel, May 1999)
Monitoring	Jun 99 - present	Groundwater sampling	Groundwater Monitoring Plan for Site 11, Old Camden County Landfill, U.S. Naval Submarine Base, Kings Bay, Georgia (Bechtel, June 1999)
Interim Measures	Jul 98 - Jul 00	IM system operation and shutdown In-Situ Chemical Oxidation Groundwater sampling	Completion Report for Interim Measures, Site 11, Jul 98 - Jul 00 (Bechtel, July 2000)
Monitoring	Jul - Sep 99	Groundwater sampling	Quarterly Groundwater Monitoring Report (Bechtel, September 1999)
Monitoring	Oct - Dec 99	Groundwater sampling	Quarterly Groundwater Monitoring Report (Bechtel, December 1999)
Monitoring	Jan - Mar 00	Groundwater sampling	Quarterly Groundwater Monitoring Report (JAJMS, March 2000)
Corrective Action	Oct 99 - Mar 00	IM system operation and shutdown In-Situ Chemical Oxidation Groundwater sampling	Semi-Annual Corrective Action Assessment Report (Bechtel, April 2000)
Monitoring	Apr - Jun 00	Groundwater sampling	Quarterly Groundwater Monitoring Report (JAJMS, June 2000)
Monitoring	Jul - Sep 00	Groundwater sampling	Quarterly Groundwater Monitoring Report (JAJMS, October 2000)
Corrective Action	Apr 00 - Sep 00	IM system operation and shutdown In-Situ Chemical Oxidation Groundwater sampling	Semi-Annual Corrective Action Assessment Report (JAJMS, October 2000)
Corrective Action	Oct 00	Source Area Delineation	Work Plan, Source Area Delineation at Site 11 (CH2M Hill, October 2000)

TABLE 2-2
CROOKED RIVER PLANTATION SUBDIVISION
IRRIGATION WELL SAMPLING
ANALYTICAL RESULTS
5-6 JUNE 1998

Current Address

Sample Location ¹	Address	Well Depth (ft bgs)	PCE (µg/l)	TCE (µg/l)	1,2 DCE (µg/l)	VC (µg/l)
1	610 Gate Lane	40	<1	<1	<1	<1
2	223 Plantation Court	NR	<1	<1	1	2
3	215 Plantation Court	10	<1	<1	<1	<1
4	213 Plantation Court	20	<1	<1	<1	<1
5	203 Plantation Court	NR	<1	1	<1	<1
6	2903 Plantation Drive	20	<1	<1	<1	<1
7	2907 Plantation Drive	20	<1	<1	<1	<1
8	2913 Plantation Drive	NR	<1	<1	<1	<1
9	218 Plantation Court	15	<1	<1	<1	<1
10	216 Plantation Court	40	<1	<1	<1	<1
11	214 Plantation Court	20	<1	<1	<1	<1
12	212 Plantation Court	20	<1	<1	<1	<1
13	210 Plantation Court	21	<1	<1	<1	<1
14	208 Plantation Court	20	<1	<1	<1	<1
15	209 Cottage Court	NR	<1	<1	56	1
16	207 Cottage Court	NR	<1	<1	<1	<1
17	205 Cottage Court	20	<1	<1	<1	<1
18	201 Cottage Court	20	<1	<1	<1	<1
19	204 Cottage Court	30	<1	<1	<1	<1
20	2705 Plantation Drive	NR	<1	<1	<1	<1
21	210 Cottage Court	NR	<1	<1	<1	<1
Drinking Water MCLs			5	5	70	2

122 Plantation Court

102 Plantation Court

108 Cottage Court

PCE = tetrachlorethene
TCE = trichloroethene
VC = vinyl chloride
1,2 DCE = cis-1,2 dichloroethene

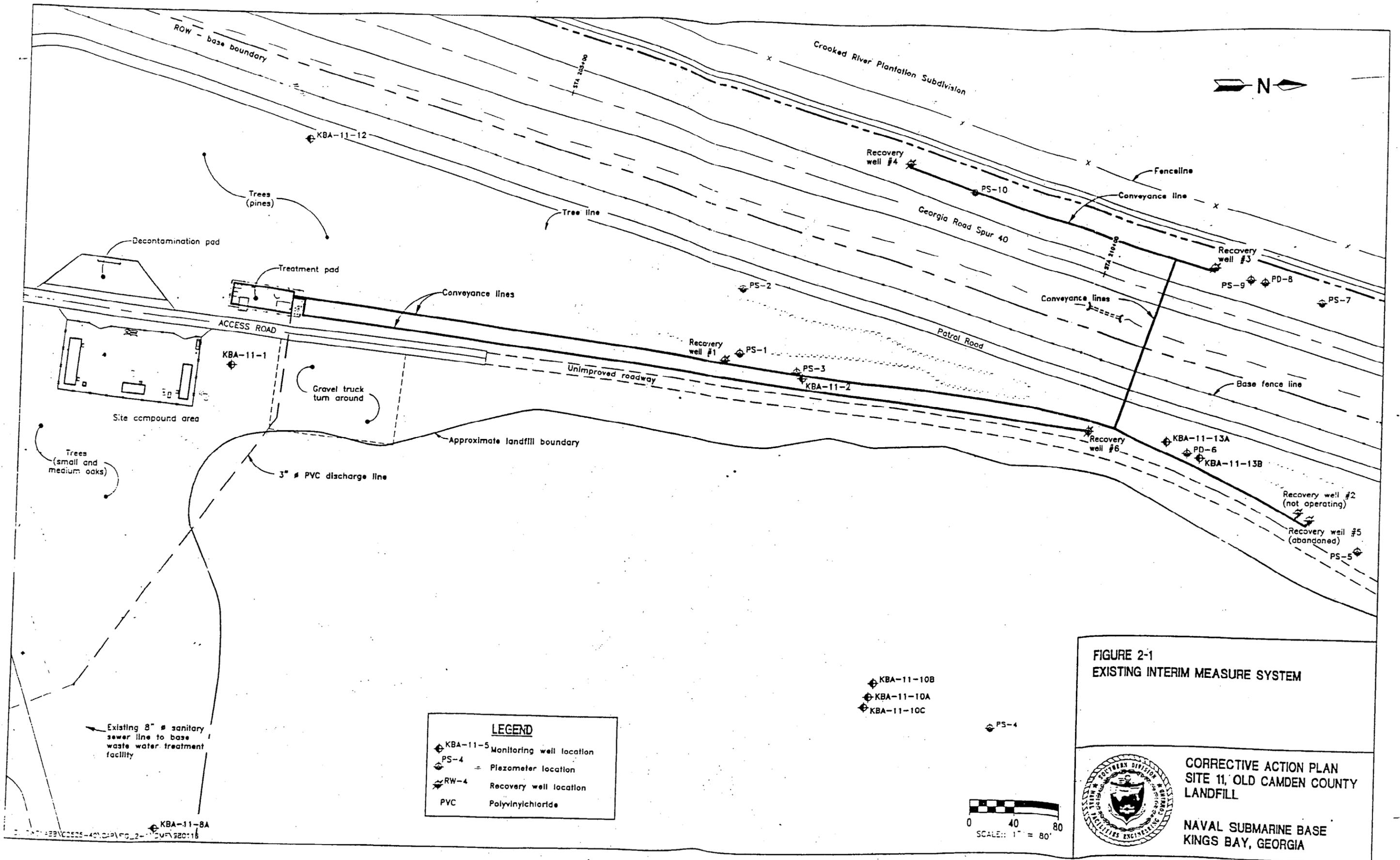
µg/l = micrograms per liter
ft bgs = feet below ground surface
NR = Not Reported
MCL = EPA Maximum Concentration Level

Note 1: Sample locations are shown on Figure 2-10.

Table 2-1 (Continued)
 Site 11 Investigation, Chronology and Source Documents

Corrective Action Plan
 Site 11, Old Camden County Landfill
 Naval Submarine Base
 Kings Bay, Georgia

Program and Activity	Dates Conducted	Activities	Source Documentation
Monitoring	Sep - Nov 00	Groundwater sampling	Quarterly Groundwater Monitoring Report (JAJMS, December 2000)
Monitoring	Dec 00 - Feb 01	Groundwater sampling	Quarterly Groundwater Monitoring Report (JAJMS, March 2001)
Corrective Action	Oct 00 - Mar 01	IM system operation and shutdown In-Situ Chemical Oxidation Groundwater sampling	Semi-Annual Corrective Action Assessment Report (JAJMS, April 2001)
Monitoring	Apr - Jun 01	Groundwater sampling	Quarterly Groundwater Monitoring Report (JAJMS, June 2001)

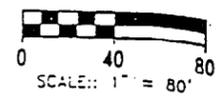


**FIGURE 2-1
EXISTING INTERIM MEASURE SYSTEM**

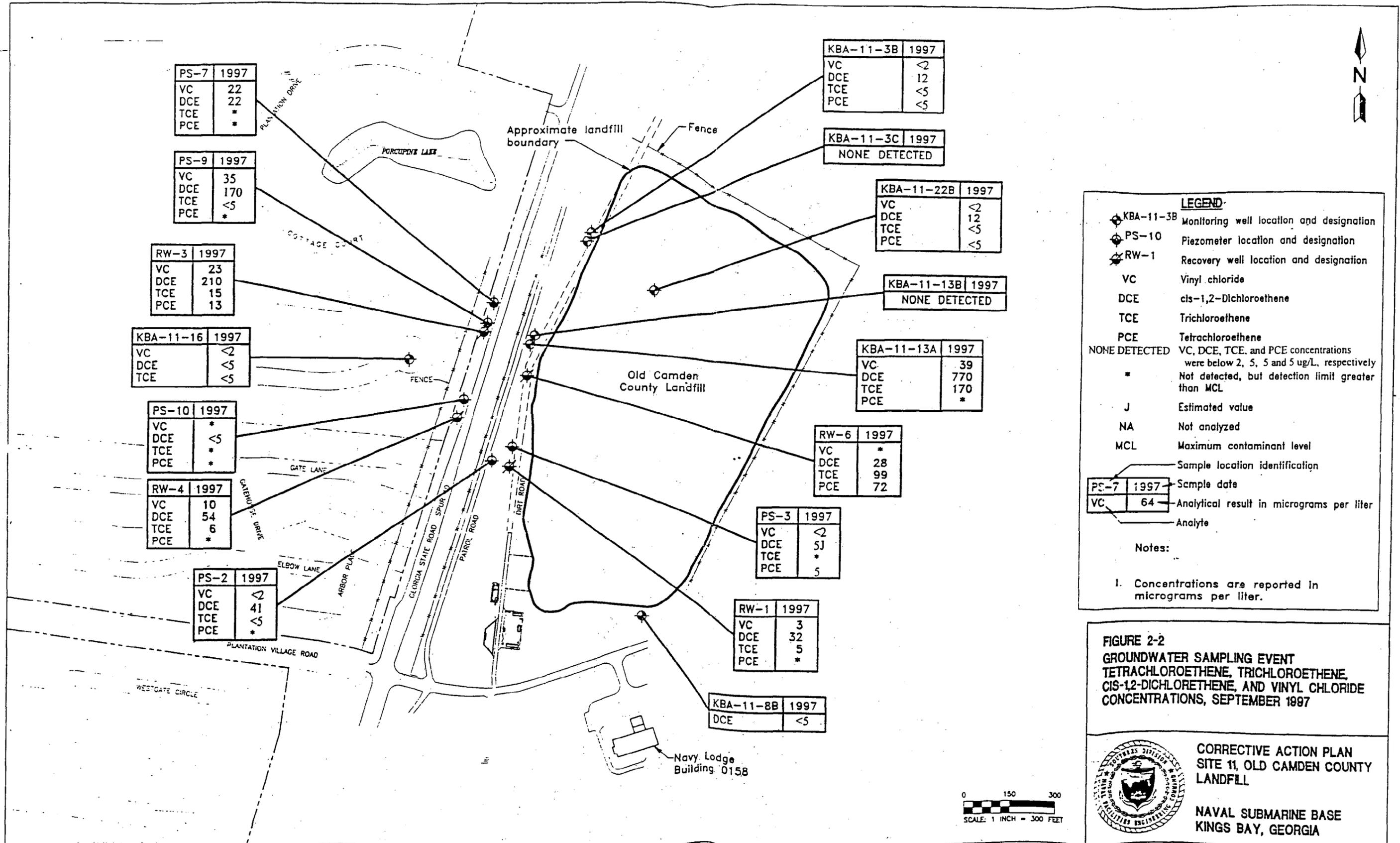
**CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL**

**NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA**

LEGEND	
◆ KBA-11-5	Monitoring well location
◆ PS-4	Piezometer location
◆ RW-4	Recovery well location
PVC	Polyvinylchloride



0534 CB1Z



PS-7	1997
VC	22
DCE	22
TCE	*
PCE	*

PS-9	1997
VC	35
DCE	170
TCE	<5
PCE	*

RW-3	1997
VC	23
DCE	210
TCE	15
PCE	13

KBA-11-16	1997
VC	<2
DCE	<5
TCE	<5

PS-10	1997
VC	*
DCE	<5
TCE	*
PCE	*

RW-4	1997
VC	10
DCE	54
TCE	6
PCE	*

PS-2	1997
VC	<2
DCE	41
TCE	<5
PCE	*

KBA-11-3B	1997
VC	<2
DCE	12
TCE	<5
PCE	<5

KBA-11-3C	1997
NONE DETECTED	

KBA-11-22B	1997
VC	<2
DCE	12
TCE	<5
PCE	<5

KBA-11-13B	1997
NONE DETECTED	

KBA-11-13A	1997
VC	39
DCE	770
TCE	170
PCE	*

RW-6	1997
VC	*
DCE	28
TCE	99
PCE	72

PS-3	1997
VC	<2
DCE	5J
TCE	*
PCE	5

RW-1	1997
VC	3
DCE	32
TCE	5
PCE	*

KBA-11-8B	1997
DCE	<5

LEGEND

- ◆ KBA-11-3B Monitoring well location and designation
- PS-10 Piezometer location and designation
- ⊙ RW-1 Recovery well location and designation
- VC Vinyl chloride
- DCE cis-1,2-Dichloroethene
- TCE Trichloroethene
- PCE Tetrachloroethene
- NONE DETECTED VC, DCE, TCE, and PCE concentrations were below 2, 5, 5 and 5 ug/L, respectively
- * Not detected, but detection limit greater than MCL
- J Estimated value
- NA Not analyzed
- MCL Maximum contaminant level

— Sample location identification

PS-7	1997
VC	64

— Sample date

— Analytical result in micrograms per liter

— Analyte

Notes:

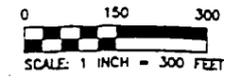
- Concentrations are reported in micrograms per liter.

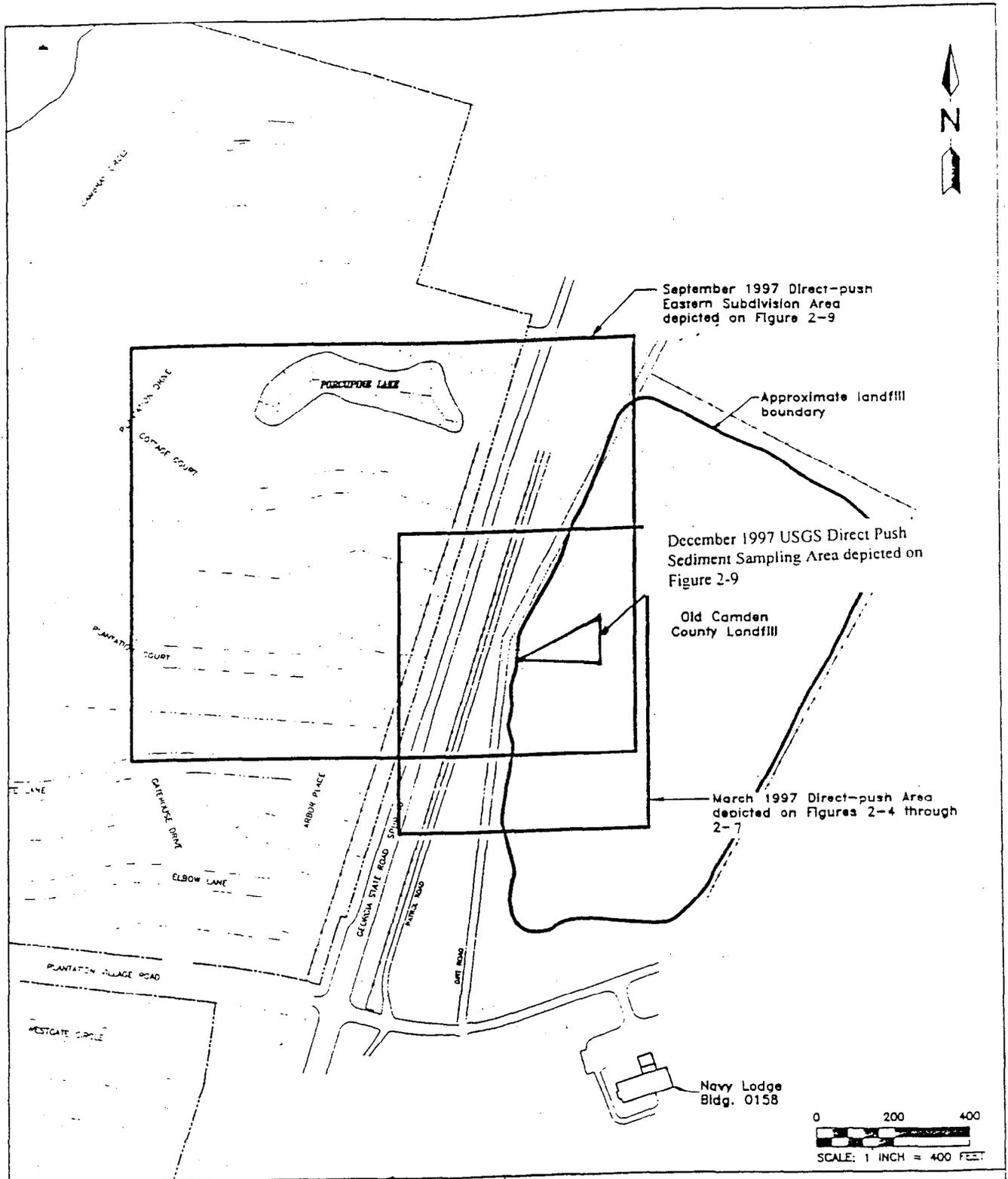
FIGURE 2-2
GROUNDWATER SAMPLING EVENT
TETRACHLOROETHENE, TRICHLOROETHENE,
CIS-1,2-DICHLOROETHENE, AND VINYL CHLORIDE
CONCENTRATIONS, SEPTEMBER 1997



CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL

NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA





**FIGURE 2-3
DIRECT PUSH SAMPLING LOCATION
AREAS, MARCH 1997, SEPTEMBER 1997,
AND DECEMBER 1997**



**CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL**

**NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA**

D:\DWG\ABB\02325-40\CAP\FIG_2-3\DMF\980303

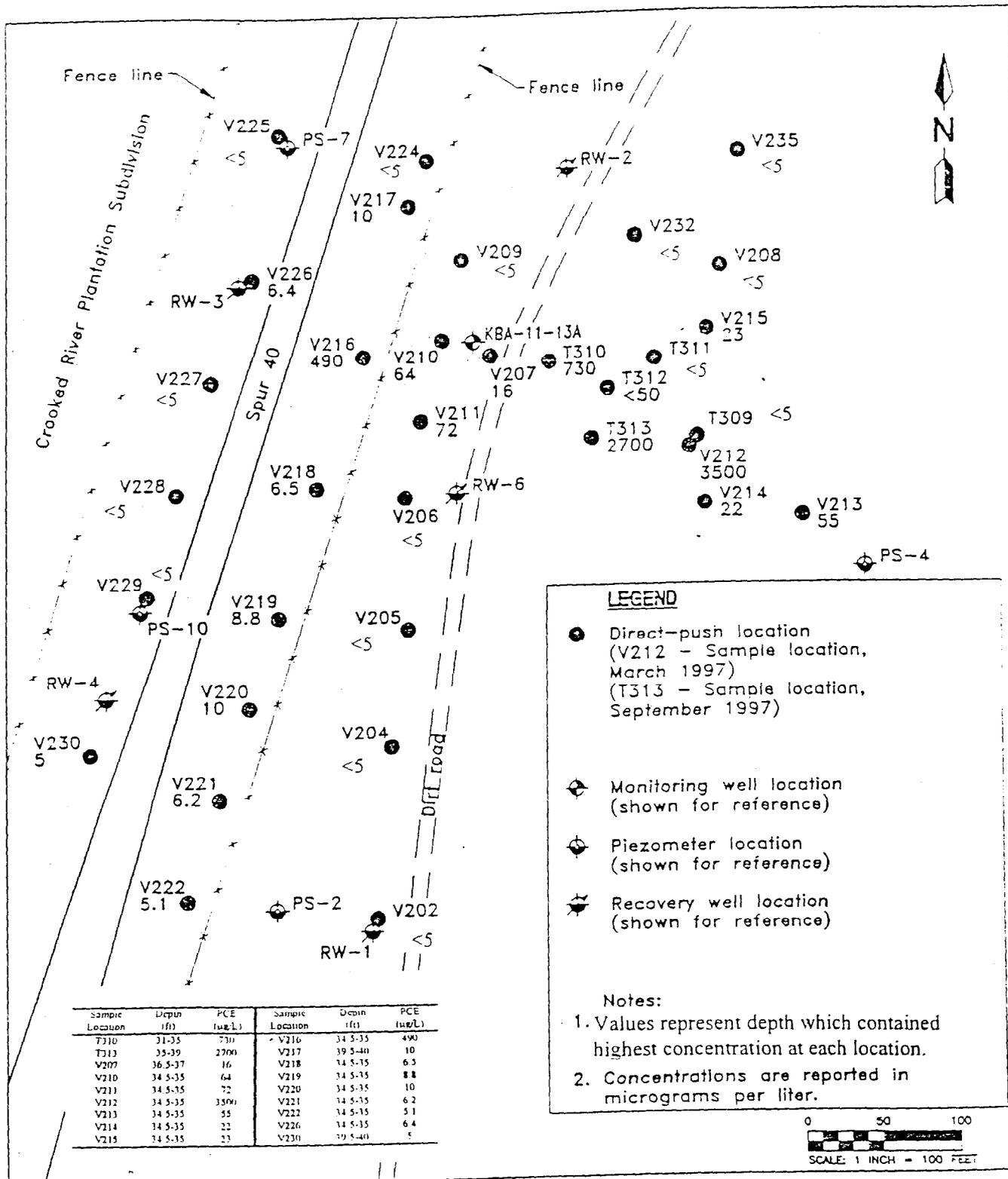
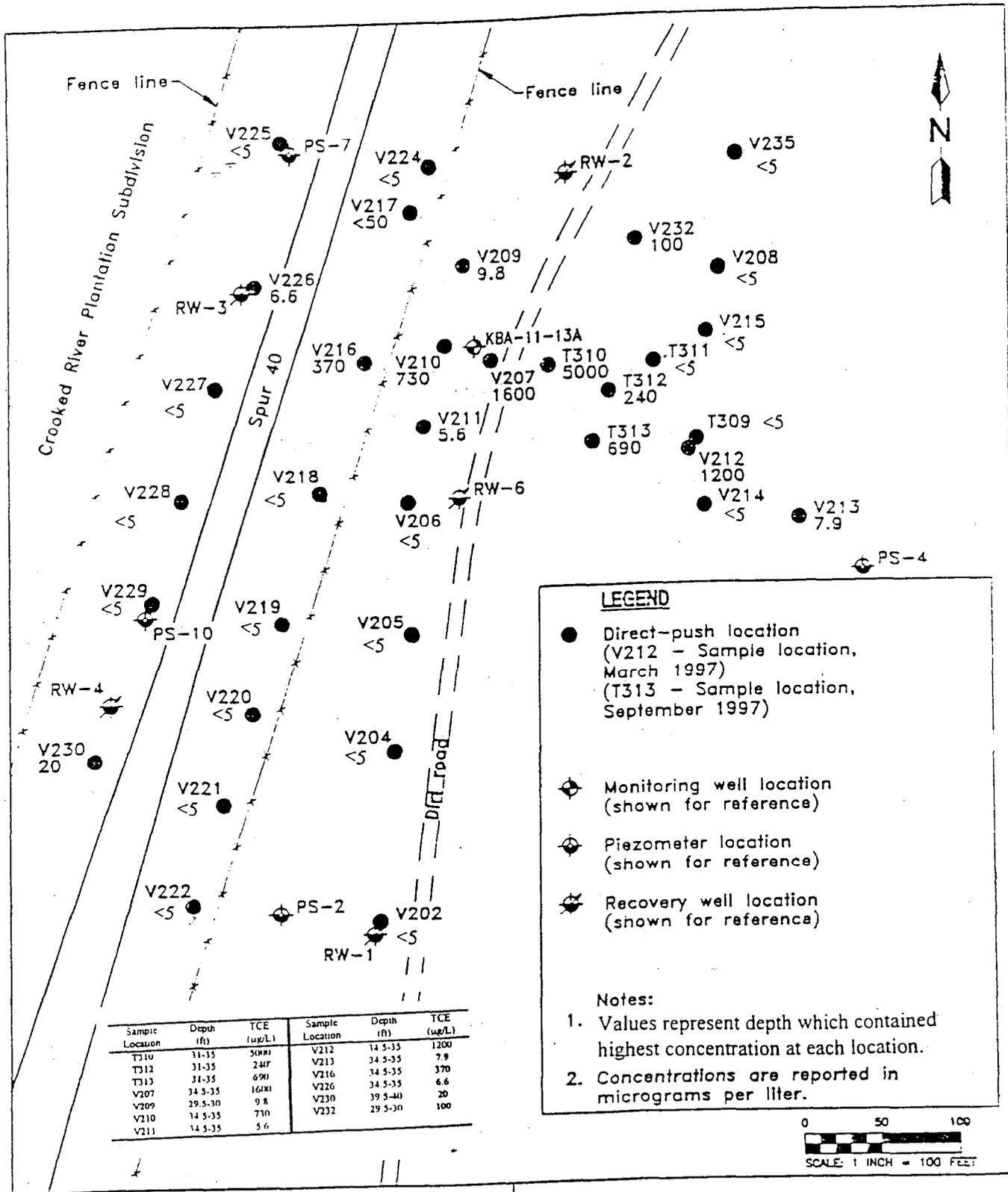


FIGURE 2-4
GROUNDWATER DIRECT-PUSH SAMPLING
LOCATIONS
TETRACHLOROETHENE CONCENTRATIONS,
MARCH 1997 AND SEPTEMBER 1997,



CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL

NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA



Sample Location	Depth (ft)	TCE (ug/L)	Sample Location	Depth (ft)	TCE (ug/L)
T310	31-35	5000	V212	14.5-35	1200
T312	31-35	2400	V213	34.5-35	7.9
T313	31-35	690	V216	34.5-35	370
V207	34.5-35	1600	V226	34.5-35	6.6
V209	29.5-30	9.8	V230	39.5-40	20
V210	14.5-35	730	V232	29.5-30	100
V211	14.5-35	5.6			

FIGURE 2-5
GROUNDWATER DIRECT-PUSH SAMPLING
LOCATIONS
TRICHLOROETHENE CONCENTRATIONS,
MARCH 1997 AND SEPTEMBER 1997.



CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL
NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA

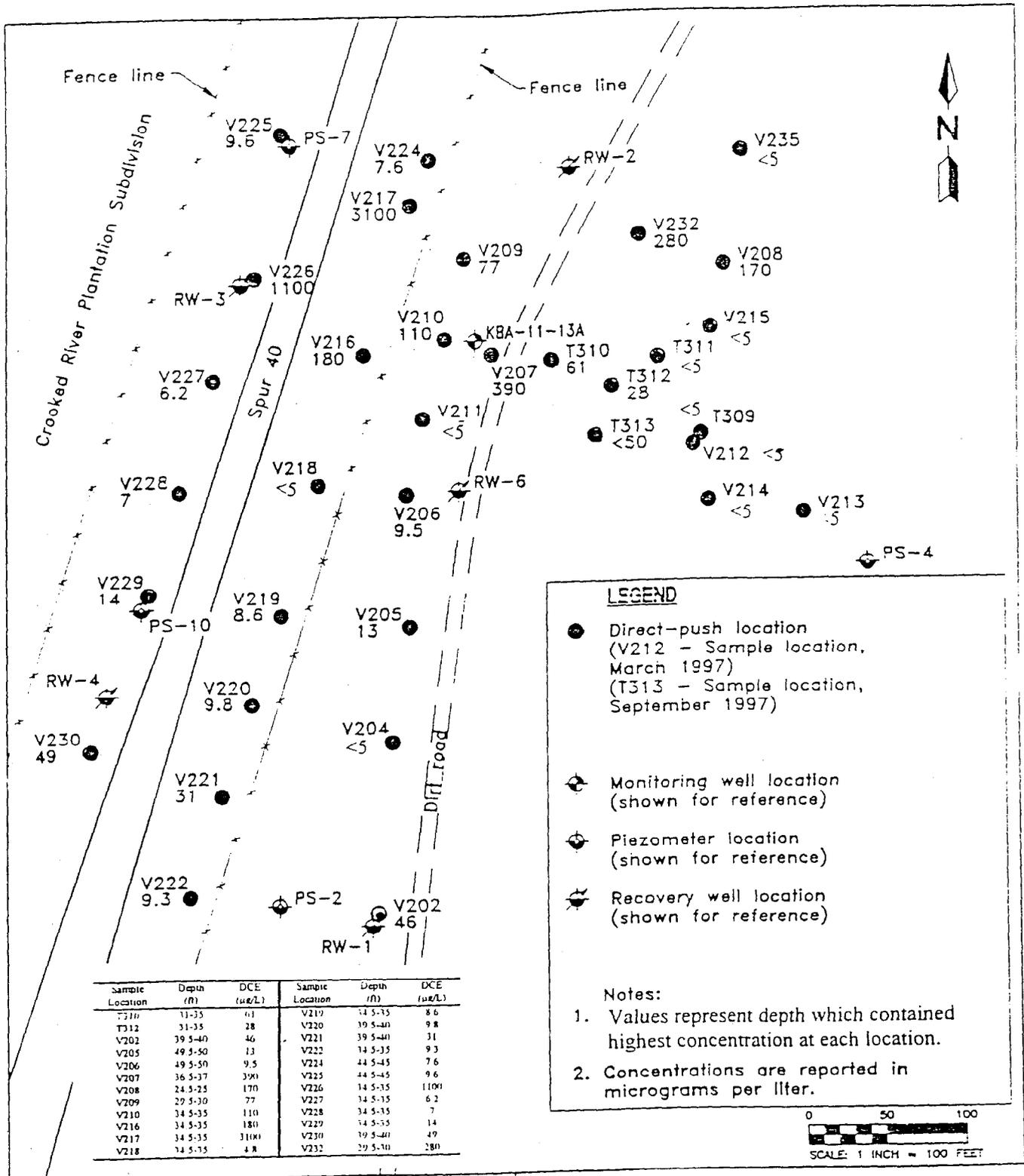
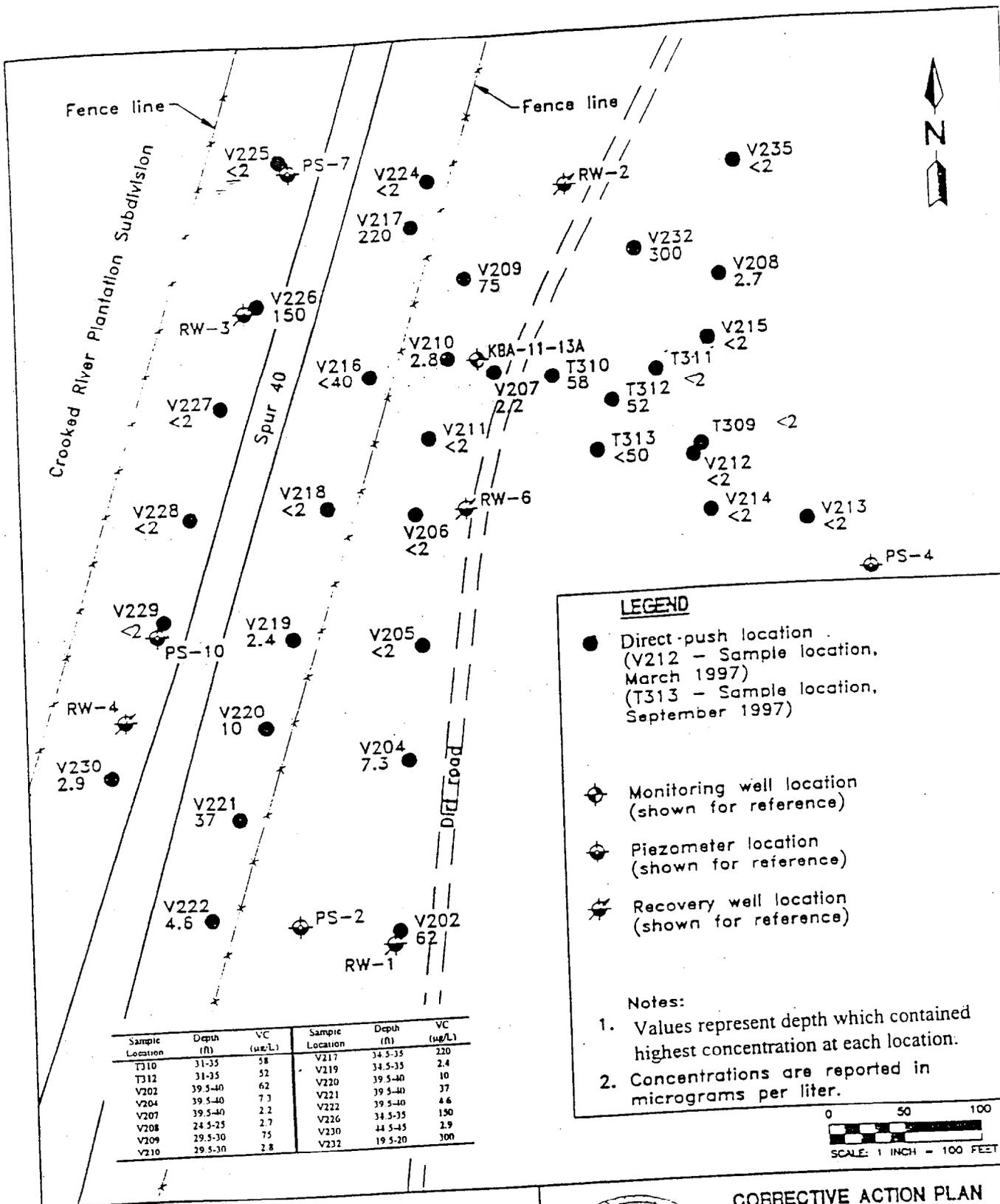


FIGURE 2-6
GROUNDWATER DIRECT-PUSH SAMPLING
LOCATIONS
CIS-1,2-DICHLOROETHENE CONCENTRATIONS,
MARCH 1997 AND SEPTEMBER 1997,



CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL

NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA



Sample Location	Depth (ft)	VC (µg/L)	Sample Location	Depth (ft)	VC (µg/L)
T310	31-35	58	V217	34.5-35	220
T312	31-35	52	V219	34.5-35	2.4
V202	39.5-40	62	V220	39.5-40	10
V204	39.5-40	7.3	V221	39.5-40	37
V207	39.5-40	2.2	V222	39.5-40	4.6
V208	24.5-25	2.7	V226	34.5-35	150
V209	29.5-30	75	V230	44.5-45	2.9
V210	29.5-30	2.8	V232	19.5-20	300

FIGURE 2-7
GROUNDWATER DIRECT-PUSH SAMPLING
LOCATIONS
VINYL CHLORIDE CONCENTRATIONS,
MARCH 1997 AND SEPTEMBER 1997



CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL

NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA

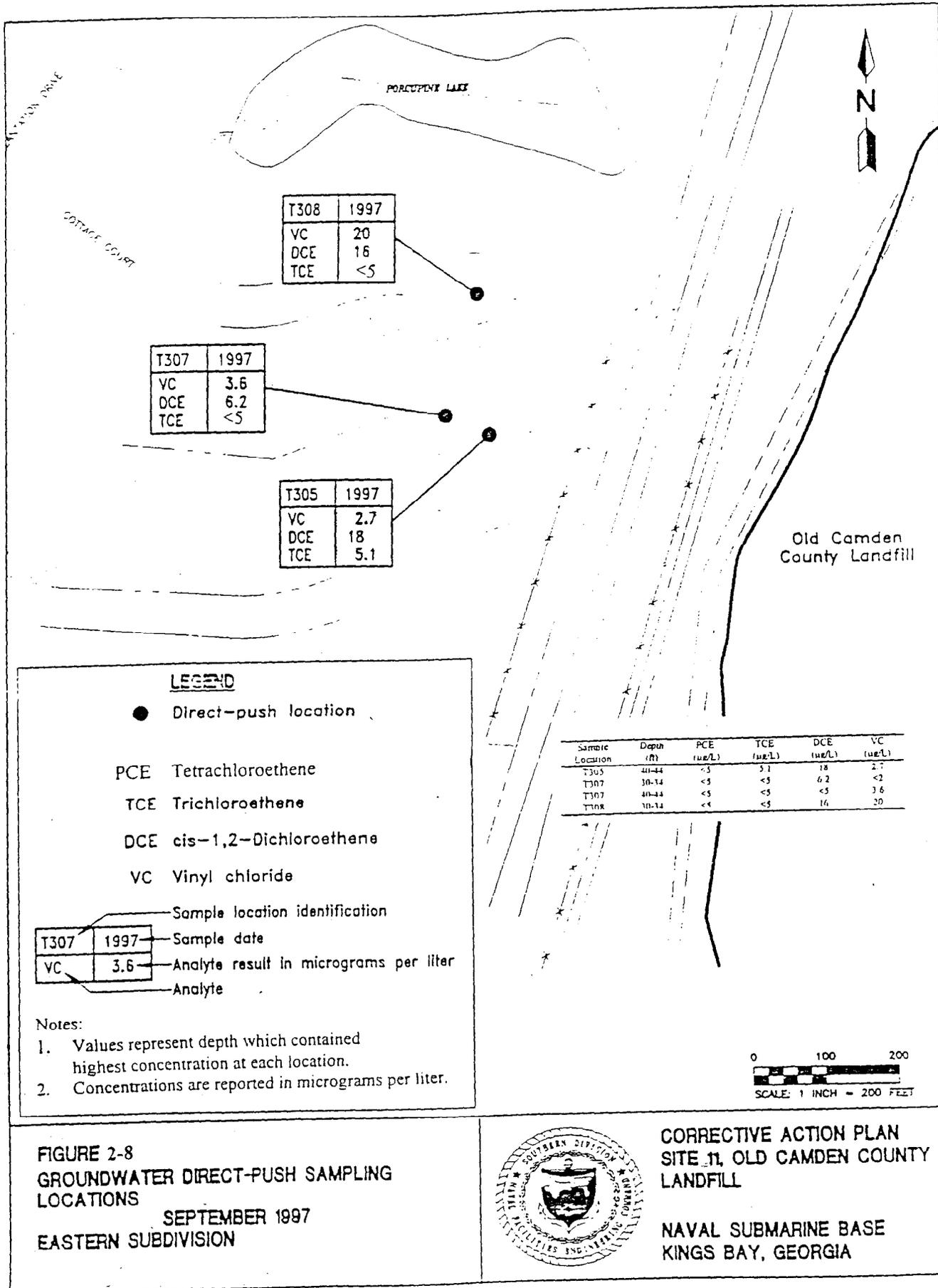
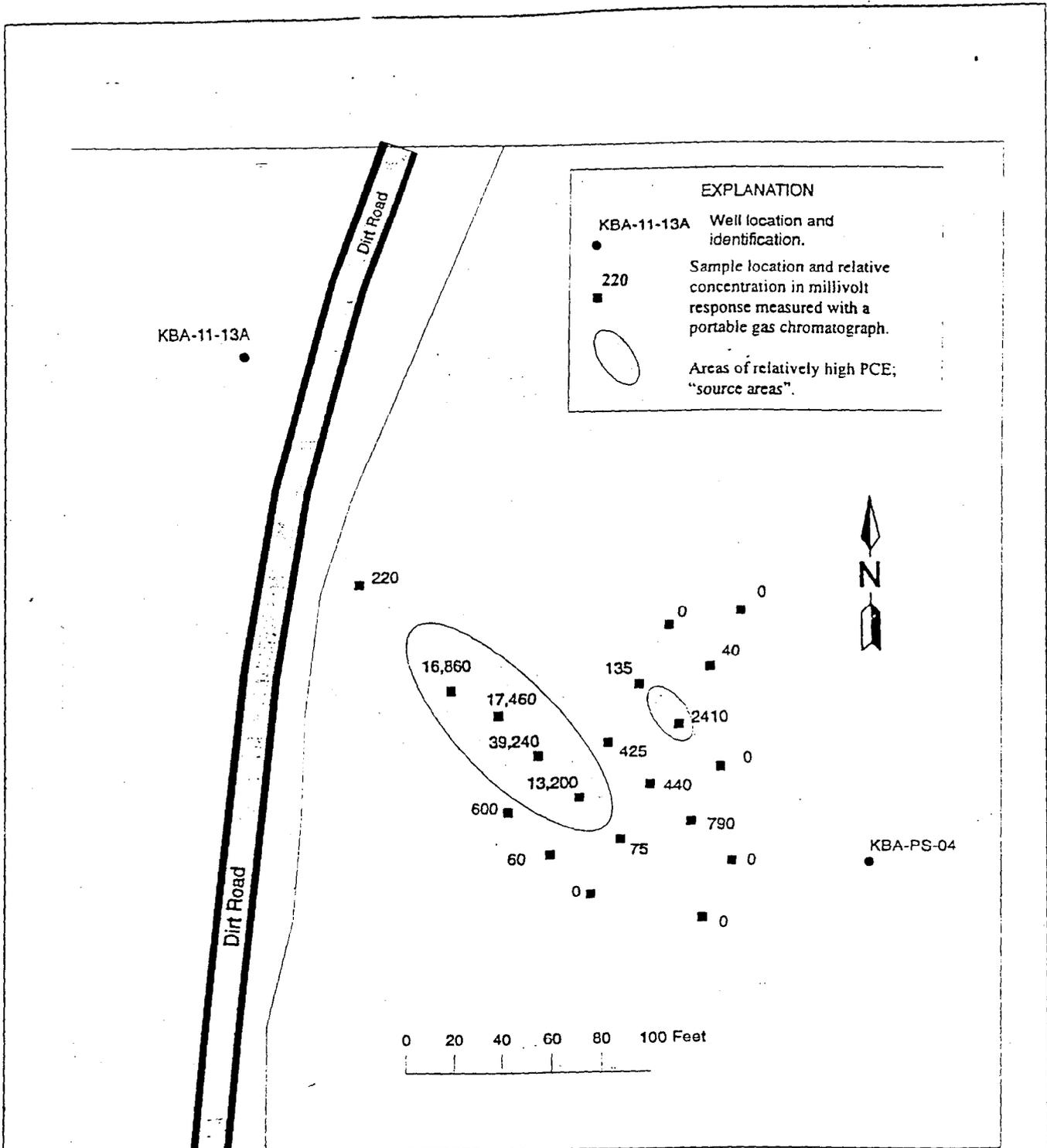


FIGURE 2-8
GROUNDWATER DIRECT-PUSH SAMPLING
LOCATIONS
 SEPTEMBER 1997
 EASTERN SUBDIVISION



CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL

NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA



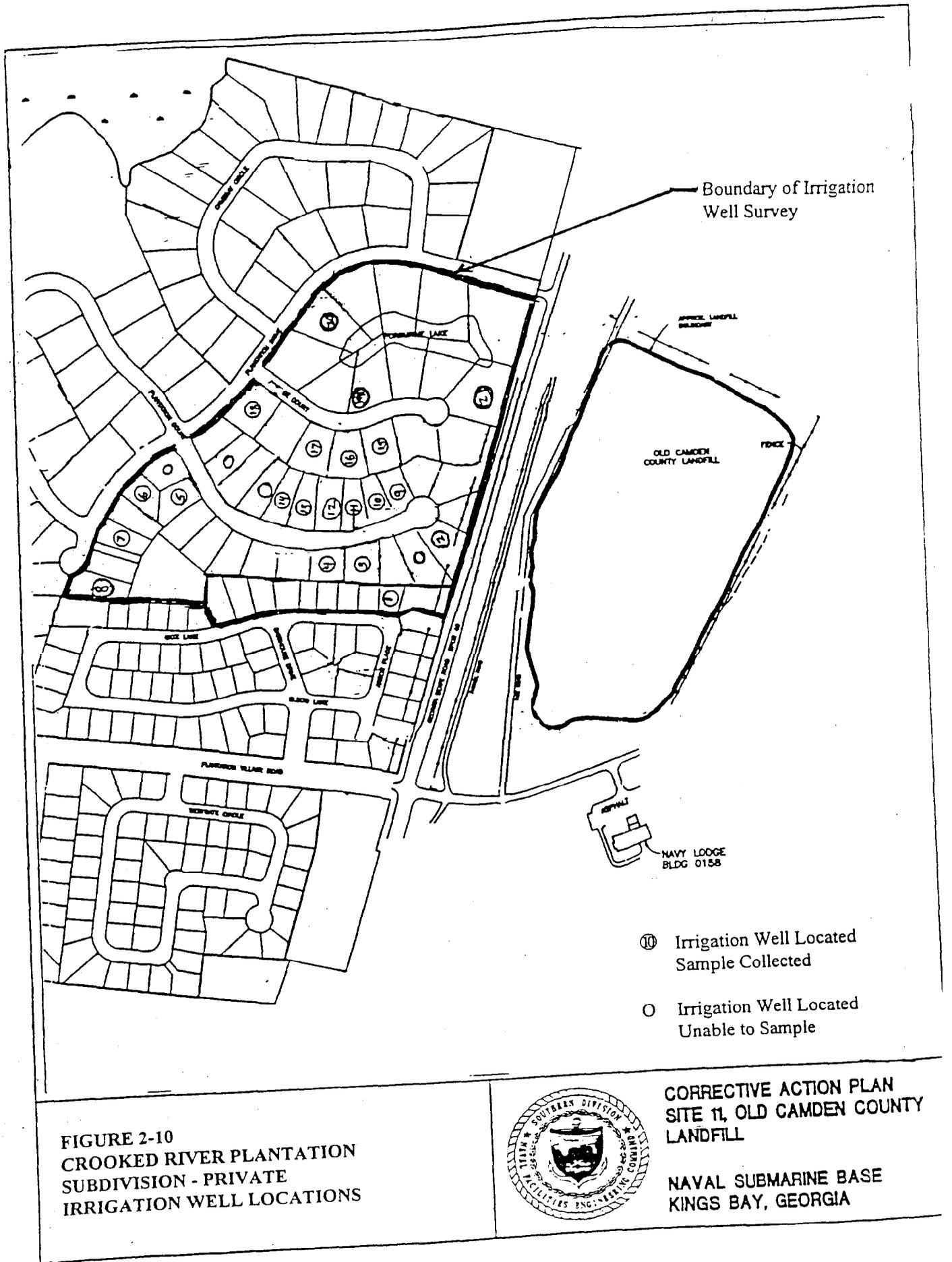
Ref. USGS 1997, Personal Communication

FIGURE 2-9
DECEMBER 1997 DIRECT-PUSH
SEDIMENT SAMPLING EVENT
FOR LOCATION OF PCE SOURCE AREA
WITHIN LANDFILL



CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL

NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA



**FIGURE 2-10
CROOKED RIVER PLANTATION
SUBDIVISION - PRIVATE
IRRIGATION WELL LOCATIONS**



**CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL**

**NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA**

3.0 DEVELOPMENT OF CORRECTIVE ACTION ALTERNATIVES

The rationale leading to the development of CAP alternatives for groundwater remediation at the Old Camden County Landfill, NSB Kings Bay, is presented in this chapter. The first step in the development of alternatives consisted of identifying remedial technologies to achieve the corrective action objectives for the site. The technologies were then screened to a manageable number, from which corrective action alternatives were formed. This screening of technologies was conducted by a subjective comparison of effectiveness, implementability, and cost of technologies relative to each other.

3.1 IDENTIFICATION OF REMEDIAL TECHNOLOGIES

The corrective action alternatives identified in this section were developed based on a strategy that addresses the remediation for the site in three distinct focus areas. Activities performed in these focus areas would provide protectiveness while facilitating remediation of the site as a whole. The focus areas are 1) the source areas which contained high concentrations of PCE during the December 1997 USGS direct-push sediment sampling event; 2) the dissolved groundwater contaminant plume located downgradient from the source areas; and 3) the areas of lower level contamination located west of Spur 40.

The source areas will be remediated utilizing in-situ treatment and/or groundwater extraction and ex-situ groundwater treatment, based upon the remedial alternative that is selected. The dissolved contaminant plume located downgradient from the source will be remediated through groundwater extraction/ex-situ treatment, and the areas of lower level contamination located west of Spur 40 will be remediated through monitored natural attenuation. Measures will also be implemented in the areas west of Spur 40 to prevent use of contaminated groundwater for irrigation or other purposes which could subject the residents to possible exposure.

Technologies considered for this CAP were categorized by their basic operating principles and are summarized in Table 3-1. The technologies were then subjectively screened to reduce the list to one or two representative technologies for each category, so that corrective action alternatives could be developed.

The following subsections discuss the identification and screening of groundwater treatment technologies.

3.1.1 In-Situ Groundwater Treatment

In-situ groundwater treatment technologies are capable of removing organic compounds from groundwater without extracting the groundwater. In contrast to groundwater extraction and ex-situ groundwater treatment, in-situ treatment does not generate water requiring discharge. Additionally, only target organic constituents are treated, as opposed to treating other non-target organic and inorganic constituents, to achieve discharge limitations for extracted groundwater. In-situ treatment technologies identified for Site 11 are presented below. The screening

**Table 3-1
Remediation Technology
Screening Matrix**

Corrective Action Plan
Site 11, Old Camden County Landfill
Naval Submarine Base
Kings Bay, Georgia

Category	Technology	Screening Comments
In-Situ Groundwater Treatment	Permeable reactive wall	Eliminated
	Air sparging	Eliminated
	Recirculation wells	Eliminated
	Chemical oxidation	Retained
	Natural attenuation	Retained ¹
Groundwater Recovery	Vertical extraction wells	Retained
	Horizontal extraction wells	Eliminated
	Collection trench	Eliminated
Ex-Situ Groundwater Treatment	UV Oxidation	Retained
	Bioreactor	Eliminated
Discharge of Treated Groundwater	Spray irrigation	Eliminated
	Reinjection wells	Eliminated
	Infiltration gallery	Retained
	NSB Land Application System	Retained
Risk Reduction in Subdivision	Monthly sampling of selected irrigation wells	Retained ¹
	Engineering controls ²	Retained ¹

¹ Included as part of all alternatives.

² Engineering Controls examples are: 1) Provide credits to the water bills for selected residents to use of city water (instead of private well) for irrigation purposes. 2) Install a shallower irrigation well for selected residents to eliminate recovery of contaminated groundwater.

recommendation, to retain or eliminate each individual treatment technology for corrective action, is included in their respective subsections.

3.1.1.1 Permeable Reactive Walls

A permeable reactive wall is an in-situ wall constructed of zero-valent iron (or other zero-valent metal) material. The wall is installed in a location to intercept contaminated groundwater. A

contaminated groundwater passes through the wall under natural groundwater flow conditions. The contaminants are removed through chemical and physical processes. This technology relies on the thermodynamic instability of carbon atoms in halogenated organic compounds, such as PCE and TCE, in a reducing environment, to cause iron in the permeable reactive wall to be oxidized while PCE and TCE are reduced. Once these chemicals have been reduced, degradation of the chemicals to ethenes and ethanes occurs. This technology is patented by the University of Waterloo of Ontario, Canada.

If this technology were implemented at Site 11, a bench-scale study would be necessary to demonstrate that the technology would be effective for the site-specific water chemistry. Additionally, a pilot-scale demonstration might be necessary to demonstrate its effectiveness under site-specific conditions. Therefore, implementation costs would be high due to depth of contamination and predesign work. The technology would also be difficult to implement in certain areas containing utilities. Based on these considerations, this technology has been eliminated from further consideration.

3.1.1.2 Air Sparging

Air sparging utilizes injection of compressed air to remove VOCs from groundwater without extracting the water. Air is injected into the saturated zone to create turbulence and volatilize organic compounds. As air moves up through the aquifer, contaminants partition into the gas phase and are then extracted as organic vapors from the vadose zone. Injected air can also stimulate microbial degradation of contaminants if the required microbes thrive in aerobic conditions.

Air sparging is typically used in combination with soil vapor extraction (SVE) to control off-gas generated by organic compound volatilization. SVE uses negative pressure to extract vapors from the subsurface. Vapor extraction wells or trenches are installed above the water table in a configuration to capture vapors generated from air sparging.

Air sparging has been eliminated from further consideration because of site-specific conditions that raise effectiveness concerns. Early site investigations indicated that the lithology of the Satilla Formation in the shallow saturated zone may cause channeling of sparging air, which could result in contaminated air being discharged in unwanted areas.

3.1.1.3 Recirculation Wells

Recirculation well technology creates a circulation sphere within the affected part of the surficial aquifer. Typically, groundwater enters through a screen in the lower part of the recirculation well, travels up through the well to an in-well stripping unit for treatment, and returns to the aquifer through a screen near the top, thus creating a spherical capture zone.

The various versions of this technology can be separated into two general categories: negative pressure systems and positive pressure systems. Both types of recirculation wells return groundwater to the aquifer without extraction. This eliminates the need to consider water

disposal options. Groundwater in the spherical treatment cell undergoes several stripping cycles, dependent on the recirculation flow rate within the well and the rate that groundwater enters the cell due to the existing natural gradient. This allows low contaminant concentration levels to be achieved within and downgradient of the recirculation cell. The vertical component of the recirculating water can also be very effective at flushing areas where contaminants may be concentrated, accelerating cleanups compared to conventional groundwater extraction, and reducing the likelihood of concentration rebound after system shutdown.

A pilot study would need to be performed at Site 11 to demonstrate the spherical capture zone under field conditions. Preliminary modeling showed the radius of this capture zone to be much less than that of vertical recovery wells. Air emissions would also occur with this technology. Because of its lesser capture zone and higher cost compared to vertical recovery wells, this technology has been eliminated from further consideration.

3.1.1.4 Chemical Oxidation

In-situ chemical oxidation is a process by which hydrogen peroxide and a catalyst, which is ferrous sulfate, is injected at high pressures into the groundwater in the location where high levels of contamination are known to exist. The process uses Fenton's Chemistry to create hydroxyl radicals, which are powerful, effective and nonspecific oxidizing agents, within the groundwater. The hydroxyl radicals react with chlorinated compounds in the groundwater to form water, carbon dioxide, and hydrogen and chloride ions, which are all nontoxic at the levels produced.

Each in-situ chemical oxidation deployment would be performed concurrently with the operation of a groundwater extraction system at the site for containment purposes. A series of monitoring wells would be installed within, and adjacent to, the source areas to evaluate the effectiveness of each deployment. Groundwater samples would be collected from the newly installed recovery wells, monitoring wells, and selected injection wells, both before and after each in-situ chemical oxidation deployment. The samples would be analyzed for the contaminants of concern and indicator parameters such as pH and chloride ion. The pre- and post-deployment analytical results for the contaminants of concern would be utilized to calculate the overall contaminant mass destruction. The analytical results for the indicator parameters would be utilized to ensure that the contaminants of concern had been chemically treated rather than removed by some other means (such as dilution) during the deployment.

It is noted that an unknown quantity of organic compounds (in addition to the contaminants of concern) are present in the area targeted for treatment. Because the Fenton's reaction is nonspecific concerning which organic compounds it will oxidize, a field demonstration would be required prior to full-scale deployment to determine specific design parameters such as injection volumes. Also for this reason, multiple deployments may be necessary to reduce the contaminants of concern to acceptable concentration levels.

Due to its potential to achieve contaminant mass reduction in a short time period, chemical oxidation is retained for further consideration.

3.1.1.5 Natural Attenuation

The term "monitored natural attenuation", as defined by the U.S. Environmental Protection Agency (USEPA, 1997) is defined as "physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater". Natural attenuation processes such as biodegradation, dispersion, dilution, sorption, volatilization, stabilization, or transformation, occur in all groundwater systems. For chlorinated ethenes, however, it is biodegradation processes that lead to the actual destruction of contaminant mass. The efficiency of biodegradation processes in groundwater systems vary considerably from place to place. Thus, a site-specific evaluation of biodegradation efficiency is necessary for monitored natural attenuation to be considered as part of a remedial strategy.

Chlorinated ethenes can be biodegraded by reductive or oxidative processes. Highly chlorinated ethenes such as PCE or TCE are relatively oxidized compounds and are most readily biodegraded by reductive processes. Lightly chlorinated ethenes such as DCE or VC, in contrast, are relatively reduced compounds and are most readily biodegraded by oxidation. In practice, the complete biodegradation of PCE and TCE is facilitated by initial reduction (to DCE and/or VC) followed by oxidation to carbon dioxide and chloride. If sequential reducing-oxidizing conditions are present at a site, then the natural attenuation of chlorinated ethenes will be relatively efficient.

Site 11 is underlain by a layer of organic-rich material which removes the dissolved oxygen from recharging water at the site, therefore, the groundwater at the 35-foot bgs zone is uniformly anoxic (USGS, 1998). According to the report, Selecting Remedial Goals by Assessing the Natural Attenuation Capacity of Ground-Water Systems (USGS, 1998), reductive dechlorination of PCE and TCE to DCE and VC is occurring under the sulfate-reducing conditions present in the landfill source area. Downgradient of the landfill, more oxidizing Fe (III) reducing conditions predominate. This sequence of reducing/oxidizing conditions results in relatively efficient contaminant biodegradation and gives the groundwater system a substantial natural attenuation capacity for chlorinate ethenes (USGS, 1998). The data presented in Section 2.0. Investigation and Remediation, are consistent with this. As shown in Figures 2-4 through 2-8, in the areas closest to the source area, the highest chlorinated ethene constituent concentrations are PCE. In the areas downgradient from the source areas, the PCE concentrations decrease substantially and the daughter products TCE, DCE and VC begin to appear due to the biodegradation of the PCE.

While relatively rapid biodegradation of chlorinated ethenes is occurring at Site 11, it is not rapid enough to prevent off-site migration of contaminants (USGS, 1998). This is largely due to the high contaminant concentrations in the source areas (~ 4 mg/L total chlorinated ethenes). If source-area concentrations were reduced without changing ambient redox conditions, ongoing biodegradation would be sufficient to prevent off-site contaminant migration if the on-site concentrations are reduced to the appropriate levels. Furthermore, the activation of an on-site groundwater recovery/ex-situ treatment system would allow the contaminant constituents more time to attenuate prior to migrating off-site. It is for these reasons that natural attenuation should

be supplemented with the active remediation technologies retained in Table 3-1 to achieve the cleanup goals at Site 11.

3.1.2 Groundwater Recovery Technologies

Groundwater recovery involves extraction of groundwater to contain or remove a contaminated plume. Groundwater can be recovered by vertical extraction wells, horizontal extraction wells, or trenches. The practicality of groundwater extraction depends on the hydrogeologic conditions at a site. These conditions have been favorably evaluated through various degrees of aquifer testing, using vertical recovery wells, over the life of the project. Horizontal wells and trenches would be costly and difficult to implement given the depth and extent of contamination. Vertical recovery wells are the most flexible and cost-effective option for groundwater recovery. Site conditions warrant the continued use of vertical recovery wells for groundwater recovery.

3.1.3 Ex-Situ Groundwater Treatment

This section presents methods for the ex-situ treatment of recovered groundwater. Treatment levels will be determined and approved during the design phase of the CAP implementation. The screening recommendation to retain or eliminate each individual treatment technology is included in their respective subsections. Based upon the February 27, 1998 letter from the GEPD to the Navy concerning air emissions, only those technologies that would result in zero emissions of toxic air contaminants were considered as potential remediation strategies. A copy of the letter is provided in Appendix B.

3.1.3.1 Ultraviolet (UV) Oxidation

UV oxidation is a technology that uses ultraviolet light in conjunction with standard oxidants such as hydrogen peroxide and ozone. When hydrogen peroxide is used as the oxidant, ultraviolet light is used to split the hydroxide molecule, which produces reactive hydroxyl radicals. The hydroxyl radicals react with the contaminants in the recovered groundwater to break them down into water, carbon dioxide, and hydrogen and chloride ions, which are nontoxic at the levels produced. The advantage of UV oxidation treatment over traditional air stripping methods is that the treatment process destroys the contamination rather than moving the contaminants from one media to another. UV oxidation is attractive for use at sites where off-gas air requirements are stringent because the process results in no emissions of toxic air contaminants. Pretreatment for removal of naturally occurring inorganics (e.g., iron or manganese) may be required to prevent fouling of the oxidation system. A bench-scale test may be required to determine optimum operating parameters such as pH and chemical dosage. Because of its ability to meet stringent off-gas air requirements, UV oxidation is retained for further consideration.

3.1.3.2 Bioreactor

Bioreactors degrade contaminants in water with microorganisms through either attached or suspended biological systems. Attached growth systems such as rotating biological contactors (RBCs) use microorganisms attached to an inert support matrix to aerobically degrade wa-

contaminants. A mixed contaminant stream of PCE, TCE, DCE and VC will not be readily oxidized to meet effluent standards using RBC technology because PCE and TCE resist degradation under aerobic conditions. Therefore, this technology has been eliminated from further consideration.

3.1.4 Discharge of Groundwater

If groundwater is remediated via extraction and treatment, the process would produce an effluent that requires discharge. The method of discharge dictates the degree of treatment required. The following four discharge options have been identified for Site 11 and are described below. A description of the screening results is provided in Section 3.1.4.5, Screening of Discharge Options.

3.1.4.1 Spray Irrigation

Groundwater extracted and treated may be discharged to the surface of Site 11 via a spray irrigation system. The effluent for the system would meet treatment levels stipulated in applicable permits, which may include a land disposal permit obtained from GEPD (GEPD Chapter 391-3-6.11). Special consideration would need to be given to the proximity of residential areas which may contribute to possible exposure pathways via the treated effluent water. To mitigate this potential threat, a stringent effluent monitoring program would have to be in place. It is noted that this alternative would not require a RCRA land disposal permit.

3.1.4.2 Reinjection Wells

Treated groundwater may be reinjected into the aquifer. The effluent for the system would meet treatment levels stipulated in applicable permits, and may include an underground injection control permit obtained from GEPD [GEPD Chapter 391-3-6-.13(3)(d)]. Special consideration would have to be given to the hydraulic effect that injection wells would have on any groundwater recovery system being used for containment or removal. In addition to groundwater mounding problems in a shallow water table, injection wells require a high degree of maintenance.

3.1.4.3 Infiltration Gallery

Treated groundwater may be infiltrated into the aquifer by means of an infiltration gallery located within or nearby the landfill. The effluent for the system would meet the treatment levels stipulated in applicable permits, and may include a land disposal permit obtained from GEPD (GEPD Chapter 391-3-6.11). An infiltration gallery could be implemented in a more flexible configuration than reinjection wells. The effluent could be applied over a larger area, resulting in less localized mounding of the water table. Installation cost and operation would also be less expensive than a reinjection well system. It is noted that this alternative would not require a RCRA land disposal permit.

3.1.4.4 NSB Land Application System (LAS)

Discharge to the NSB LAS is being utilized for the IM groundwater extraction and treatment system currently operating on the site. The effluent from the system would meet the treatment levels stipulated in the Base's LAS Permit #GA 03-751 issued by the GEPD Industrial Wastewater Program. The permit must be modified for any discharge above 86,400 gallons per day or any discharge that takes place after December 15, 1999.

3.1.4.5 Screening of Discharge Options

Reinjection wells were eliminated due to capital and operation and maintenance costs. Spray irrigation systems will be evaluated further during the design phase of CAP implementation. Discharge by infiltration gallery and/or the NSB LAS is/are the preferred option(s). Discharge may be accomplished solely by infiltration gallery, base LAS, or a combination of both. The actual method(s) of discharge will be determined during the design phase of the project.

3.1.5 Risk Reduction in Subdivision

This section presents methods of risk reduction to protect the residents in the areas located west of Spur 40. Based upon the results from the June 1998 irrigation well sampling, provided in Section 2.0, Investigation and Remediation, the irrigation wells located at 223 Plantation Court and 209 Cottage Court exhibited concentrations above detection limits for DCE and VC, and the irrigation well located at 203 Plantation Court exhibited a concentration above detection limits for TCE. For this reason, risk reduction measures will be implemented at these residencies to prevent use of contaminated groundwater for irrigation or other purposes which could subject the residents to possible exposure.

The three wells which exhibited concentrations above detection limits will be sampled monthly for analyses of the contaminants of concern as part of CAP implementation. If concentrations show a significant increase, or do not decrease as expected as a result of the CAP implementation, additional engineering controls for risk reduction will be applied. The engineering controls could include installing shallower wells for irrigation usage and/or providing credits to the residents toward their water bills for use of city water (instead of private well) for irrigation purposes.

3.2 DEVELOPMENT OF ALTERNATIVES

With the exception of the No Action alternative, technologies passing the screening step in the previous section were formulated into remedial alternatives. These alternatives include the following:

Alternative 1: No Action

Alternative 2: Monitored Natural Attenuation

- remediation utilizing monitored natural attenuation,

- no active remediation on- or off-site, and
- risk reduction in the subdivision utilizing monthly monitoring and/or engineering controls.

Alternative 3: Groundwater Recovery and UV Oxidation Treatment:

- remediation of source areas utilizing groundwater recovery well(s), placed within the source areas,
- containment in the vicinity of and crossgradient from KBA-11-13A utilizing groundwater recovery well(s),
- treatment of recovered groundwater on-site utilizing UV oxidation,
- discharge of treated groundwater using an on-site infiltration gallery and/or the Kings Bay NSB LAS,
- monitored natural attenuation, and
- risk reduction in the subdivision utilizing monthly monitoring and/or engineering controls.

Alternative 4: Groundwater Recovery and UV Oxidation Treatment and In-Situ Groundwater Treatment using Chemical Oxidation:

- remediation of source areas using in-situ chemical oxidation,
- remediation of source areas utilizing groundwater recovery well(s), placed immediately downgradient from the source areas,
- containment in the vicinity of and crossgradient from KBA-11-13A utilizing groundwater recovery wells,
- treatment of recovered groundwater on-site using UV oxidation,
- discharge of treated groundwater using an on-site infiltration gallery network and/or the Kings Bay NSB LAS,
- monitored natural attenuation, and
- risk reduction in the subdivision utilizing monthly monitoring and/or engineering controls.

These alternatives are described and evaluated in detail in Chapter 4.0.

4.0 EVALUATION OF ALTERNATIVES

This chapter presents the detailed evaluation of alternatives for Site 11 at NSB Kings Bay. Following the evaluation presented in this chapter, a recommendation and justification for a selected alternative will be presented in Chapter 5.0. A detailed evaluation is performed to provide decision makers with sufficient information to select the appropriate corrective action for Site 11. The detailed evaluation of corrective action alternatives in this chapter includes the following:

- a detailed description of the alternative, emphasizing the applications of the technology or process options proposed for the alternative; and
- a detailed evaluation of the alternative against several criteria.

The alternatives have been evaluated using the following criteria:

- **Protectiveness:** The alternative's effectiveness in protecting human health and the environment, and the attainment of cleanup goals.
- **Regulatory compliance:** The alternative's compliance with applicable regulatory requirements. Specific requirements applicable to corrective action for groundwater include the GEPD Rules for Safe Drinking Water MCLs (Chapter 391-3-5) and the USEPA Drinking Water Regulations MCLs.
- **Short- and long-term effectiveness:** The effectiveness of the alternative in protecting human health and the environment during construction and implementation (short-term effectiveness), and after remediation goals have been met (long-term effectiveness).
- **Reduction of toxicity, mobility, and volume:** Extent to which the alternative accomplishes corrective action objectives by altering the disposition of the contaminants, as opposed to altering contaminant transport pathways.
- **Implementability:** The technical and logistical feasibility of the alternative, the availability of required materials, equipment, and services, and the reliability of the alternative's performance.
- **Cost:** The one-time initial cost (capital cost) and the annual operations and maintenance (O&M) cost. The descriptions of alternatives are conceptual, and the cost estimates have a projected range of -30 to +50 percent.

4.1 ALTERNATIVE 1: NO ACTION

This alternative consists of no corrective action activities and serves as a baseline consideration.

4.1.1 Description

No Action assumes that no corrective action will occur. The existing IM groundwater extraction and treatment system would be deactivated. The site would otherwise remain in its current condition.

4.1.2 Evaluation

Protectiveness. No Action may not contain or isolate contaminated groundwater that could eventually come in contact with receptors.

Regulatory Compliance. Section III, Part D, Paragraph 2 of GEPD Hazardous Waste Facility Permit Number HW-014 (S)(2) is not addressed by the implementation of Alternative 1.

Short- and Long-Term Effectiveness. There will be no short-term risks to workers, the community, or the environment from the implementation of Alternative 1 because it does not include any type of construction. This alternative may not be sufficient due to the proximity of potential receptors under potential future uses.

Reduction in Toxicity, Mobility, or Volume. The toxicity, mobility, or volume of contaminated groundwater would only be reduced due to naturally occurring factors (natural attenuation), over an extended period of time.

Implementability. No Action is technically implementable since no construction would occur. If approved, there would be no administrative issues and no need to coordinate with other agencies or acquire permits. Future corrective actions, if needed, would not be hindered by the No Action alternative.

Cost. There would be no costs associated with the implementation of this alternative. Fines may be incurred as a consequence of not meeting the provisions of the Hazardous Waste Permit, the Corrective Action Consent Order, and any other applicable regulatory requirements.

4.2 ALTERNATIVE 2: MONITORED NATURAL ATTENUATION

This alternative consists of no corrective action activities other than monitored natural attenuation. This alternative would provide risk reduction in the subdivision area.

4.2.1 Description

The existing IM groundwater extraction and treatment system would be deactivated and monitored natural attenuation would be utilized to achieve cleanup goals. The site would otherwise remain in its current condition. Risk reduction in the subdivision would be provided utilizing monthly monitoring and/or engineering controls.

4.2.2 Evaluation

Protectiveness. The alternative may not contain or isolate contaminated groundwater that could eventually come in contact with receptors.

Regulatory Compliance. Section III, Part D, Paragraph 2 of GEPD Hazardous Waste Facility Permit Number HW-014 (S)(2) is not addressed by the implementation of Alternative 2.

Short- and Long-Term Effectiveness. There will be no short-term risks to workers, the community, or the environment from the implementation of this alternative because it does not include any type of construction. This alternative does provide long term effectiveness, but not in an acceptable time frame. Although this alternative offers a reduction in risk over time as a result of the natural attenuation of groundwater contaminants, it may not be sufficient due to the proximity of potential receptors under potential future uses.

Reduction in Toxicity, Mobility, or Volume. This alternative would allow contaminants to migrate off base. Natural attenuation would reduce the toxicity, mobility, or volume of contaminated groundwater over an extended period of time.

Implementability. Monitored Natural Attenuation is technically implementable since no construction would occur. If approved, there would be no administrative issues and no need to coordinate with other agencies or acquire permits. Future corrective actions, if needed, would not be hindered by the implementation of this alternative.

Cost. No active remedial action would occur and there would be only the costs associated with groundwater monitoring. Fines may be incurred as a consequence of not meeting the provisions of the Hazardous Waste Permit, the Corrective Action Consent Order, and any other applicable regulatory requirements.

4.3 ALTERNATIVE 3: GROUNDWATER RECOVERY AND UV OXIDATION TREATMENT

This alternative consists of hydraulic control of contaminated groundwater through recovery, ex-situ treatment via UV oxidation, and discharge to an infiltration gallery and/or the NSB LAS.

4.3.1 Description

This alternative consists of treatment of VOCs in extracted groundwater to treatment levels for discharge to an infiltration gallery and/or the NSB LAS. Treatment via UV oxidation is expected to achieve the treatment levels.

This alternative consists of the following components:

- hydraulic control of groundwater: (1) in the areas in the vicinity of and crossgradient from KBA-11-13A, and (2) within the landfill to reduce source areas:

- treatment of recovered groundwater on-site using UV oxidation;
- discharge of treated groundwater on-site using an infiltration gallery and/or the NSB LAS;
- monitored natural attenuation; and
- risk reduction in the subdivision.

A treatment train for this alternative is depicted on Figure 4-1.

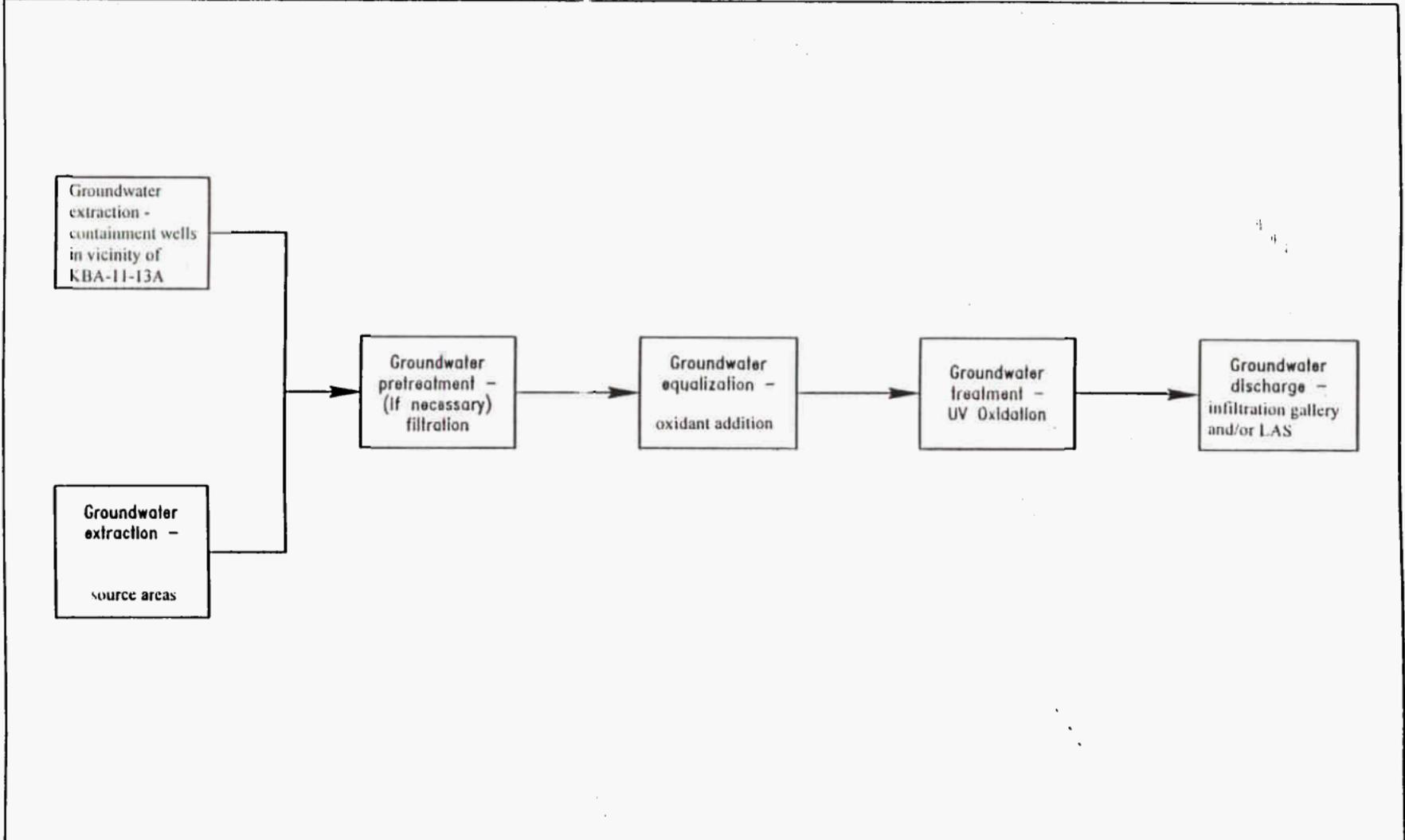
Hydraulic Control. Hydraulic control of contaminated groundwater would be achieved through the use of a recovery well network. The extraction system would be positioned (1) in the areas in the vicinity of and crossgradient from KBA-11-13A; and (2) within the source areas to reduce elevated concentrations.

The exact location of the recovery wells and corresponding operational parameters such as well construction details and pumping rates would be evaluated during the design phase of CAP implementation based upon groundwater modeling. Recovery wells would be connected via manifold and conveyance piping to the groundwater treatment system. For cost purposes only, it is assumed that the extraction system would remain in place for 20 years, based upon the performance of this technology at similar sites. This time frame is representative of the extended remedial duration required for alternatives that rely on groundwater pumping.

UV Oxidation. The extracted groundwater would be treated ex-situ to achieve discharge requirements. Variables such as lamp size, oxidant feed rates, and retention time would be determined during the design phase of CAP implementation. These variables would largely be dependant upon required treatment levels, flow rates and influent concentrations.

Treated Groundwater Discharge. Treated groundwater from the UV oxidation unit would be discharged via an infiltration gallery and/or the NSB LAS. The discharge would adhere to all provisions stipulated in applicable permits. The decision on the method of discharge (i.e. infiltration gallery, LAS, or a combination) would be determined during the design phase of CAP implementation, based upon the capacity of the LAS and a cost analysis. Factors that would affect cost include effluent flow rate, sampling and analytical requirements, size of the infiltration gallery, per gallon cost of discharging to the LAS, and operation and maintenance costs.

The infiltration gallery, if chosen, would be sized based upon effluent flow rate and the results from an infiltration test that would be conducted at the site. The infiltration gallery would be located at a specified distance upgradient and crossgradient from the source area to prevent enhancing migration of contamination off-site.



**FIGURE 4-1
TREATMENT TRAIN ALTERNATIVE 3:
GROUNDWATER EXTRACTION
UV OXIDATION AND DISCHARGE
VIA INFILTRATION GALLERY AND/
OR NSB LAS**



**CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL**

**NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA**

Monitored Natural Attenuation. Monitored natural attenuation is proposed as an activity to be performed concurrently with the active remedial measures.

Risk Reduction. Risk reduction in the subdivision would be provided utilizing monthly monitoring and/or engineering controls.

4.3.2 Evaluation

Protectiveness. By implementing this alternative, hydraulic control and contaminant mass reduction in the source areas should be obtained. During implementation of this alternative, groundwater containing VOCs would be extracted, thus reducing the mass of dissolved contaminants remaining in the groundwater. The UV oxidation system could be designed to completely destroy VOCs in the extracted groundwater, utilizing UV oxidation.

Regulatory Compliance. This alternative complies with the requirements contained in the GEPD Hazardous Waste Facility Permit Number HW-014. If groundwater pumping exceeds 100,000 gallons per day (69.4 gallons per minute), a withdrawal permit would be obtained. No air quality control permits would be required since no off-gas emissions are generated.

Short- and Long-Term Effectiveness. This alternative would be protective of human health and the environment during the construction phase, which would require installation of groundwater recovery wells in areas of contaminated groundwater. In addition, utility trenches to the extraction wells and treatment system would be needed. The work in these areas would be performed in accordance with the provisions of the applicable health and safety plan to ensure protection of site workers. Waste generated during construction, which would consist primarily of drill cuttings, would be characterized and disposed of at a suitable facility. The alternative would reduce VOC mass by extracting contaminated groundwater.

Reduction in Toxicity, Mobility, and Volume. This alternative would permanently reduce the toxicity, mobility, and volume of VOCs dissolved in groundwater. Additionally, the pathway of contaminant migration would be contained to impede further migration of contaminants off base. This alternative would gradually reduce the volume of the VOCs in groundwater by recovering the groundwater and removing the corresponding VOCs from the subsurface.

Implementability. Construction of the extraction and treatment system would be relatively easy to implement using standard construction equipment. Components of the proposed system are readily available. An infiltration test may be required to supply design information for the infiltration gallery.

Cost. The costs to implement this alternative are included in Table 4-1. This estimate includes corrective action implementation cost, annual O&M cost, and annual monitoring and reporting costs. The 20-year present worth cost is included to depict the extended remedial time frame required for alternatives that rely on groundwater pumping.

Table 4-1
Estimated Cost for Groundwater Recovery and UV Oxidation Treatment

Corrective Action Plan Site 11, Old Camden County Landfill Naval Submarine Base Kings Bay, Georgia	
Implementation	\$425,000
Operations and maintenance (annual)	\$65,000
Monitoring (annual)	\$25,000
Reporting (annual)	\$10,000
Total Year 1 Cost	<u>\$525,000</u>
Present worth cost, 2 years	\$611,000
Present worth cost, 10 years	\$1,197,000
Present worth cost, 20 years	\$1,671,000

4.4 ALTERNATIVE 4: GROUNDWATER RECOVERY AND UV OXIDATION TREATMENT WITH IN-SITU GROUNDWATER TREATMENT USING CHEMICAL OXIDATION

This alternative consists of hydraulic control of contaminated groundwater through recovery, ex-situ treatment via UV oxidation, and discharge to an infiltration gallery, and/or the NSB LAS. Additionally, this alternative would provide for in-situ treatment of VOCs in the source areas.

4.4.1 Description

This alternative consists of the treatment of VOCs in the source area using both in-situ treatment and groundwater extraction technologies, and containment of the groundwater contamination utilizing groundwater extraction. Chemical oxidation would be used for in-situ treatment and the extracted groundwater would be treated prior to discharge using ex-situ UV oxidation.

This alternative consists of the following components:

- in-situ treatment of groundwater within the source areas identified during the December 1997 USGS direct-push sediment sampling event;
- hydraulic control of groundwater: (1) in the areas in the vicinity of and crossgradient from KBA-11-13A, and (2) immediately downgradient from the source areas;
- treatment of recovered groundwater on-site using UV oxidation;
- discharge of treated groundwater on-site using an infiltration gallery and/or the NSB LAS;

- monitored natural attenuation; and
- risk reduction in the subdivision.

A treatment train for this alternative is depicted on Figure 4-2.

In-Situ Chemical Oxidation. Groundwater remediation in the source areas would be achieved rapidly through the strategic application of in-situ chemical oxidation. The injection locations would be strategically selected based on the December 1997 USGS direct-push investigation results. The position of the injection point(s) would allow for the greatest and most rapid mass removal of contaminants. The initial injection event would be performed subsequent to the installation and startup of a groundwater extraction and ex-situ groundwater treatment system at the site.

The effectiveness of the technology would be determined based upon pre- and post-injection groundwater samples collected in the source areas at the site. Multiple deployments may be necessary to reduce the contaminant concentrations to acceptable levels. The results from the initial injection event would be used to evaluate the strategy for subsequent events if required.

Hydraulic Control. Hydraulic control of contaminated groundwater would be achieved through the use of a recovery well network. The recovery wells would be positioned 1) in the vicinity of and crossgradient from KBA-11-13A, and (2) immediately downgradient from the source areas to allow effective containment of all locations of remedial concern.

The exact location and number of the recovery wells and corresponding operational parameters, such as well construction details and pumping rates, would be evaluated during the design phase of CAP implementation based upon groundwater modeling. Recovery wells would be connected via manifold and conveyance piping to the groundwater treatment system. For cost purposes only, it is assumed that the extraction system would remain in place for 2 years, based upon the performance of this technology at similar sites.

UV Oxidation. The treatment of extracted groundwater would be treated ex-situ to achieve discharge requirements. Variables such as lamp size, oxidant feed rates, and retention time would be determined during the design phase of CAP implementation. These variables would largely be dependant upon required treatment levels, flow rates and influent concentrations.

Treated Groundwater Discharge. Treated groundwater from the UV oxidation unit would be discharged via an infiltration gallery and/or the NSB LAS. The discharge would adhere to all provisions stipulated in applicable permits. The decision on the method of discharge (i.e. infiltration gallery, LAS, or a combination) would be determined during the design phase of CAP implementation, based upon the capacity of the LAS and a cost analysis. Factors that would effect cost include effluent flow rate, sampling and analytical requirements, size of the

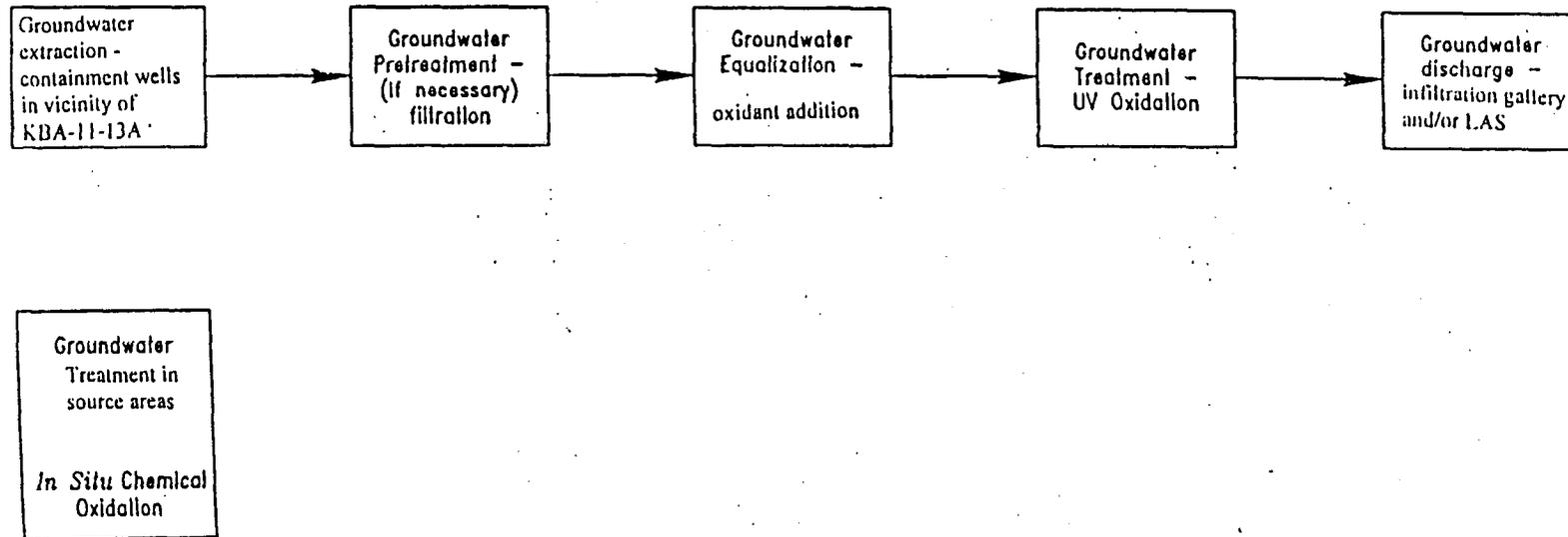


FIGURE 4-2
TREATMENT TRAIN ALTERNATIVE 4:
GROUNDWATER EXTRACTION
UV OXIDATION, IN SITU CHEMICAL
OXIDATION, AND DISCHARGE
VIA INFILTRATION GALLERY AND/
OR NSB LAS



CORRECTIVE ACTION PLAN
SITE 11, OLD CAMDEN COUNTY
LANDFILL

NAVAL SUBMARINE BASE
KINGS BAY, GEORGIA

infiltration gallery, per gallon cost of discharging to the LAS, and operation and maintenance costs.

The infiltration gallery, if chosen, would be sized based upon effluent flow rate and the results from an infiltration test that would be conducted at the site. The infiltration gallery would be located at a specified distance upgradient and crossgradient from the source area to prevent enhancing migration of contamination off-site.

Monitored Natural Attenuation. Monitored natural attenuation is proposed as an activity to be performed concurrently with the active remedial measures.

Risk Reduction. Risk reduction in the subdivision would be provided utilizing monthly monitoring and/or engineering controls.

4.4.2 Evaluation

Protectiveness. By implementing this alternative, hydraulic control and contaminant mass reduction in the source areas should be obtained. During implementation of this alternative, groundwater containing VOCs would be treated in-situ and ex-situ, thus reducing the mass of contaminants remaining in the groundwater. The ex-situ treatment system could be designed to completely destroy VOCs in the extracted groundwater, utilizing UV oxidation.

Regulatory Compliance. This alternative complies with the requirements contained in the GEPD Hazardous Waste Facility Permit Number HW-014. Injection permits would be obtained prior to execution of in-situ chemical oxidation. If groundwater pumping exceeds 100,000 gallons per day (69.4 gallons per minute), a withdrawal permit would be obtained. No air quality control permits are required. No off-gas emissions are generated.

Short- and Long-Term Effectiveness. This alternative would be protective of human health and the environment during the construction phase, which would require installation of components for both a hydraulic containment system as well as an in-situ chemical oxidation system. Components for the hydraulic containment system would include groundwater extraction wells in areas of contaminated groundwater, and utility trenches to the extraction wells and treatment system. Components for the in-situ chemical oxidation system would include injection wells to allow injection of oxidant compounds. The work in these areas would be performed in accordance with the provisions of the applicable health and safety plan to ensure protection of site workers. Waste generated during construction, which would consist primarily of drill cuttings, would be characterized and disposed of at a suitable facility. The alternative would remove VOC mass by treating the most contaminated groundwater in-situ, and extracting less-contaminated groundwater from a containment system. The processes are irreversible, and the alternative would have long-term permanence and effectiveness.

Reduction in Toxicity, Mobility, or Volume. This alternative would permanently reduce the toxicity, mobility, or volume of VOCs in groundwater. Analytical results from groundwater samples, collected before and after each in-situ chemical oxidation deployment, would be used to calculate mass destruction. Groundwater samples would also be collected for analyses of

indicator parameters such as pH and chloride ion. The analytical results for the indicator parameters would be utilized to ensure that the contaminants of concern had been chemically treated rather than removed by some other means such as dilution. The pathway of contaminant migration would be contained by the recovery system to prevent further migration of contaminants off base. In-situ chemical oxidation could quickly reduce the volume of the VOCs in the source areas to levels in which natural attenuation would be sufficient for remediation. An unknown quantity of organic compounds (in addition to the contaminants of concern), present in the area targeted for treatment, could reduce the effectiveness of the mass destruction of the contaminants of concern, due to the nonspecific nature of the Fenton's reaction.

Implementability. Construction of both the in-situ and ex-situ treatment systems would be relatively easy to implement and would not pose a threat to workers or the community. Components for the groundwater extraction and treatment system are readily available. An infiltration test may be required to supply design information for the infiltration gallery. In-situ chemical oxidation is considered an innovative technology with a small number of technology vendors. A thorough technical evaluation would be conducted prior to selection of a particular technology vendor to conduct the chemical injections. Because the Fenton's reaction is nonspecific concerning which organic compounds it will oxidize, a field demonstration would be required prior to full-scale deployment to determine specific design parameters such as injection volumes. Also for this reason, multiple deployments may be necessary to reduce the contaminants of concern to acceptable concentration levels.

Cost. The costs to implement this alternative are included in Table 4-2. This estimate includes corrective action implementation cost, annual O&M cost, and annual monitoring and reporting costs. The 2-year present worth cost is included to depict the assumed remedial time frame for this alternative.

Table 4-2
ESTIMATED COST FOR
GROUNDWATER RECOVERY AND UV OXIDATION TREATMENT
WITH IN-SITU CHEMICAL OXIDATION

Corrective Action Plan
Site 11, Old Camden County Landfill
Naval Submarine Base
Kings Bay, Georgia

Implementation	\$900,000
Operations and maintenance (annual)	\$65,000
Monitoring (annual)	\$40,000
Reporting (annual)	\$15,000
Total Year 1 Cost	<u>\$1,050,000</u>
Present worth cost, 2 years	\$1,123,000
Present worth cost, 10 years	NA ¹
Present worth cost, 20 years	NA ¹

¹ Assumed period of remediation is 2 years.

Note: NA = not applicable

5.0 ALTERNATIVE JUSTIFICATION AND RECOMMENDATION

The following sections provide a summary of the key comparative features of the selected alternatives for Site 11 with the evaluation criteria listed in Chapter 4.0. The purpose of the comparisons is to provide a qualitative means of ranking various alternatives to reveal the strengths and weaknesses of each alternative. The comparative analyses focus on the key differences between the alternatives and attempts to highlight critical issues of concern that will be important when selecting the final alternative.

The main objective for the preferred corrective action is to be protective of human health and the environment and to comply with regulatory requirements. These two criteria are referred to as threshold criteria because it is essential that any alternative being considered for final selection meet the threshold criteria. Alternatives 1 and 2 are removed from further consideration because they do not meet the threshold criteria.

The balancing criteria include short- and long-term effectiveness; reduction in toxicity, mobility, or volume; implementability; and cost. The balancing criteria require the most discussion in this section because the major tradeoffs between alternatives frequently relate to one or more of these criteria.

Final comments addressing State and community acceptance will be included in the permit modification process following preparation of this CAP.

5.1 PROTECTIVENESS

By implementing either Alternative 3 or 4, the reduction of concentrations of VOCs in groundwater should be achieved, and the further migration of contaminants off base will be prevented.

Alternative 3 would provide a groundwater extraction and treatment system (i.e., pump-and-treat) to directly remove dissolved VOCs from groundwater and establish hydraulic control. These alternatives are proven techniques for reducing contamination, but experience has shown that attainment of treatment levels within the aquifer may take an extended period of time. For the purposes of this CAP, it is assumed the cleanup time is 20 years.

Alternative 4, like Alternative 3, provides a containment system and aggressive groundwater extraction for source area remediation (extraction wells immediately downgradient from source areas), but also provides in-situ chemical oxidation in the source areas which could greatly reduce or even eliminate these source areas in a much shorter period of time. Reduction of VOC contamination at the source areas will contribute to faster, more effective, destruction of downgradient contaminants through natural attenuation. For the purposes of this CAP, it is assumed the cleanup time is 2 years.

5.2 REGULATORY COMPLIANCE

Assuming approval of related discharge or injection permits, as applicable, both alternatives would comply with regulatory requirements to an equal extent. Neither alternative would be more or less desirable with regard to compliance with regulatory requirements.

5.3 SHORT- AND LONG-TERM EFFECTIVENESS

Both Alternatives 3 and 4 are nearly equal in providing short-term effectiveness in protecting human health and the environment during construction. Alternative 4 may attain cleanup goals in a much shorter period of time than Alternative 3 due to the destructive nature of in-situ chemical oxidation in the source areas.

5.4 REDUCTION OF TOXICITY, MOBILITY, OR VOLUME

Alternative 3 relies solely on mechanical ex-situ treatment processes to extract and treat contaminated groundwater. By extracting the groundwater, the mass of VOCs remaining in the groundwater would decrease over time. The selected technology for treatment would provide reduction in toxicity, mobility, or volume of organic contaminants.

Alternative 4 relies on ex-situ treatment processes for the groundwater containment system and both ex-situ and in-situ treatment for the source areas. Demonstrations at other sites have shown Alternative 4 has the potential to provide the quickest and most effective reduction in toxicity, mobility, and volume of organic contaminants.

5.5 IMPLEMENTABILITY

Alternative 3 includes the installation of groundwater extraction wells, a treatment system, and possibly an infiltration gallery. Alternative 4 includes the installation of groundwater extraction wells, a treatment system, and possibly an infiltration gallery. Both Alternatives 3 and 4 are relatively easy to implement. The various technologies currently available for in-situ chemical oxidation are proprietary.

Since both alternatives would involve extraction and treatment of groundwater, a land disposal permit may be required for the infiltration gallery, which is a component of both alternatives. The injection well network for Alternative 4 would require a permit for the injection of oxidant compounds at the site. From the above discussion, Alternative 4 is slightly less implementable than Alternative 3 because of the added injection permit.

5.6 COST

Table 5-1 summarizes the estimated cost for the two alternatives.

Table 5-1
Cost Comparison, Alternative 3 Versus Alternative 4

Corrective Action Plan
Site 11, Old Camden County Landfill
Naval Submarine Base
Kings Bay, Georgia

	Alternative 3	Alternative 4
Implementation Cost	\$425,000	\$900,000
Annual O&M Monitoring and Reporting	<u>\$100,000</u>	<u>\$120,000</u>
Year 1 Cost	\$525,000	\$1,050,000
Present Worth:		
Year 2	\$611,000	\$1,123,000
Year 10	\$1,197,000	N/A
Year 20	\$1,671,000	N/A

¹ Assumed period of remediation is 2 years.

Note: NA = not applicable.
All costs are estimated and approximated.

5.7 SUMMARY

Table 5-2 presents a summary of the comparative evaluation between the alternatives. Based on the comparative evaluation, Alternative 4 would be the most desirable of the two groundwater corrective action alternatives because: 1) it has equal compliance with regulatory requirements as Alternative 3; 2) it is protective of downgradient receptors and site workers; and 3) it has the potential to achieve remediation goals in much less time.

If in-situ chemical oxidation were deleted from Alternative 4, the two alternatives would be the same except that the source area recovery wells in Alternative 3 would be located immediately downgradient from the source areas in Alternative 4. Therefore, Alternative 4 may attain cleanup goals in a much shorter period of time than Alternative 3 due to the destructive nature of in-situ chemical oxidation in the source areas.

Based on the above evaluation, it is recommended that Alternative 4 be implemented at the site.

Table 5-2
Summary of Comparative Analyses

Corrective Action Plan
Site 11, Old Camden County Landfill
Naval Submarine Base
Kings Bay, Georgia

Criteria	Alternative 3	Alternative 4
Protectiveness	Yes	Yes
Regulatory compliance	Yes	Yes
Effectiveness	Medium	High
Reduction in toxicity, mobility or volume	Medium	High
Implementability	High	Medium - High
Cost	\$1,671,000 ¹	\$1,123,000 ²

¹ Present worth, 20-year cost, assumed duration of remediation.

² Present worth, 2-year cost, assumed duration of remediation.

6.0 PROPOSED IMPLEMENTATION SCHEDULE

Figure 6-1 presents a schedule for implementing the proposed corrective action for contaminated groundwater. Pending approval from GEPD of the activities proposed in this CAP, the initial tasks will include preparation of a design package for implementing Alternative 4. Upon finalization of the design package, the field installation of the groundwater extraction/ex-situ treatment system specified in Alternative 4 will occur. Field installation includes the following components: monitoring wells, recovery wells, injection wells, conveyance piping, infiltration gallery, and treatment system. Following installation, the initial operation of the system will be optimized and performance monitoring will be initiated. After this system is in operation, commencement of the in-situ chemical oxidation deployments will occur.

		Months											
Activity Description	Duration Months	1	2	3	4	5	6	7	8	9	10	11	12
GEPD CAP Approval	0												
Permitting	3	█	█	█									
Chemical Oxidation	1												█
Design	4	█	█	█	█								
Installation	6				█	█	█	█	█	█			
Startup & Optimization	2										█	█	
Naval Submarine Base, King's Bay, Georgia Corrective Action Plan Corrective Action Implementation Schedule													
FIGURE 6-1 PROPOSED IMPLEMENTATION SCHEDULE													

7.0 CONTINGENCIES AND EXIT STRATEGY BASED UPON LONG TERM MONITORING RESULTS

A long term monitoring plan specifies monitoring well installations, monitoring well abandonments, sampling frequencies, sampling locations, and analytical parameters (Bechtel, 1999a). The plan states that if any sampling location is below MCLs for a design-specified period of time, the sampling frequency at that location will be reduced.

In-situ oxidation and targeted excavation successfully reduced source area contamination (Bechtel, 2000 and GDNR, 2000). Pump and treat remediation was discontinued in March 1999 due to repeated fouling of extraction wells and pumps. (Bechtel, 1999b and Bechtel, 2000). Unused treatment equipment will be removed and extraction wells will be abandoned in 2001 (GDNR, 2001).

Concentrations of total chlorinated ethenes (summation of PCE, TCE, DCE, and VC) must be reduced to less than 100 micrograms per liter (ug/L) at each monitoring well associated with this site. This criterion is based upon the information provided in the report, Selecting Remediation Goals by Assessing the Natural Attenuation Capacity of Ground-Water Systems (USGS, 1998, Appendix A).

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SELECTING REMEDIATION GOALS BY ASSESSING THE NATURAL ATTENUATION CAPACITY OF GROUND-WATER SYSTEMS

By Francis H. Chapelle and Paul M. Bradley

ABSTRACT

Remediation goals for the source areas of a chlorinated ethene-contaminated ground-water plume in Kings Bay, GA were identified by assessing the natural attenuation capacity of the aquifer system. The redox chemistry of the site indicates that sulfate-reducing ($H_2 \sim 2$ nanomoles per liter, (nM)) conditions near the contaminant source grades to Fe(III)-reducing conditions ($H_2 \sim 0.5$ nM) downgradient of the source. Sulfate-reducing conditions facilitate the initial reduction of perchloroethene (PCE) to trichloroethene (TCE), cis-dichloroethene (cis-DCE), and vinyl chloride (VC). Subsequently, the Fe(III)-reducing conditions drive the oxidation of cis-DCE and VC to carbon dioxide and chloride. This sequence of redox conditions gives the aquifer a substantial capacity for biodegrading chlorinated ethenes. Natural attenuation capacity, defined as the slope of the steady-state contaminant concentration profile along a ground-water flowpath, is a function of biodegradation rates, aquifer dispersive characteristics, and ground-water flow velocity.

Natural attenuation capacity at the Kings Bay site was assessed by estimating ground-water flow rates ($\sim 0.23 \pm 0.12$ m/d) and aquifer dispersivity (~ 1 m) from hydrologic and scale considerations. Apparent biodegradation rate constants (PCE and TCE ~ 0.01 d⁻¹; cis-DCE and VC ~ 0.025 d⁻¹) were estimated from observed contaminant concentration changes along aquifer flowpaths. Given estimates for these parameters, a boundary-value problem approach was used to estimate levels to which contaminant concentrations in the source-areas must be lowered (by engineered removal), or ground-water flow velocities lowered (by pumping) in order for the natural attenuation capacity to achieve maximum concentration limits (MCLs) prior to reaching a predetermined regulatory point of compliance.

INTRODUCTION

Chlorinated ethenes are subject to natural attenuation processes such as dilution, adsorption, and biodegradation in all ground-water systems (Wiedemeier et al., 1997). However, the efficiency of biodegradation, the process that causes the actual destruction of contaminants, varies widely. In many ground-water systems, biodegradation and other natural attenuation processes are not sufficient to protect downgradient receptors from contamination. For this reason, U.S. Environmental Protection Agency (EPA) guidance has stressed that natural attenuation is most often appropriate when used in conjunction with engineered reduction of contaminant sources:

“In the majority of cases where monitored natural attenuation is proposed as a remedy, its use may be appropriate as one component of the total remedy, that is, either in conjunction with active remediation or as a follow-up measure” (U.S. EPA, 1997, p.1).

The manner in which natural attenuation and active remediation measures (such as source removal, pump-and-treat, chemical oxidation, or enhanced bioremediation) are combined depends on the natural attenuation capacity of a system. If the natural attenuation capacity is small, for example, then active remediation measures will need to remove or immobilize a high proportion of the contaminant source in order to protect

downgradient receptors from contamination. Conversely, if the natural attenuation capacity is large, then less source removal may be required in order to protect downgradient receptors. In either case, it is necessary to quantify the natural attenuation capacity of a system in order to effectively combine contaminant source-removal methods with natural attenuation. The purpose of this paper is to assess the natural attenuation capacity of a chlorinated ethene-contaminated aquifer in Kings Bay, GA, and to use this assessment for selecting engineered source-reduction goals at the site.

Natural Attenuation Capacity

The concept of "assimilative capacity" is well-known in soil science (Charbeneau and Daniel, 1993, p. 15.1) and surface water hydrology (Chapra, 1996, p. 11) and refers to the capacity of a system to absorb and/or transform pollutants. By analogy, a "natural attenuation capacity" can be defined for ground-water systems as being the ability to lower contaminant concentrations along aquifer flowpaths.

In surface-water systems, assimilative capacity depends upon hydrologic (stream flow, mixing, and hydrodynamic dispersion), and biological (biological oxygen demand) factors and is assessed using analytical or digital water-quality models. Similarly, the natural attenuation capacity of ground-water systems depends upon hydrologic (dispersion and advection) and biological (biodegradation rates) factors that can also be assessed using quantitative models. The sum of dispersive, advective, sorptive, and biodegradative processes acting on a solute in a one-dimensional flow system is given by the solute-transport equation:

$$\frac{C}{t} = D \frac{\partial^2 C}{\partial x^2} - v \frac{\partial C}{\partial x} - \frac{\rho_b K_d}{n} \frac{\partial C}{\partial t} - kC \quad (1)$$

where D is the coefficient of hydrodynamic dispersion (m^2/d), v is the velocity of ground-water flow (M/d), ρ_b is bulk density, K_d is a linear

sorption distribution coefficient, n is porosity, and k is a first-order biodegradation rate constant (d^{-1}) (Freeze and Cherry, 1979, p. 402 and p. 552). The coefficient of hydrodynamic dispersion, in turn, is proportional to ground-water velocity and scale-dependent aquifer dispersivity D^* (m):

$$D = v D^* \quad (2)$$

Appropriate procedures for solving equation (1) depend on the ground-water system in question, and the specific problems being addressed. When a contaminant plume has reached approximate steady-state conditions (that is, the plume is not expanding or contracting with time and $\partial C / \partial t = 0$), the sorption term becomes small relative to the other three terms, and the solute-transport equation simplifies to the ordinary differential equation:

$$D \frac{d^2 C}{dx^2} - v \frac{dC}{dx} - kC = 0 \quad (3)$$

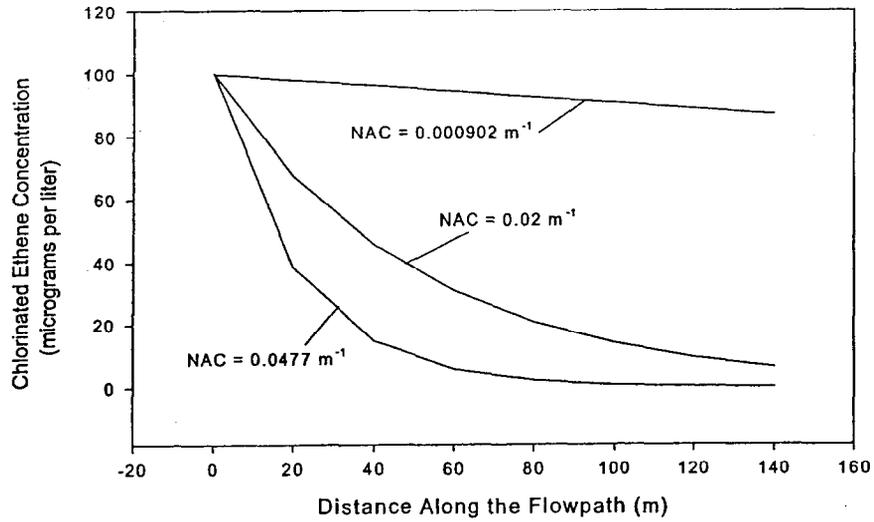
For boundary conditions of $C = C_0$ at $x=0$, and $C=0$ as $x \rightarrow \infty$, equation 3 has the particular solution:

$$C(x) = C_0 \exp \left[-\frac{v + \sqrt{v^2 + 4Dk}}{2D} x \right] \quad (4)$$

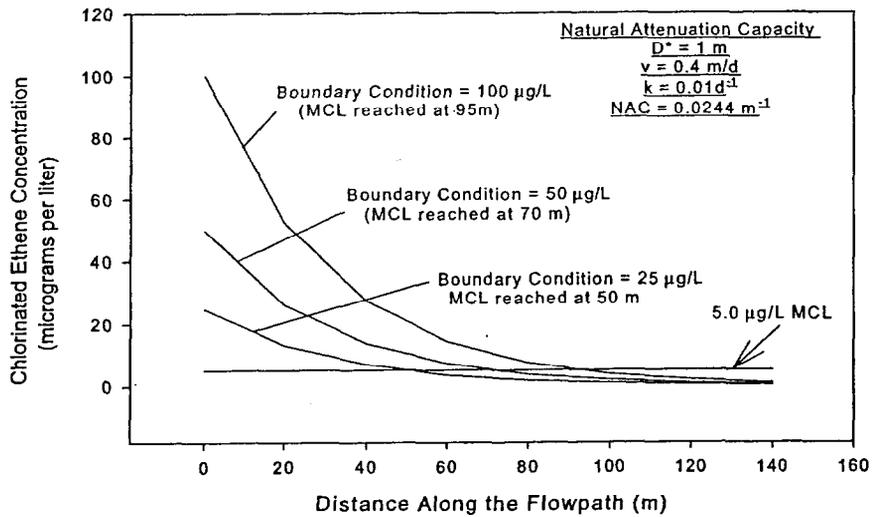
Equation (4) indicates that the steady-state solute concentration decrease away from a constant source is dependent on hydrodynamic dispersion (D), the biodegradation rate constant (k), and ground-water velocity (v). With this usage, a positive value of k indicates contaminant loss. The slope of the solute concentration profile along a flowpath is proportional to the value of:

$$\left[\frac{v + \sqrt{v^2 + 4Dk}}{2D} \right] \quad (5)$$

The term *natural attenuation capacity* (NAC), as used in this paper refers to the quantity given in



(A)



(B)

Figure 1.—Schematic diagram showing (A) the affect of natural attenuation capacity and (B) the affect of source-area concentrations on the distance required to decrease contaminant concentrations below MCLs.

equation 5, which has units of m^{-1} . Conceptually, it may be thought of as the contaminant-lowering capacity of an aquifer per meter of flowpath.

The concept of natural attenuation capacity as defined in equation 5 is useful because it illustrates those characteristics of a hydrologic system that affect the efficiency of natural attenuation. For example, if the biodegradation rate constant is small ($\sim 0.001 d^{-1}$) relative to the ground-water velocity ($\sim 1 m/d$) and aquifer dispersivity (10 m), the NAC of the system will also be small ($0.009902 m^{-1}$). Because of this small NAC, contaminants will be transported relatively long distances downgradient of a source area (Fig. 1A). Conversely, if the biodegradation rate constant is high ($0.01 d^{-1}$) relative to ground-water velocity ($0.2 m/d$) and aquifer dispersivity (1 m), the NAC will be proportionally higher ($0.0477 m^{-1}$) and the transport of contaminants will be restricted closer to the source area (Fig. 1A).

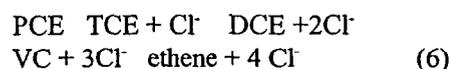
In addition to natural attenuation capacity, the distance that contaminants are transported in a ground-water system depends on contaminant concentrations at the source area (C_0 in equation 4). If contaminant concentrations at the source are relatively high, a longer ground-water flowpath will be required for a given NAC to reach MCLs than if source-area concentrations are lower (Fig. 1B).

This reasoning identifies two ways in which the natural attenuation capacity of a ground-water system can be integrated with engineered methods to achieve overall site remediation. The first way is to use engineering methods (excavation, in-situ chemical oxidation, in-situ bioremediation, etc.) to lower source area concentrations to levels that the NAC present in the aquifer can lower contaminant concentrations to MCLs at a given point of compliance. The second way is to decrease the velocity of ground-water flow away from a contaminant source area, which in turn increases NAC (Fig. 1A). This can be accomplished using conventional pump-and-treat technology.

Biodegradation of Chlorinated Ethenes

The biodegradation of chlorinated ethenes

is complex because these compounds are subject to reductive (Vogel et al., 1987; McCarty and Semprini, 1994; Bouwer, 1994), oxidative (Bradley and Chapelle, 1996), and cometabolic (Vogel et al., 1987; McCarty and Semprini, 1994) biodegradation processes. Under anoxic conditions, chlorinated ethenes such as perchloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE) and vinyl chloride (VC) are subject to reductive dechlorination according to the sequence:



However, the efficiency of dechlorination differs for methanogenic, sulfate-reducing, or Fe(III)-reducing conditions (Smatlak et al., 1996). Under methanogenic and sulfate-reducing conditions, dechlorination of PCE and TCE is rapid and efficient. Dechlorination is less efficient under Fe(III)-reducing conditions, and dechlorination does not occur under oxygen-reducing conditions. Thus, the distribution of redox conditions affects the rate and extent of reductive dechlorination of chlorinated ethenes in ground-water systems.

Highly chlorinated ethenes such as PCE and TCE are not generally subject to oxidative biodegradation processes. Lightly chlorinated ethenes such as DCE and VC, however, can be oxidized to carbon dioxide (CO_2) under oxic or Fe(III)-reducing conditions. It is not yet clear, however, whether DCE oxidation under Fe(III) reducing conditions is first preceded by reductive dechlorination to VC (Bradley and Chapelle, 1996). Cometabolic processes, in which chlorinated ethenes are gratuitously degraded by enzymatic processes designed to metabolize organic compounds other than chlorinated ethenes, have been widely documented (Vogel et al., 1987; McCarty and Semprini, 1994) and can be an important component of natural attenuation in some systems.

It is observed that sequential reduction of PCE and TCE followed by oxidation of DCE and VC is the most efficient combination of mechanisms for completely degrading chlorinated ethenes (Cox and others, 1995). Thus, the efficiency of natural attenuation, and thus the

natural attenuation capacity of ground-water systems, is directly related to the distribution of ambient redox processes (Chapelle, 1996).

Estimating Natural Attenuation Capacity

The natural attenuation capacity at individual field sites can be estimated by obtaining estimates of k , v , and D (equation 5). Values of v can be estimated using standard field hydrologic methods, and D can be estimated from v (equation 2) and the scale of the plume (Gelhar and others, 1992). Similarly, the kinetics of biodegradation can be estimated using field methods (Buscheck and Alcantar, 1995; Chapelle and others, 1996; Weaver and others, 1996). If v and D can be reliably estimated, and if concentration changes of contaminants can be documented with field data, k can be estimated by curve-fitting solutions of equation 4 to field data. This can be done by coding equation 4 as a transform in a spreadsheet, or can be done using an established computer code such as Bioscreen (Newell and others, 1996). Site-specific D , v , and k values, in turn, can be used to quantitatively describe the natural attenuation capacity (equation 5) of particular ground-water systems.

Sources of Uncertainty

Estimating biodegradation rate constants using field data is subject to numerous sources of uncertainty which need to be explicitly considered in any application. These uncertainties include (1) variation of ground-water flow rates, (2) uncertainty in adequately sampling contaminant concentrations within the plume, and (3) deviations from steady-state conditions within the plume. Variation of ground-water flow rates in time and space due to heterogeneity of hydraulic conductivity and hydraulic gradient changes due to recharge events occurs in all shallow aquifers. This is an important source of uncertainty in estimating biodegradation rate constants because an n -fold error in groundwater flow velocity (v) results in an n -fold error in calculated biodegradation rate constant (k) (equation 3). Because of this inherent error, which can vary in time, it is appropriate to use ranges of v in

estimating k , and reporting k values as \pm the range of variation. This is the procedure used in this paper. If variations in ground-water flow with time are large, then the steady-state assumption inherent in equation 3 is not appropriate and time-dependent solutions of equation 1 must be used (Rifai and others, 1995). Furthermore, if transverse dispersion is significant in a system, then a 2-D or 3-D treatment of the problem is more appropriate (Weaver and others, 1996).

Adequate sampling of contaminant concentrations in a plume can be a significant source of uncertainty in evaluating the behavior of chlorinated ethene concentrations (Cherry, 1996). Contaminant concentrations are observed to vary significantly between the "core" and "fringes" of plumes. These variations can significantly effect natural attenuation capacity estimates and calculated biodegradation rates.

Field methods for estimating biodegradation rate constants were first applied to petroleum hydrocarbon contaminants (Buscheck and Alcantar, 1995; Chapelle and others, 1996) in ground water. For chlorinated ethenes, this procedure is complicated by the fact that TCE, DCE, and VC are produced as daughter products from PCE as well as being degraded. TCE, DCE, and VC concentration changes along a flowpath segment reflect the difference between production and degradation. Thus, for TCE, *cis*-DCE, and VC, this procedure yields overall degradation rate constants which *underestimate* actual degradation rate constants.

Clearly there are numerous sources of uncertainty inherent in quantifying biodegradation rate constants using field data. Furthermore, many of these uncertainties are difficult or impossible to quantify. While uncertainty can be reduced by extensive data collection, they cannot be eliminated entirely. For these reasons, biodegradation rate constants, and estimates of natural attenuation capacity, obtained using these methods should be regarded as estimates.

RESULTS AND DISCUSSION

Geology, Hydrology, and Site History

The site used for this study is an

abandoned landfill known as the Old Camden Road Landfill located at the Naval Submarine Base (NSB) Kings Bay, Georgia. A map of the landfill and the orientation of the contaminant plume, as determined by monitoring wells and direct-push data is shown in Figure 2. This site is underlain by sediments of back-barrier island and

barrier island origin. The most permeable sands underlying the site are present between depths of 10 and 11 m below land surface, and record the sedimentation of a prograding barrier island. This permeable zone is referred to informally as the "11 meter" aquifer in this report. This permeable zone is underlain and overlain by finer-grained sands

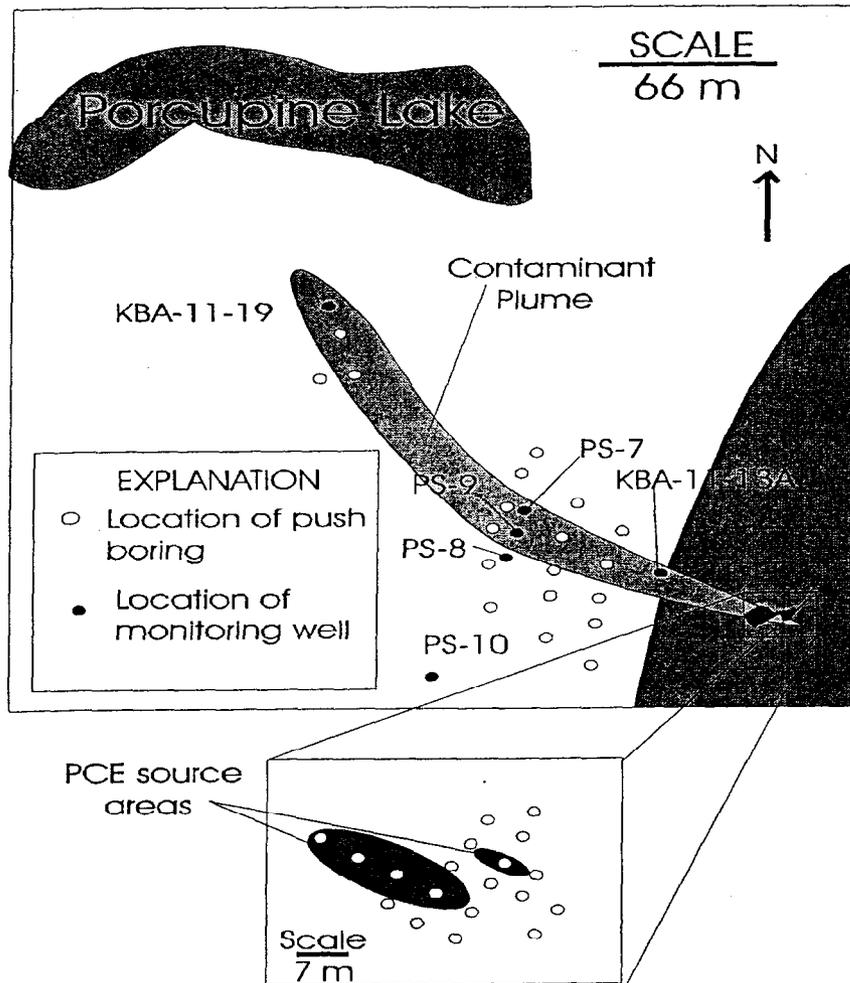


Figure 2.--Location of PCE source areas and orientation of chlorinated ethene contaminant plume.

exhibiting lower hydraulic conductivity. Aquifer tests and slug tests at this site indicate that hydraulic conductivities of the sands range from 0.6 to 3 m/d. The lithology of these sands suggest that the 11-meter aquifer is characterized by higher hydraulic conductivities ($K \sim 10$ m/d) relative to overlying and underlying sands. Because of its relative permeability, the 11-meter aquifer is a preferential pathway for horizontal ground-water flow and contaminant transport in this system.

Overlying the 11-meter aquifer at depths of approximately 3-5 meters below land surface is

a layer of organic-rich sands. This organic-rich layer has the important effect of removing dissolved oxygen from recharging water and producing uniformly anoxic conditions in the 11-meter aquifer. In addition, organic matter that was disposed of in the landfill contributes to highly reducing conditions. Ground-water flow in the 11-meter aquifer is predominantly to the west, and can be easily traced by methane-bearing water originating from the landfill.

The Old Camden Road landfill was used to dispose of municipal waste between 1974 and 1981. Trenches were excavated to a

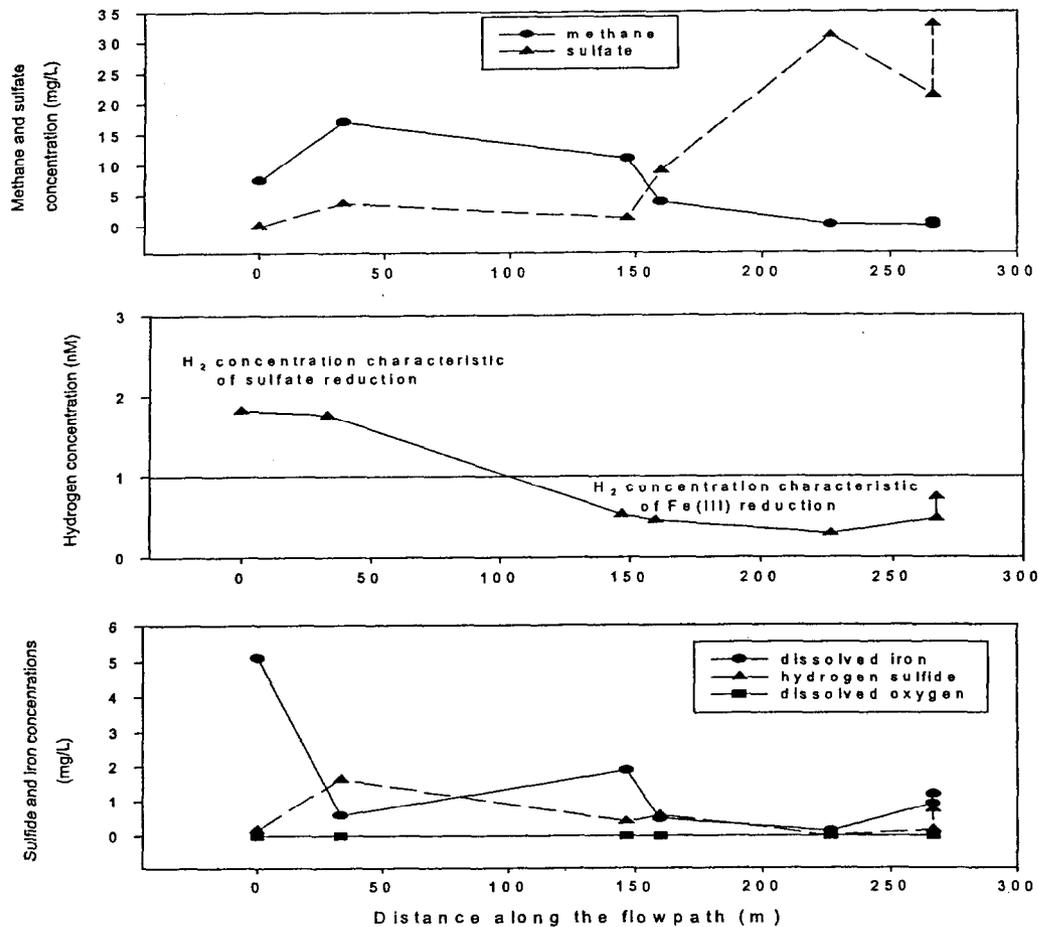


Figure 3.--Redox chemistry of ground water in the contaminant plume.

depth of between 2 and 4 meters, filled with waste, and covered with fill. At some time during waste-disposal operations, PCE was released at the landfill. Two discrete PCE sources were identified by direct-push sampling of ground water and aquifer sediments (Fig. 2) as part of this study. These sources are highly localized suggesting that the contamination events occurred at two discrete times. Emanating from these sources is a discrete plume of chlorinated ethene-contaminated ground water that flows toward Porcupine Lake located adjacent to the landfill (Fig. 2). The geometry and extent of the contaminant plume was previously delineated by direct push methods (ABB Environmental Services, Inc., 1997).

Delineation of Redox Processes

Ground-water chemistry data were used to delineate the distribution of redox processes in the ground-water system underlying and downgradient of the Old Camden Road landfill. The methodology used in this delineation has been described previously (Chapelle, 1996). Concentrations of redox-sensitive parameters dissolved oxygen, methane, sulfate, molecular hydrogen (H_2), sulfide and dissolved iron are plotted versus distance along the flowpath are shown in Figure 3. Sulfate concentrations are relatively low underlying the landfill, while methane concentrations are relatively high. The high methane concentrations indicate the presence of active methanogenesis in the landfill itself. However, measured concentrations of hydrogen (H_2) indicate that sulfate reduction is the predominant redox process in the 11-meter aquifer underlying the landfill, and grades into uniformly Fe(III)-reducing conditions downgradient of the landfill. Concentrations of dissolved sulfide and ferrous iron are consistent with this interpretation, with relatively high concentrations of sulfide underlying the landfill that decrease downgradient. Downgradient of the landfill, concentrations of ferrous iron (1-2 mg/L) are consistent with ongoing Fe(III) reduction. These sequential reducing (sulfate

reducing) to more oxidizing (Fe(III) reduction) conditions are favorable for degrading chlorinated ethenes, and would be expected to confer a substantial natural attenuation capacity to the system.

Concentration Changes of Chlorinated Ethenes

Ground-water chemistry data collected by direct push methods in this study (Fig. 2) indicate that PCE is the principal contaminant in the source area, and that PCE is sequentially dechlorinated along the ground-water flowpath. Additional direct-push data (ABB Environmental Services, Inc., 1997) documents contaminant behavior in the plume. Concentrations of PCE, TCE, cis-DCE, and VC within the plume are plotted versus distance along the flowpath in Figure 4.

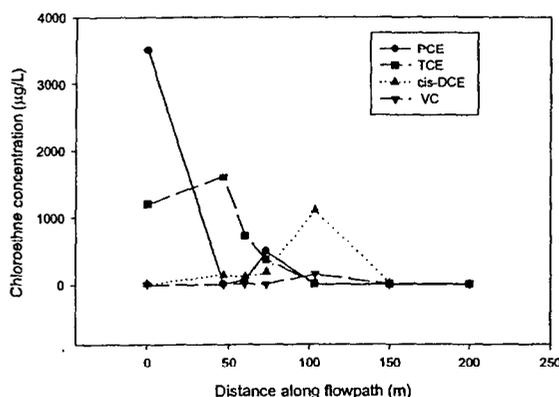


Figure 4. Concentrations of PCE, TCE, cis-DCE, and VC along the flowpath within the contaminant plume.

Near the source areas, PCE and TCE are the only measureable contaminants. By 50 meters downgradient, however, PCE concentrations have decreased to near the detection limit and the principal contaminant is TCE. TCE concentrations decrease along the flowpath and by

100 meters along the flowpath, cis-DCE is the principal contaminant and VC concentrations increase. By 150 meters along the flowpath, VC is the principal contaminant remaining. These data show that daughter products of reductive dechlorination are actively produced in this system, and are direct evidence of reductive dechlorination in this ground-water system. Furthermore, the decrease of cis-DCE and VC along the flowpath suggests continued reductive biodegradation, the

initiation of oxidative biodegradation, or both.

Kinetics of Chlorinated Ethene Biodegradation

The data of Figure 4 can be used to estimate degradation rate constants for individual chlorinated ethenes. Observed decreases in individual chlorinated ethene concentrations with fixed values of v and D^* are shown fitted to the

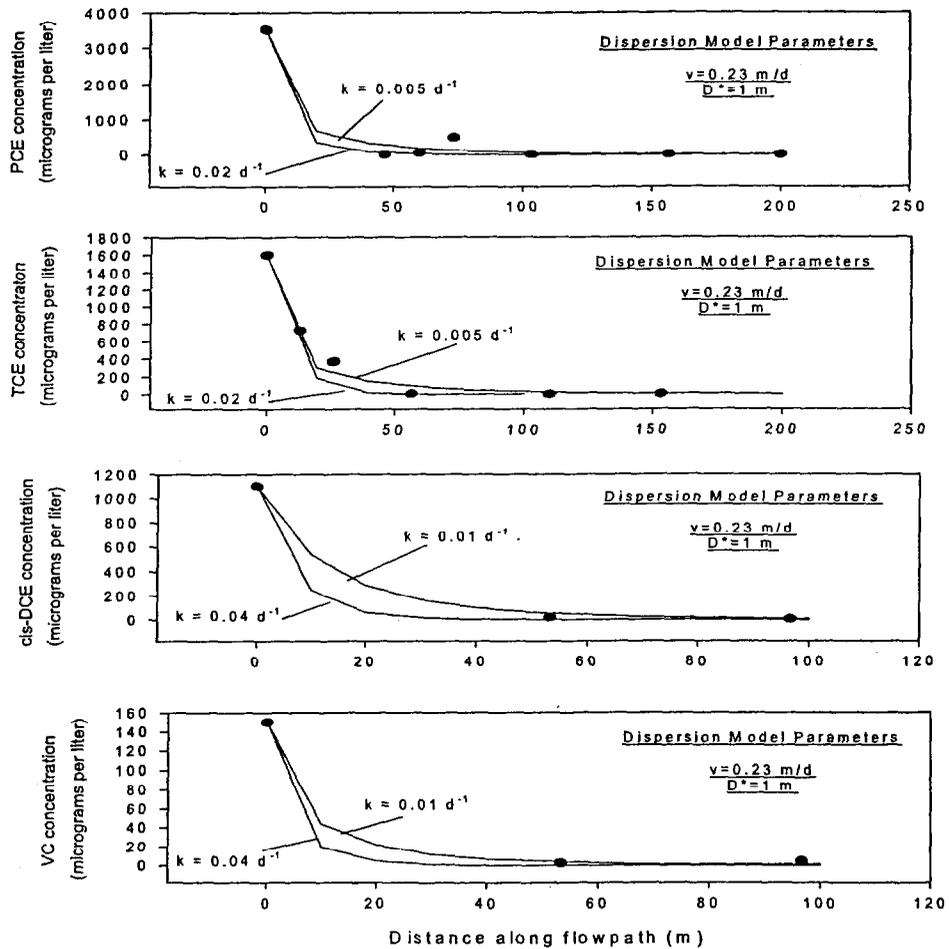


Figure 5.--Estimated values for PCE degradation rate constant and apparent degradation rate constants for TCE, cis-DCE, and VC.

dispersion equation in Figure 5. These individual rate constant estimates were made by curve-fitting only those portions of the concentration profiles where concentrations were declining (Fig. 4). Thus, the PCE curve began at zero distance downgradient, TCE at 50 meters downgradient, and cis-DCE and VC at 100 meters downgradient (Fig. 4). As pointed out previously, this procedure probably underestimates true degradation rate constants. Because ground-water flow velocity estimates have a factor of 2 range (0.23 ± 0.12 m/d), the estimated degradation rate constants also have a range of \pm a factor of 2, in addition to the upper and lower k estimates. Values for estimates of k for the chlorinated ethenes PCE, TCE, cis-DCE, and VC are given in Table 1.

Table 1.--Ranges of estimated values for biodegradation rate constants of chlorinated ethenes.

Chlorinated Ethene	Range of estimated k (d^{-1}) values
PCE	0.02 - 0.005
TCE	0.02 - 0.005
cis-DCE	0.04 - 0.01
VC	0.04 - 0.01

Using the Natural Attenuation Capacity to Estimate Source-Reduction Goals

The kinetic parameters estimated in Table 1, together with estimates of v (0.11-.35 m/d) and D^* (~1 m) can be used to quantify the natural attenuation capacity (NAC) of this ground-water system. The observed NAC can then be used to estimate distances of travel for each chlorinated ethene given an initial concentration. For example, if PCE concentrations in the source area are lowered to 100 $\mu\text{g/L}$ by engineered removal, then contaminant concentrations are predicted to be below the 5 $\mu\text{g/L}$ cleanup standard approximately 70 meters along the flowpath (Figure 6). However, because of the uncertainty associated with the parameter

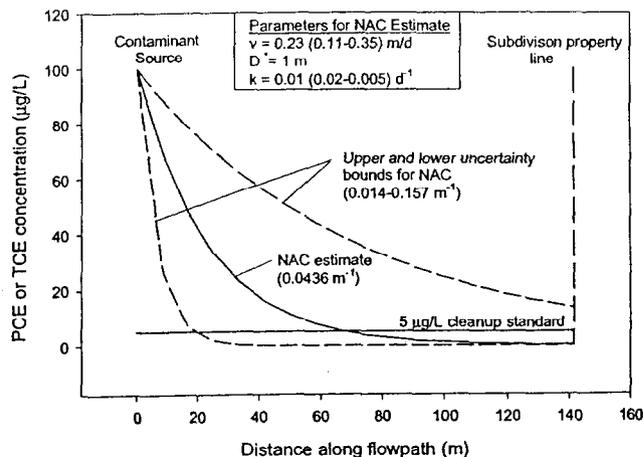


Figure 6.--Estimated distance of transport for PCE and TCE is source area concentrations are lowered to 100 $\mu\text{g/L}$.

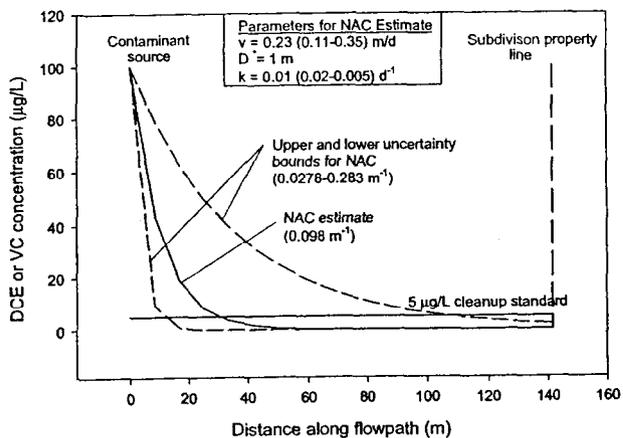


Figure 7.--Estimated distance of transport for DCE and VC from an initial source concentrations of 100 $\mu\text{g/L}$.

estimates, the cleanup standard may be reached in as little as 20 meters, or as much as 160 meters. Similar estimates can be made for TCE (Fig. 6), or DCE and VC (Fig. 7). For DCE and VC, an initial concentration of 100 $\mu\text{g/L}$ would be

estimated to be lowered below the 5 µg/L cleanup standard in 30 meters. Because of the uncertainty, however, this distance may be as little as 10 meters or as much as 110 meters.

Estimating Ground-water Velocity Decrease Goals

Source reduction is not the only engineering option that can be evaluated by considering the natural attenuation capacity. Pump and treat technology is widely used to contain contaminants from offsite migration (NRC, 1997). One effect of pump and treat is to change the rate that contaminated ground water migrates away from a site. This, in turn, can be used to increase the NAC of a site. Given a fixed biodegradation rate constant (0.01 d⁻¹) and a

fixed value of D* (1 m), decreasing the average velocity of ground water leaving a source area by a factor of two increases the NAC by about the same amount (Fig. 8). Because of this increase in NAC, the 5 µg/L cleanup standard for these individual compounds can be achieved in proportionally less flowpath distance than with unmodified ground-water velocity. Because pump-and-treat is an established technology, increasing the NAC by lowering ground-water velocity may be an appropriate strategy at some sites.

CONCLUSIONS

The ground-water system underlying the Kings Bay site grades from relatively reducing (sulfate-reducing) to more oxidizing (Fe(III)-reducing) conditions. In the zone of sulfate reduction, PCE and TCE are rapidly dechlorinated to cis-DCE and VC. In the Fe(III)-reducing zone, cis-DCE and VC are oxidized to carbon dioxide and chloride. This sequence of redox conditions results in efficient contaminant biodegradation and gives the ground-water system a substantial natural attenuation capacity for chlorinated ethenes. Despite this natural attenuation capacity, ground water containing concentrations of chlorinated ethenes higher than regulatory limits leaves the site and migrates to a nearby point of compliance. This, in turn, necessitates engineered remediation in order to achieve the required site remediation. A kinetic assessment of the natural attenuation capacity indicates that concentrations of PCE and TCE must be lowered below 100 µg/L at least 70 meters from the point of compliance, and that concentrations of DCE and VC must be

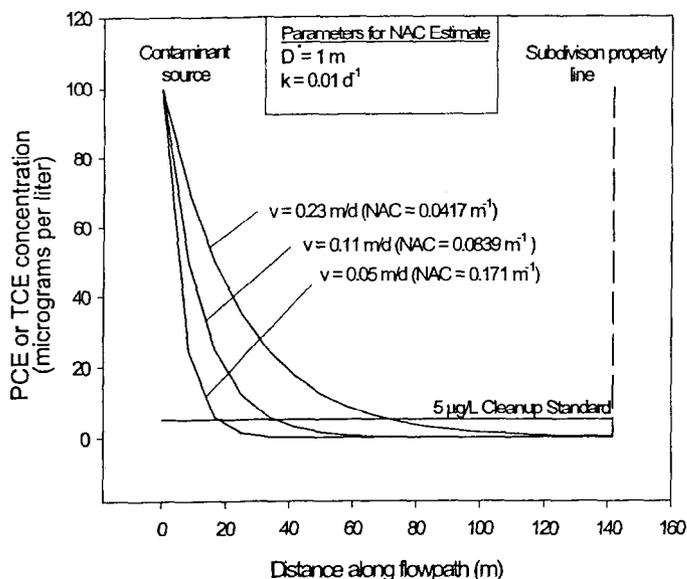


Figure 8.--Estimated distance of transport for PCE and TCE if ground-water velocity away from a source area are decreased from 0.23 to 0.05 m/d.

lowered below 100 µg/L at least 30 meters from the point of compliance. Because the natural attenuation capacity of a system can be increased by decreasing rates of ground-water flow away from a source area, remediation goals can also be accomplished using conventional pump-and-treat technology.

ACKNOWLEDGMENTS

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February 27,

Mr. Anthony B. Robinson
Installation Restoration I Branch
Southern Division, Naval Facilities Engineering Command
P. O. Box 190010
2155 Eagle Drive
North Charleston, South Carolina 29419-9010

Re: Code 18511
Request for Air Treatment Standards

Dear Mr. Robinson:

We have reviewed your letter of December 11, 1997, requesting a determination of air emissions standards for vinyl chloride monomer (VCM) at the Old Camden County Landfill site at the Naval Submarine Base Kings Bay. To recap our discussion of this subject at the October 1997 team meeting, the Environmental Protection Division (EPD) seeks the following:

1. The protection of human health and the environment from releases of chlorinated hydrocarbons, especially VCM, a known human carcinogen.
2. The cessation of air stripping followed by carbon adsorption. This technology has been demonstrated by the Navy's own studies to result in no significant destruction or removal from the environment of VCM.

During the February 18, 1998, team meeting the Navy's contractor proposed essentially a single corrective action alternative: air stripping with "possible" offgas control. We have subsequently determined that this proposal was based on incomplete background assumptions. This letter is written to clarify our requirements for air stripping.

First, if you wish to propose a pump-and-treat system for groundwater followed by air stripping, the offgases from the air stripping must be treated with the best available control technology, and the system must achieve the lowest achievable emission rate (BACT/LAER). Attached is an EPD policy statement germane to this issue. According to EPD's Air Branch, BACT for chlorinated organics, including VCM, is thermal or catalytic oxidation; LAER is 99.5% mass destruction and removal.

Second, the base would be committing to periodic (probably annual) performance and compliance testing for the air pollution control device. There would also be periodic performance and certification testing for the continuous emissions monitoring system for the unit. This is a corollary to the requirement for achieving LAER. This testing

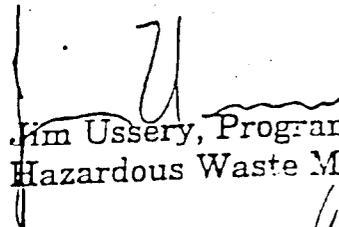
regimen would be required in addition to the periodic groundwater monitoring needed to determine the overall efficacy of the corrective action program.

Finally, a risk assessment would be required to demonstrate protection of human health and the environment. Air emissions, and the resulting ambient pollutant concentrations, are highly installation-specific, and are dependent upon control efficiency, plume dispersion, and many other factors. If groundwater treatment were performed in the liquid medium, the risk assessment would not be necessary because the cleanup target would be set for each of the site's contaminants of concern at EPA's Maximum Contaminant Limit (MCL), itself a risk-based standard. We have enclosed a copy of EPD's risk guidance.

We applaud your efforts to incorporate innovative methods into your Corrective Action Plan, specifically the in-situ chemical oxidation for parent compounds. The EPD urges the Navy to include liquid phase destruction or removal of VCM and its parent compounds from the contaminated media at the site. Based on our experience at other sites, a liquid-phase treatment scheme is likely to be less expensive, more effective, and exhibit less impact on the environment than air stripping with end-of-pipe controls.

If you have further questions, please contact Billy Hendricks at 404-656-2833.

Sincerely,


Jim Ussery, Program Manager
Hazardous Waste Management Branch

c: John Garner, NSB
File: NSB (B)
R:\BILLY\FACILITY\SUBBASE\NSBAIRVCLTR

August 1, 1989

MEMORANDUM

TO: Air Pollution Compliance Program

FROM: Robert H. Collom *RHC*

SUBJECT: Groundwater Cleanup Actions

If contaminated groundwater is required to be cleaned up pursuant to RCRA regulations administered by the Land Branch, the Division has established a policy that any air stripping must be controlled with the best available control procedures and technology. This is predicated on the fact that such contaminants in groundwater are labeled toxic or hazardous under that law and the Division does not want to allow their uncontrolled release to the atmosphere.

The use of best technology for any air stripping in such circumstance is required, even though the Air Branch Toxic Guidelines may not show or demonstrate a need for any control of those air emissions.

I am informing you in this manner since I recently discovered there is some confusion on this point.

RHC:njj:2177N
cc: Harold Reheis
John Taylor