NAVAL FACILITIES ENGINEERING COMMAND
Washington, DC 20374-5065

Site Specific Report
SSR-2539-ENV

MARINE CORPS BASE CAMP LEJEUNE
Operable Units 1 and 2

REMEDIAL ACTION OPERATION OPTIMIZATION CASE STUDY

January 2000

Prepared for
Department of the Navy RAO/LTM Optimization Working Group

Approved for public release; distribution is unlimited.

Printed on recycled paper

FINAL

Marine Corps Base Camp Lejeune
Operable Units 1 and 2

Remedial Action Operation (RAO) Optimization Case Studies

Contract No. N47408-99-C-7017

Prepared for:

Department of the Navy
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370

Prepared by:

Radian International
1600 Perimeter Park Drive
Morrisville, NC 27560

January 2000

TABLE OF CONTENTS

Section **Page**

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION....1-1
1.1 Purpose and Objectives....1-1
1.2 Optimization Approach....1-1

2.0 LOCATION AND PHYSICAL SETTING OF MCB CAMP LEJEUNE....2-1
2.1 Location of MCB Camp Lejeune and Case Study Operable Units....2-1
2.2 Physical Setting....2-1
2.2.1 Geology....2-1
2.2.2 Hydrology....2-1
2.2.3 Groundwater....2-1
2.2.4 Geography....2-3

3.0 OU1 NORTH REMEDIAL SYSTEM ASSESSMENT....3-1
3.1 OU1 Background and Regulatory Framework....3-1
3.1.1 OU1 Site Description....3-1
3.1.2 OU1 Regulatory Framework....3-1
3.1.3 OU1 Activity Status....3-3
3.2 Current OU1 Conceptual Model....3-3
3.3 OU1 North P&T System Description and Design Basis....3-10
3.3.1 Description of Extraction and Monitoring Well Networks at OU1 North....3-10
3.3.2 Description of Aboveground Treatment Train at OU1 North....3-12
3.3.3 Design Specifications and Parameters for OU1 North....3-14
3.3.4 System Upgrades and Modifications for OU1 North....3-16
3.4 OU1 North Good Management Pratices....3-16
3.5 OU1 North System Performance Evaluation....3-17
3.5.1 OU1 North System Performance Plots....3-17
3.5.2 OU1 North Extraction and Monitoring Well Network Performance....3-26
3.5.3 OU1 North Aboveground Treatment Train Performance....3-26

4.0 CONCLUSIONS AND RECOMMENDATIONS FOR OU1 NORTH P&T SYSTEM....4-1
4.1 OU1 North Optimization Recommendations....4-1
4.1.1 OU1 North Extraction and Monitoring Well Network Recommendations....4-2
4.1.2 OU1 North Aboveground Treatment Train Recommendations....4-5
4.2 OU1 North Recommendations Life Cycle Costs....4-6

5.0 OU1 SOUTH REMEDIAL SYSTEM ASSESSMENT....5-1
5.1 OU1 South Background and Regulatory Framework....5-1
5.2 Current OU1 South Conceptual Model and Remedial Action Status....5-1
5.3 OU1 South P&T System Description and Design Basis....5-1
5.3.1 Description of Extraction and Monitoring Well Network at OU1 South....5-1
5.3.2 Description of Aboveground Treatment Train at OU1 South....5-5
5.3.3 Design Specifications and Parameters for OU1 South....5-5
5.3.4 System Upgrades and Modifications for OU1 South....5-5

TABLE OF CONTENTS (continued)

Section **Page**

5.4 OU1 South Good Management Practices....5-6
5.5 OU1 South System Performance Baseline....5-6
5.5.1 OU1 South System Performance Plots....5-7
5.5.2 OU1 South Extraction and Monitoring Well Network Performance....5-13
5.5.3 OU1 South Aboveground Treatment Train Performance....5-15

6.0 CONCLUSIONS AND RECOMMENDATIONS FOR OU1 SOUTH P&T SYSTEM....6-1
6.1 OU1 South Optimization Recommendations....6-1
6.1.1 OU1 South Extraction and Monitoring Well Network....6-4
6.1.2 OU1 South Aboveground Treatment Train Recommendations....6-4
6.1.3 OU1 South Recommendations Life Cycle Costs....6-5

7.0 OU2 REMEDIAL SYSTEM ASSESSMENT....7-1
7.1 OU2 Background and Regulatory Framework....7-1
7.1.1 OU2 Description....7-1
7.1.2 OU2 Regulatory Framework....7-1
7.1.3 Activity Status....7-3
7.2 Current OU2 Conceptual Model and Remedial Action Status....7-3
7.3 OU2 System Descriptions and Design Basis....7-8
7.3.1 Description of Extraction and Monitoring Well Network at OU2....7-12
7.3.2 Description of Aboveground Treatment Train at OU2....7-13
7.3.3 Design Specifications and Parameters for OU2....7-15
7.3.4 System Upgrades and Modifications....7-17
7.3.5 Total Capital Costs....7-17
7.4 OU2 Good Management Practices....7-17
7.5 OU2 System Performance Baseline....7-17
7.5.1 OU2 Treatment System Cost and Performance Baseline....7-18
7.5.2 OU2 Extraction and Monitoring Well Network Performance....7-23
7.5.2.1 OU2 Shallow Extraction and Monitoring Well Network Performance....7-23
7.5.2.2 OU2 Deep Extraction and Monitoring Well Network Performance....7-25
7.5.3 OU2 Aboveground Treatment Train Performance....7-27

8.0 CONCLUSIONS AND RECOMMENDATIONS FOR OU2 SYSTEM....8-1
8.1 Long-Term Remedial Strategy Considerations for OU2....8-1
8.1.1 Establishment of Alternate Concentration Limits (ACLs)....8-2
8.1.2 Innovative Technology Enhancements for OU2....8-3
8.1.3 Decision Criteria for Remedial Strategy for OU2....8-3
8.2 OU2 Extraction and Monitoring Well Network Recommendations....8-5
8.2.1 Shallow Zone at OU2....8-5
8.2.2 Deep Zone at OU2....8-10
8.3 OU2 Aboveground Treatment Train Recommendations....8-13
8.4 OU2 Life Cycle Cost Analysis....8-14

TABLE OF CONTENTS (continued)

Section **Page**

9.0 DATA ANALYSIS, TREND EVALUATION, AND REPORTING 9-1
9.1 Performance Plots 9-1
9.2 Contaminant Migration Tracking and Plume Contours 9-1
9.3 Zone of Capture 9-2
9.4 Operational and Performance Reporting 9-2

10.0 REFERENCES 10-1

APPENDIX A: Innovative Technology Evaluation of OU2

LIST OF FIGURES

Section **Page**

1-1 Cleanup Decision Process for Groundwater Pump and Treat Systems. 1-3
2-1 General Location Map of Operable Units at MCB Camp Lejeune. 2-2
3-1 Sample Location Map for OU1, Site 78..... 3-4
3-2a VOC Contaminant Plume at OU1 North Plant, July 1996..... 3-6
3-2b VOC Contaminant Plume at OU1 North Plant, July 1997..... 3-7
3-2c VOC Contaminant Plume at OU1 North Plant, January 1998 3-8
3-3 OU1, Site Map..... 3-11
3-4 Process Flow Diagram OU1 North and South Groundwater Treatment Plant..... 3-13
3-5 Influent VOC Concentrations vs. Time OU1 (Site 78) - North Plant..... 3-18
3-6 Influent VOC Concentrations vs. Time OU1 (Site 78) - North Plant..... 3-19
3-7 Cumulative Mass Recovered vs. Time OU1 (Site 78) - North Plant..... 3-20
3-8 Cumulative Costs vs. Cumulative VOCs Recovered OU1 (Site 78) - North Plant..... 3-22
3-9 Average Cost Per Pound Recovered vs. Time OU1 (Site 78) - North Plant..... 3-23
5-1a VOC Contaminant Plume at OU1 South Plant, July 1996..... 5-2
5-1b VOC Contaminant Plume at OU1 South Plant, January 1997 5-3
5-1c VOC Contaminant Plume at OU1 South Plant, January 1998 5-4
5-2 Influent VOC Concentrations vs. Time OU1 (Site 78) South Plant..... 5-9
5-3 Cumulative Mass Recovered vs. Time OU1 (Site 78) South Plant..... 5-10
5-4 Cumulative Costs vs. Cumulative VOCs Recoverd OU1 (Site 78) South Plant..... 5-11
5-5 Average Cost Per Pound Recovered vs. Time OU1 (Site 78) South Plant..... 5-12
7-1 Sample Location Map for OU2, Sites 6 and 82..... 7-4
7-2a VOC Contaminant Plume in the Shallow Zone at OU2, Fourth Quarter 1998 7-6
7-2b VOC Contaminant Plume in the Deep Zone at OU2, Fourth Quarter 1998..... 7-7
7-3 Shallow Groundwater Extraction System, OU2..... 7-10
7-4 Deep Groundwater Extraction System, OU2 7-11
7-5 Process Flow Diagram, OU2 Groundwater Treatment Plant..... 7-14
7-6 Influent VOC Concentrations vs. Time OU2 (Lot 203) - Shallow and Deep Aquifers..... 7-19
7-7 Cumulative Mass Recovered vs. Time OU2 (Lot 203) - Shallow and Deep Aquifers..... 7-20
7-8 Cumulative Costs vs. Cumulative VOCs Recovered OU2 (Lot 203) - Shallow and Deep Aquifers..... 7-21
7-9 Average Cost per Pound vs. Time OU2 (Lot 203) - Shallow and Deep Aquifers 7-22
8-1 Decision Criteria for Remedial Strategy for OU2 Pump and Treat System 8-4
8-2 Groundwater Screening and Sampling Locations 8-11

LIST OF TABLES

Section **Page**

3-1 Summary of Site Information for OU1 3-2
3-2 Summary of Regulatory Framework for OU1 3-2
3-3 Summary of Monitoring Status for OU1 3-3
3-4 Remediation Levels for Contaminants of Concern at OU1 (Sites 24 And 78) MCB Camp Lejeune, North Carolina 3-9
3-5 Summary of the OU1 Groundwater Treatment Plants Instrumentation and Control System 3-14
3-6 Effluent Standards for the OU1 Treatment Plants 3-15
3-7 Monthly Performance Monitoring for the OU1 Groundwater Treatment Plants 3-15
3-8 OU1 North System Design Versus Performance Data 3-21
3-9 Annual Operations and Maintenance Costs for the OU1 North Groundwater P&T System 3-27
4-1 OU1 North Evaluation and Optimization Summary 4-3
4-2 Life Cycle Cost Analysis for OU1 North Aboveground Treatment Train 4-7
5-1 OU1 South System Design Versus Performance Data 5-8
5-2 Annual Operations and Maintenance Costs for the OU1 South Groundwater P&T Systems 5-15
6-1 OU1 South Evaluation and Optimization Summary 6-2
6-2 Life Cycle Costs for OU1 South Aboveground Treatment Train 6-6
7-1 Summary of Site Information for OU2 7-2
7-2 Summary of Regulatory Framework for OU2 7-2
7-3 Summary of Monitoring Status for OU2 7-3
7-4 Remediation Levels for Contaminants of Concern at OU2 (Sites 6 And 82) MCB Camp Lejeune, North Carolina 7-9
7-5 Summary of the OU2 Groundwater Treatment Plant Instrumentation and Control System 7-15
7-6 Effluent Standards for OU2 Treatment Plant 7-16
7-7 Monthly Performance Monitoring for OU2 Groundwater Treatment Plant 7-16
7-8 OU2 System Design Versus Performance Data 7-23
7-9 Annual Operation and Maintenance Costs for the OU2 Groundwater P&T System 7-29
8-1 OU2 Evaluation and Optimization Summary 8-6
8-2 Life Cycle Costs for OU2 Aboveground Treatment Train 8-15

LIST OF ACRONYMS

AFVR	Aggressive Fluid Vapor Recovery
AST	Aboveground Storage Tank
bls	Below land surface
BTEX	Benzene, toluene, ethylbenzene, and xylenes
COC	Contaminants of Concern
CPT	Cone Penetrometer Testing
CSM	Conceptual Site Model
DNAPL	Dense Non-aqueous Phase Liquids
DON	Department of the Navy
DPT	Direct Push Technology
GAC	Granular Activated Carbon
gpm	Gallons per minute
GWRTAC	Groundwater Remediation Technologies Analysis Center
HPFF	Hadnot Point Fuel Farm
HPIA	Hadnot Point Industrial Area
HRA	Health Risk Assessment
IDW	Investigation Derived Waste
lb(s)	Pounds
LNAPL	Light non-aqueous phase liquids
LTM	Long-term monitoring
MCB	Marine Corps Base
MCL	Maximum contaminant levels
MNA	Monitored Natural Attenuation
NAPL	Nonaqueous phase liquid
NC DENR	North Carolina Department of Environment and Natural Resources
ND	Non-detect
NFA	No further action
NFESC	Naval Facilities Engineering Service Center

LIST OF ACRONYMS (continued)

NPDES	National Pollution Discharge Elimination System
O&M	Operation and Maintenance
OU	Operable Unit
P&T	Pump and treat
PCB	Polychlorinated biphenyls
PCE	Perchloroethylene
pH	Hydrogen Potential
PLC	Programmable Logic Controller
ppm	Parts per million
RAO	Remedial action operation
RBC	Risk-based concentrations
RI	Remedial Investigation
ROD	Record of Decision
SVE	Soil-vapor extraction
SVOC	Semivolatile organic compound
TCE	Trichloroethylene
TDS	Total dissolved solids
TSCA	Toxic Substances Control Act
TSS	Total suspended solids
USGS	United States Geological Survey
USMC	United States Marine Corps
UST	Underground Storage Tank
VOC	Volatile organic compound

EXECUTIVE SUMMARY

ES.1 Purpose of the Case Study Report

This case study report includes an effectiveness evaluation for three separate groundwater pump and treat (P&T) systems located at Marine Corps Base (MCB) Camp Lejeune, North Carolina. The systems evaluated within this report are the North and South P&T systems within Operable Unit 1 (OU1), and the Operable Unit 2 (OU2) P&T system. The primary purpose of the evaluation is to assess the ongoing remedial action operation (RAO) program for these three systems, and provide recommendations resulting in attainment of site remedial action objectives and ultimate closure for optimal life cycle costs. For the purposes of this report, optimal is defined as the minimum cost without sacrificing data quality or decision-making.

This project was conducted for the Naval Facilities Engineering Service Center (NFESC) under a Broad Agency Announcement contract. NFESC is leading a Department of the Navy (DON) working group in developing guidance on optimizing monitoring and remedial action operations for Navy/Marine Corps activities. This working group is comprised of members from NFESC, Atlantic Division (LANTDIV), other Engineering Field Divisions/Activities, Naval Facilities Engineering Command, and Chief of Naval Operations.

ES.2 Optimization Approach

The approach employed in this RAO optimization project to achieve site closeout for optimal life cycle cost is outlined in the steps below. A site visit at MCB Camp Lejeune was conducted from April 27-30, 1999 to gather the required information for this report.

- Gain a detailed understanding of the remedial decision-making framework, remedial action objectives, and site closure criteria for each site.
- Describe and understand past investigation and remedial actions taken to date, and how they have affected the current evolution and understanding of the conceptual site model.
- Describe the current conceptual site model, i.e., geology, pathways, receptors, and contaminants of concern (COCs).
- Gain an understanding of other remedial actions and associated data at MCB Camp Lejeune having potential applicability at OU1 and OU2.
- Describe the system design basis and operational objectives for the P&T systems, including extraction well network, at each operable unit.
- Baseline the past and current cost and operational data for each system.
- Compare the cost and performance data with the system design basis.

- Assess the need for additional system operation.
- Provide the future decision strategy framework and prioritized recommendations to improve total system performance and achieve site remedial action objectives for optimal cost.

ES.3 Operable Unit 1 (OU1) North and South System Descriptions

The OU1 North and South P&T systems were evaluated over an operating period of approximately 2.5 years (September 1996 to March 1999). The treatment systems are of identical design and include oil-water separation, followed by air stripping, granular activated carbon (GAC), and discharge to the sanitary sewer system. The systems were designed to accommodate influent flowrates up to 80 gallons per minute (gpm). The extraction well fields consist of three active wells for OU1 North and seven active wells for OU1 South. Extraction wells were expected to produce up to 5 gpm each.

Remedial action objectives for both systems are covered under a Record of Decision (ROD) signed in 1994 which specifies plume capture and treatment to a combination of federal Maximum Contaminant Levels (MCLs), State of North Carolina (NC) standards, and risk-based standards. The point of compliance for these treatment objectives is throughout the contaminated plume at OU1. Current total VOC contaminant levels in the influent are 200-500 parts per billion (ppb).

ES.4 OU1 North and South System Performance Summary

The technical and cost effective performance for the North and South systems for the period from September 1996 to March 1999 has been poor. It also appears that both the North and South plumes have been stable for several years and are no longer migrating. The overall performance for both systems is summarized below:

- Low hydraulic conductivity of the shallow aquifer has resulted in influent treatment plant flowrates of less than 9% of design capacity.
- Combined total mass removal for both systems has been limited to approximately 23 pounds in 2.5 years of operation.
- The average cost per pound of contaminant removed has been approximately $30,000.
- There is little evidence to suggest that either system can achieve ROD-specified cleanup objectives throughout the aquifer in their current configuration and mode of operation.
- Both systems have a history of significant maintenance problems and associated downtime.

ES.5 OU1 North System Recommendations

Based on the information reviewed and presented in Section 3.0 of this report, several primary recommendations can be made for the OU1 North P&T system. Complete implementation of these recommendations will likely require an Explanation of Significant Difference (ESD) or a ROD amendment to the current OU1 ROD.

1. Perform a monitored natural attenuation (MNA) assessment on the OU1 North plume, according to established Department of Defense (DoD) and Environmental Protection Agency (EPA) protocols.
2. In parallel with recommendation 1, continue to operate the OU1 North P&T system on an interim basis until contaminant mass removal from extraction wells RW-10, 11, and 12 reach asymptotic levels.
3. Shut down the OU1 North system upon achievement of objectives in recommendation 2.
4. Should state guidelines permit risk assessment in the future, consider revising the baseline human health risk assessment assumptions and associated cleanup level calculations to reflect an industrial future land use category as the most probable scenario.
5. If MNA does not prove feasible as the long-term remedy for OU1 North, consider applying remedial options currently in use at Hadnot Point Fuel Farm (HPFF), along with enhanced biodegradation remedies. These alternative remedies could include air sparging/soil-vapor extraction (AS/SVE) and application of hydrogen releasing compound (HRC).
6. Leverage the performance assessment within this report, as well as the data and information from implementation of the above recommendations, as the foundation for the upcoming five-year review at OU1.

In addition, detailed recommendations are provided to help optimize the OU1 North P&T system during its interim operation period. Several of these recommendations may also be applicable for future remedial actions. All recommendations for the extraction and monitoring well network and the aboveground treatment trains for the OU1 North P&T system are summarized in Table 4-1.

ES.6 OU1 South System Recommendations

Based on the information reviewed and presented in Section 5.0 of this report, several primary recommendations can be made for the OU1 South P&T system. As with OU1 North, complete implementation will likely require an ESD or ROD amendment to the current OU1 ROD.

1. Shut down the operation of the OU1 South system at the earliest opportunity. Continued active pumping is difficult to justify given the low permeability of the aquifer, current total VOC concentrations, and the likelihood of passive natural attenuation processes already at work.

2. In parallel with recommendation 1, perform a monitored natural attenuation (MNA) assessment on the OU1 South plume according to established DoD and EPA protocols. Data gaps to better define the extent of the plume in three dimensions can be filled as part of the MNA assessment.
3. Should state guidelines permit risk assessment in the future, consider revising the baseline human health risk assessment assumptions and associated cleanup level calculations to reflect an industrial future land use category as the most probable scenario.
4. If MNA does not prove feasible as the long-term remedy for OU1 South, consider applying remedial options currently in use at HPFF, along with enhanced biodegradation remedies. These alternative remedies could include AS/SVE and application of hydrogen releasing compound (HRC).
5. Leverage the performance assessment within this report, as well as the data and information from implementation of the above recommendations, as the foundation for the upcoming five-year review at OU1.

In addition, recommendations are provided to optimize the OU1 South P&T system as it is currently operating if system shutdown cannot be immediately implemented. Recommendations are summarized in Table 6-1.

ES.7 OU2 System Description

The OU2 P&T system was evaluated over an operating period of approximately two years (January 1997 to March 1999). There are two, co-located aboveground treatment trains for this system; one for the shallow aquifer zone, and one for the combined flow of both the shallow and deep aquifer zones. Water from the shallow aquifer is first treated for iron removal (mix tank, clarifier, and sludge thickening) prior to being combined with extracted groundwater from the deep aquifer zone. The combined flow is treated via air stripping, filtration, and granular activated carbon, and then discharged to Wallace Creek. The system capacity flow is 500 gpm. The shallow zone and deep zone extraction well fields consist of six and four wells, respectively.

Remedial action objectives for the system are covered under a Record of Decision (ROD) signed in September 1993 which specifies plume capture and treatment to federal MCLs or State of North Carolina (NC) standards, whichever is more stringent. The point of compliance for these treatment objectives is throughout the contaminated plume at OU2. Influent volatile organic compounds (VOCs) contaminant levels at OU2 average 21 parts per million (ppm), indicating the presence of dense non-aqueous phase liquids (DNAPL) in the subsurface aquifer.

ES.8 OU2 System Performance Summary

The performance of the OU2 treatment system from both mass removal and cost-effectiveness standpoints has been good. Average flow into the system is 60% of the design capacity of 500 gpm, and more than 40,000 pounds of contamination have been removed from the aquifer at an average cost of only $49 per pound. However, the likely presence of DNAPL coupled with the existence of several critical data gaps, make it highly unlikely that OU2 can be remediated to ROD-specified cleanup levels with existing technology. The data gaps and overall performance of the OU2 system are summarized below:

- The system has cost-effectively removed significant contaminant mass from the aquifer (more than 40,000 pounds at $49 per pound);
- The vertical and lateral extent of contamination in both the shallow and deep aquifer zones is unknown;
- DNAPL source areas require better delineation and definition;
- Data to support natural attenuation and passive biodegradation processes for the dissolved phase portions of the plume has not been collected for the shallow and deep aquifer zones;
- Plume capture in the shallow zone cannot be confirmed with the current monitoring network;
- Due to a dilution effect, the five downgradient extraction wells in the shallow zone are reducing the mass removal effectiveness of the extraction network;
- Plume capture in the deep zone is likely but the hydraulic gradients are insufficient to prevent further downward migration of DNAPL; and
- Mass removal from the deep aquifer zone may be diluted due to wells being screened over most of the well depth, instead of being targeted at zones containing the highest concentrations of contaminants.

ES.9 OU2 Recommendations

The primary recommendation for OU2 is to pursue separate but integrated remedial activities for the DNAPL source areas and dissolved phase portions of the plume, both in the shallow and deep aquifer zones. The initial phase in this approach requires that existing data gaps be filled to the extent practicable. In particular:

- The extent of contamination in the shallow and deep zones should be delineated, including the DNAPL source areas;
- Natural biodegradation data in the wetlands area of Wallace Creek, and monitored natural attenuation data for the dissolved phase portions of the plume should be collected; and

- Discussions should begin with the regulatory agencies to establish alternate concentration limits (ACLs) for groundwater discharging to Wallace Creek.

For the shallow zone, additional recommendations include monitoring the mass removal from each extraction well, and installing additional extraction wells in the vicinity of the current hot spot. For the deep zone, other recommendations include the use of diffuser sampling bags to delineate the vertical distribution of contamination, and performing additional investigations to better define stratigraphy and contaminant extent. Based on an analysis of this data, additional deep zone extraction wells may be required.

For the aboveground treatment plant, recommendations include:

- Modifying the National Pollution Discharge Elimination System (NPDES) permit to allow bypass of the GAC polishing step during normal operation;
- Replacing the existing polymer feed pump; and
- Monitoring mass removal from individual extraction wells to optimize operation and placement of future wells.

1.0 INTRODUCTION

The Department of the Navy (DON) recently formed a working group to provide guidance for optimizing remedial action operation (RAO) and long-term monitoring (LTM) programs at remediation sites. This working group, led by the Naval Facilities Engineering Service Center (NFESC), selected four pump and treat (P&T) sites for detailed RAO evaluations. Three of these sites are at Marine Corps Base (MCB) Camp Lejeune, North Carolina, and the fourth is located at Naval Air Station (NAS) Brunswick, Maine. This case study report includes an evaluation of groundwater P&T systems located within two sites, Operable Units (OUs) 1 and 2 at MCB Camp Lejeune. Two P&T systems are located at OU1, OU1 North and OU1 South. One P&T system is located at OU2. Separate reports are available for evaluations of P&T systems at the Campbell Street Fuel Farm (MCB Camp Lejeune), and the Eastern Groundwater Plume at NAS Brunswick.

1.1 Purpose and Objectives

The primary purpose of this case study is to evaluate and assess the ongoing RAO program at OUs 1 and 2 at MCB Camp Lejeune, North Carolina; and provide recommendations resulting in attainment of site remedial action objectives and ultimate closure for optimal life cycle costs.

Specific elements to be evaluated for each site and associated P&T system include the following:

- Overall site remediation strategy and approach;
- Best operation and management practices already in place;
- Extraction system network, including all wells, screen intervals, and piping;
- Performance of treatment system components, including control systems;
- Operation, maintenance, and control of the treatment units;
- Treatment system data collection, analysis, and reporting;
- Effluent discharge options;
- Appropriate exit strategy for site closeout, including recommendations for the use of alternative technologies, as appropriate; and
- Total estimated cost avoidance/savings from optimized operations.

1.2 Optimization Approach

The overall goal of this case study report is to provide a decision framework and associated recommendations that will facilitate attainment of site remedial action objectives and ultimate closure for optimal life cycle costs. For the purposes of this report, optimal is defined as the minimum cost without sacrificing data quality or decision-

making. The approach employed in this RAO optimization project to achieve this goal is outlined by the steps below and is illustrated in Figure 1-1:

- Gain a detailed understanding of the remedial decision-making framework, remedial action objectives, and site closure criteria for each site;
- Describe and understand past investigation and remedial actions taken to date, and how they have affected the current evolution and understanding of the conceptual site model;
- Describe the current conceptual site model, i.e., geology, pathways, receptors, and contaminants of concern (COCs);
- Gain an understanding of other remedial actions and associated data at MCB Camp Lejeune having potential applicability at OU1 and OU2;
- Describe the system design basis and operational objectives for the P&T systems, including extraction well network, at each operable unit;
- Baseline the past and current cost and operational data for each system;
- Compare the cost and performance data with the system design basis;
- Assess the need for additional system operation; and
- Provide the future decision strategy framework and prioritized recommendations to improve total system performance and achieve site remedial action objectives for optimal cost.

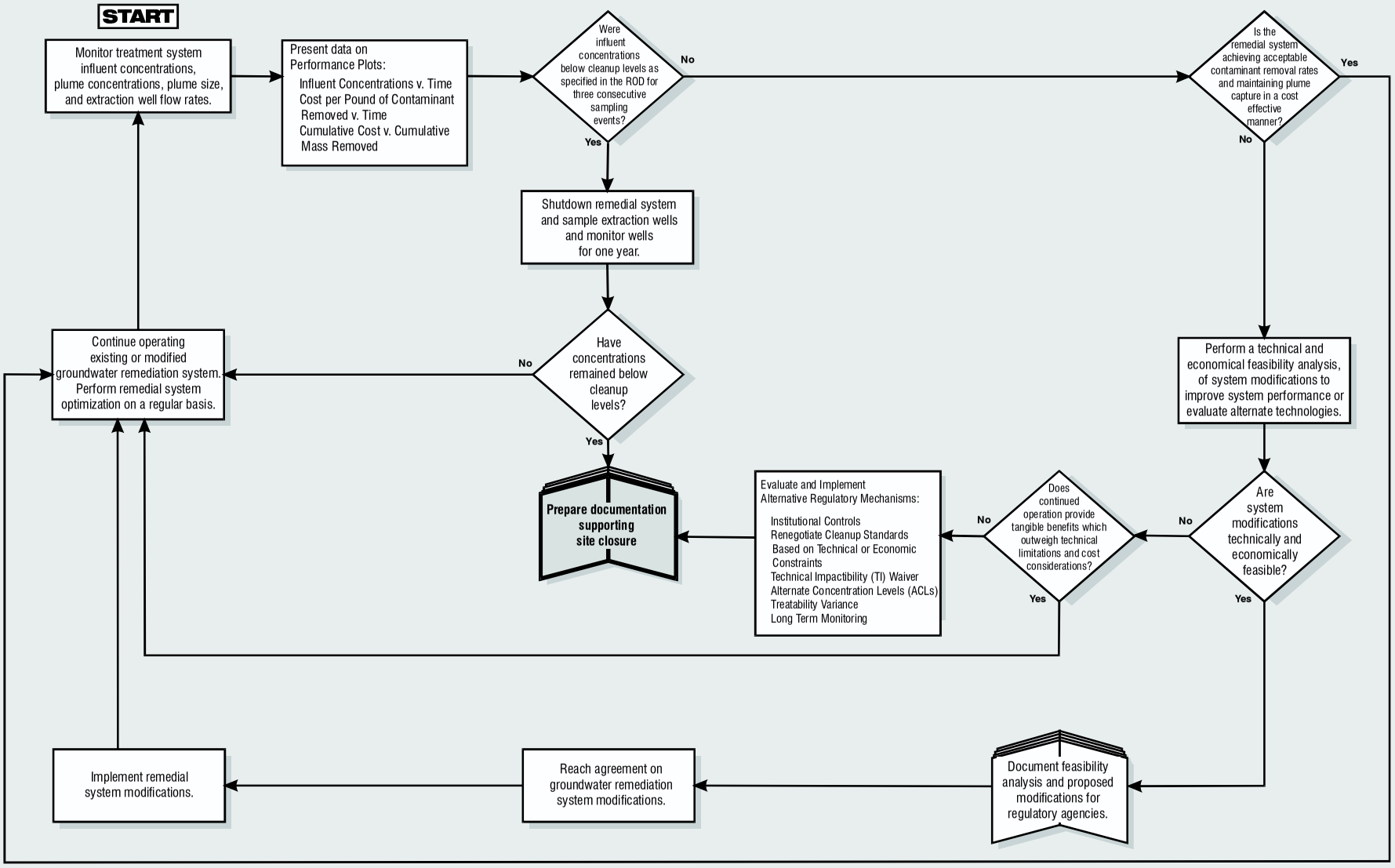


FIGURE 1-1.
Cleanup Decision Process for Groundwater Pump and Treat Systems

2.0 LOCATION AND PHYSICAL SETTING OF MCB CAMP LEJEUNE

MCB Camp Lejeune is a 236-square mile (153,439 acre) training base for the United States Marine Corps (USMC). The installation is located in Onslow County, North Carolina, and has 14 miles of coastline on the Atlantic Ocean.

2.1 Location of MCB Camp Lejeune and Case Study Operable Units

There are six OUs that are undergoing active monitoring at MCB Camp Lejeune. Two of the OUs are the focus of this RAO optimization report. They are:

- OU No. 1 (Sites 21, 24, and 78); and
- OU No. 2 (Sites 6, 9, and 82).

The locations of these OUs at MCB Camp Lejeune are shown in Figure 2-1. Descriptions of OU1 are provided in Sections 3.0 and 5.0. Descriptions of OU2 are provided in Section 7.0.

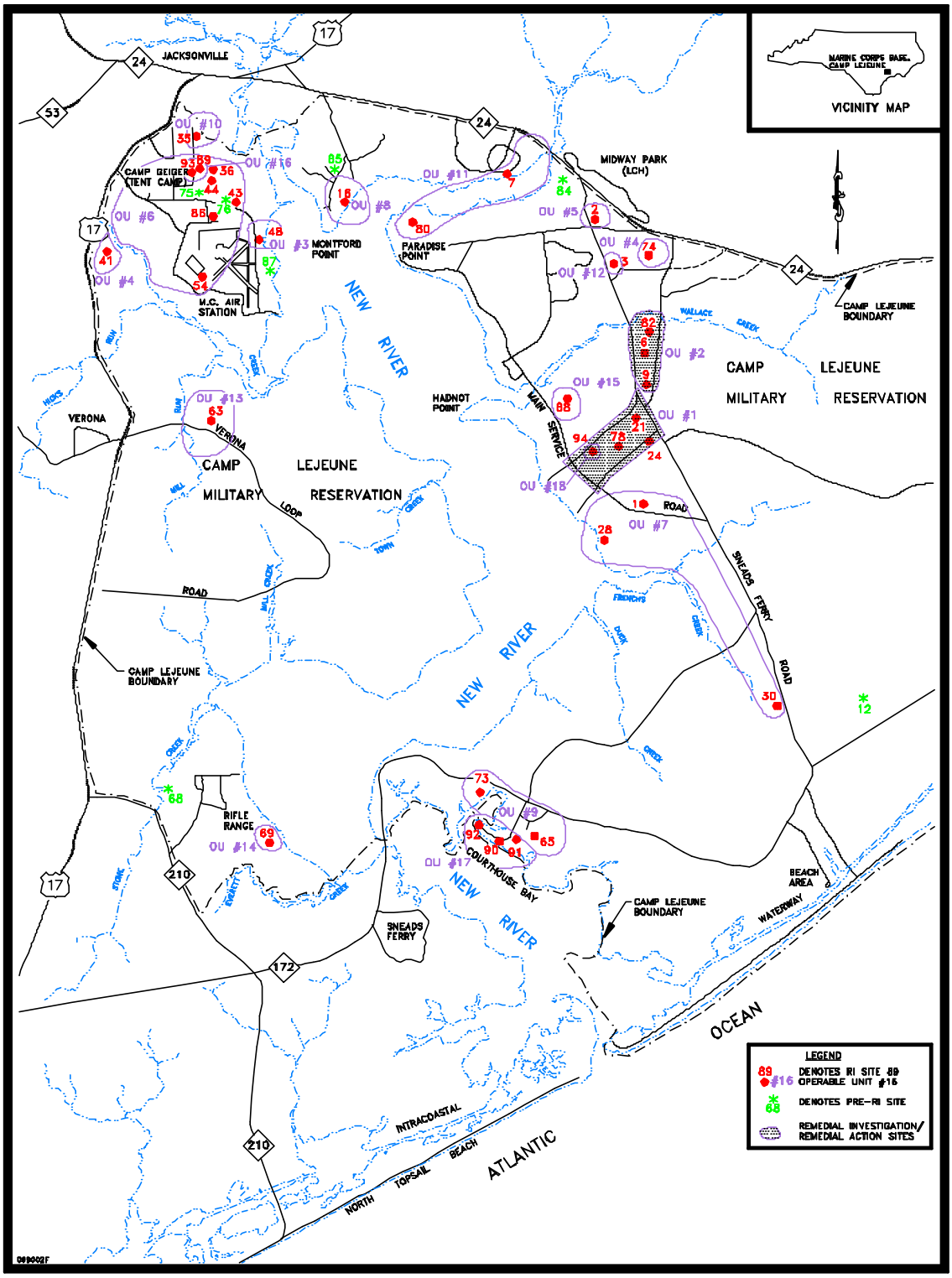
2.2 Physical Setting

This section describes the geology, hydrogeology, and geography at MCB Camp Lejeune. The information in this section is summarized from the *Basewide Remediation Assessment Groundwater Study*, (Baker Environmental, April 1998).

2.2.1 Geology—MCB Camp Lejeune is located in the Atlantic Coastal Plain geologic province. The Atlantic Coastal Plain consists of unconsolidated sediments ranging in size from clay to gravel. These sediments were eroded from the Appalachian and Piedmont geologic provinces to the west. They were transported by fluvial processes and deposited in alluvial fans and as tidal marine muds during advance and retreat of the ocean. These sediments overlie the Precambrian igneous and metamorphic bedrock in this area.

2.2.2 Hydrology—The majority of MCB Camp Lejeune drains into the New River, which bisects the base. In the vicinity of Camp Lejeune, the New River flows to the south, through a wide estuary, and into the Atlantic Ocean via the New River Inlet. Several other small coastal creeks also drain parts of Camp Lejeune. These drain into the Intercoastal Waterway and eventually into the Atlantic Ocean via a series of inlets.

2.2.3 Groundwater—An unnamed surficial unit is the shallowest water-bearing formation underlying Camp Lejeune. The thickness of the deposit containing the surficial aquifer ranges from 0 to approximately 100 feet. Beneath the surficial water-bearing unit is the Castle Hayne Aquifer, which consists primarily of fine sand, shell, and limestone. The Castle Hayne confining unit, composed of clay and sandy clay, separates the Castle Hayne



SOURCE: BAKER

SCALE IN MILES 0 1.75 2.5

RADIAN INTERNATIONAL
A BAKER & MOORE GROUP COMPANY

Figure 2-1. GENERAL LOCATION MAP OF OPERABLE UNITS AT MCB CAMP LEJEUNE

DRAWING NO.	CONTRACT NO	DATE
lej99126.dwg	BD3016.0402	07/29/99

aquifer from the surficial aquifer. In the area of Camp Lejeune, the confining unit averages 9 feet thick, except near the New River and some of its larger tributaries where there is hydraulic communication between the surficial aquifer and the Castle Hayne Aquifer. The Castle Hayne Aquifer is used for domestic water supply at MCB Camp Lejeune.

There are five more aquifers that underlie Camp Lejeune. These are the Beaufort, the Peedee, the Black Creek, and the Upper and Lower Cape Fear aquifers. All of these aquifers are over 400 feet deep and are isolated from the shallower units by the Beaufort confining layer.

Groundwater monitoring and aquifer testing studies at MCB Camp Lejeune have focused on the surficial and the Castle Hayne aquifers. This is because contamination from installation activities is limited to these two water-bearing units and is prevented from migration to deeper aquifers by the Beaufort confining layer.

Groundwater flows toward discharge areas on Camp Lejeune which include the New River, its tributaries, and other surface water bodies such as wetlands.

2.2.4 Geography—Construction of MCB Camp Lejeune was initiated in 1941. Today, more than 40,000 military, civilian, and contract personnel work at Camp Lejeune. The nearest community to the installation is the city of Jacksonville, North Carolina, with a population of approximately 75,000.

Land use around MCB Camp Lejeune includes residential, park, industrial, and commercial properties. On base, natural areas such as wetlands and wooded areas are interspersed with developed land occupied by administrative and mission-related buildings and airfield facilities. It is not anticipated that land use, either on or off base, will change in the foreseeable future.

3.0 OU1 NORTH REMEDIAL SYSTEM ASSESSMENT

3.1 OU1 Background and Regulatory Framework

This section provides a description, regulatory information, and site activity status for OU1 North. The information is also summarized in Tables 3-1 to 3-3.

3.1.1 OU1 Site Description—OU1 occupies approximately 690 acres, one mile east of the New River. As illustrated on Figure 2-1, it consists of Site 21, Transformer Storage Lot 140; Site 24, Industrial Fly Ash Dump; and Site 78, Hadnot Point Industrial Area (HPIA).

Site 21 has had a history of pesticide usage and reported transformer oil disposal (Baker Environmental, 1994c). This site includes the Former Pesticide Mixing/Disposal Area, located in the southern portion of the site. It is thought that approximately 350 gallons of pesticide mixing equipment wash water was discharged to the ground surface each week in 1977. Although this site was active from 1958 to 1977, it is not known how long the washing activities took place.

The former Transformer Oil Disposal Pit is also located at Site 21, in the northeastern part of the site. This area was reportedly used to dispose of transformer oil from 1950 to 1951. The total quantity of transformer oil disposed in this area is unknown.

Site 24 was used for the disposal of fly ash, cinders, solvents, spent paint stripper, sewage sludge, and water treatment sludge from the late 1940s until 1980 (Baker Environmental, 1994c). As a result of disposal activities at this site, there are five main areas of concern: the Spiractor Sludge Disposal Area, the Fly Ash Disposal Area, the Borrow and Debris Disposal Area, and two Buried Metal Areas.

Site 78, the HPIA, was the first major industrial area developed at MCB Camp Lejeune. This site had multiple past releases of contamination from various sources related to the numerous industrial shops, gas stations, storage yards, and underground storage tanks (USTs).

3.1.2 OU1 Regulatory Framework—A Record of Decision (ROD) was signed for OU1 in September 1994. The selected remedy components and associated cleanup criteria are summarized in Table 3-2. As shown in the table, the ROD specifies a remedial action of pumping and treating for two plumes located at Site 78 (North and South, respectively), along with the implementation of an LTM program. These two pump and treat systems have been operating at Site 78 since 1995, and the LTM program was initiated in 1997.

For groundwater, ROD-specified cleanup levels are a combination of federal maximum contaminant limits (MCLs), State of North Carolina standards, and risk-based standards. The ROD states that the selected remedy will be operated until the remediation levels for chemicals of concern (COCs) have been met.

Table 3-1. Summary of Site Information for OU1

Site	Description	Years of Operation	Contaminated Media	Contaminants of Concern
21	Transformer Storage Lot 140	1958 to 1977	Soil	Pesticides and PCBs
24	Industrial Fly Ash Dump	1940s to 1980	Groundwater and soil	Groundwater: metals and heptachlor epoxide Soils: pesticides and metals
78	Hadnot Point Industrial Area	1940s to present	Groundwater and soil	Groundwater: VOCs (BTEX and chlorinated solvents) and metals Soils: pesticides and SVOCs

NOTES:
BTEX = Benzene, toluene, ethylbenzene, and xylenes
OU = Operable Unit
PCBs = Polychlorinated biphenyls
SVOC = Semivolatile organic compound
VOC = Volatile organic compound

Table 3-2. Summary of Regulatory Framework for OU1

Date of ROD	Site	Remedy Components	Cleanup Criteria for Active Systems	Criteria to Stop Monitoring
September 1994	21	• Excavate approximately 1050 cubic yards of soil contaminated with PCBs and pesticides for off-site disposal.	Groundwater: Federal MCLs, state groundwater standards, risk-based levels Soil: EPA Region III RBCs	Three consecutive rounds in which samples have non-detect (ND) concentrations or concentrations protective of human health have been demonstrated to the satisfaction of the regulatory agencies.
	24	• Restrict the use of nearby water supply wells and installation of new water supply wells within the OU. • Implement an LTM program.		
	78	• Pump and treat contaminated groundwater from extraction wells installed within the plumes at Site 78. • Restrict the use of nearby water supply and restrict the installation of new water supply wells within the OU. • Implement an LTM program.		

NOTES:
LTM = Long-term monitoring
EPA = Environmental Protection Agency
RBC = Risk-based concentrations
ND = Non-detect
ROD = Record of Decision
MCLs = Maximum contaminant levels
OU = Operable Unit
PCBs = Polychlorinated biphenyls

Table 3-3. Summary of Monitoring Status for OU1

Site	Status of Monitoring	Monitored Medium	Sampling Frequency: Initial/Current (or Final)	Current Number of Monitoring Points	Remedial Actions
21	NFA	NA	NA	NA	Soil removal action completed in 1993.
24	Begun in 1997; discontinued in July 1998.	Groundwater	Quarterly/ Semiannually	NA	NA
78	Active; begun in 1997.	Groundwater	Quarterly/ Semiannually	22 wells	Two active pump and treat systems.

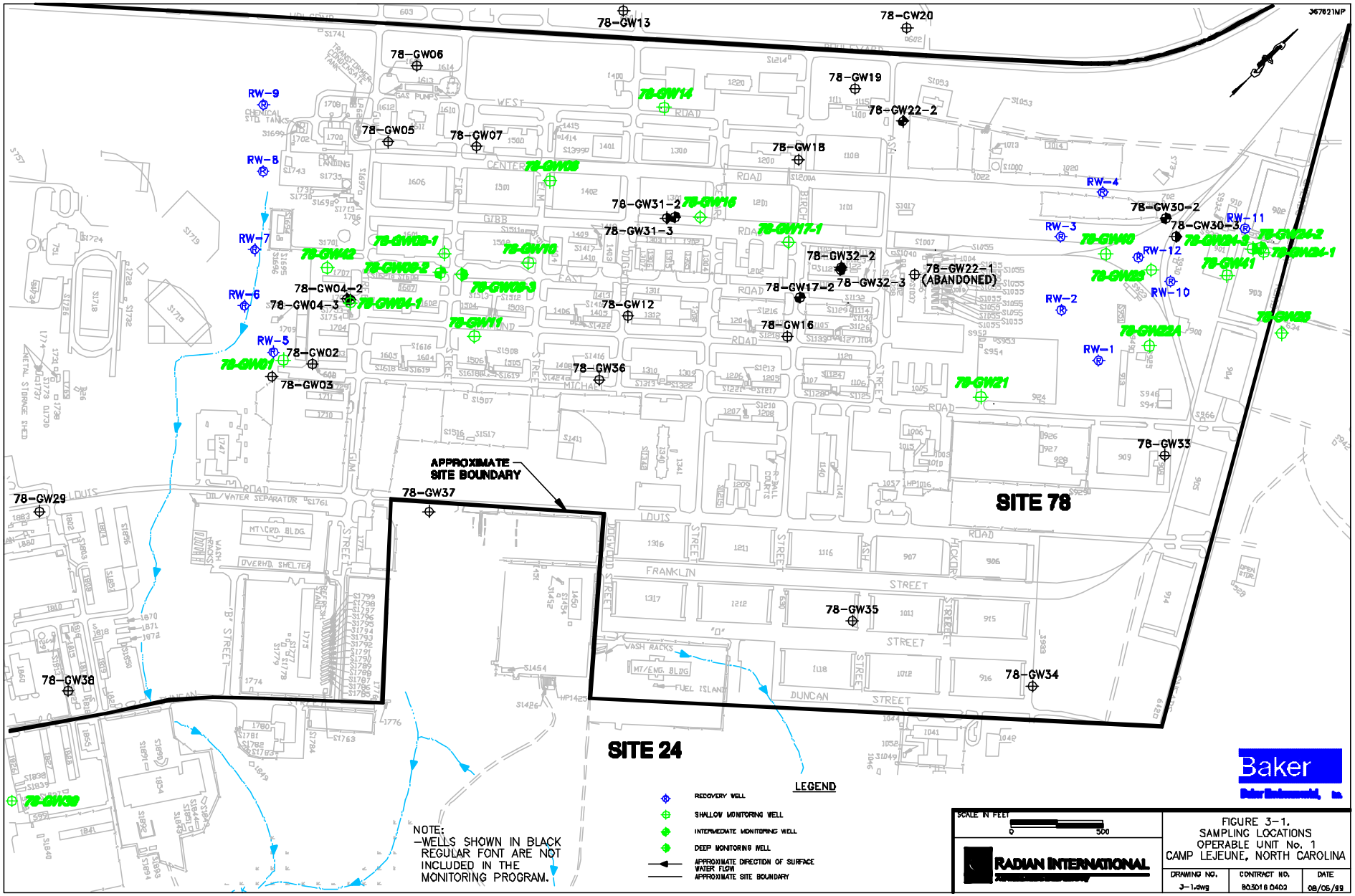
NOTES:
NA = Not applicable
NFA = No further action
OU = Operable Unit

3.1.3 OU1 Activity Status—The LTM program at OU1 began in 1995. The program initially called for quarterly sampling but was reduced to semiannual in July 1997, after data from two rounds of sampling were evaluated. A removal action to eliminate soils contaminated with polychlorinated biphenyls (PCBs) was specified in the ROD for Site 21. The removal action was conducted in 1993, and no further action is required for Site 21. Site 24 was eliminated from the LTM program in July 1998, after samples collected in several rounds had NDs for site contaminants. Currently, 18 shallow wells, two intermediate-depth wells, and two deep wells, for a total of 22 wells, are being monitored at Site 78. The sampling points for Site 78 are shown in Figure 3-1.

Two pump and treat systems have been operating at Site 78 since 1995. This site has two distinct plumes, north and south, that are being treated by the systems.

3.2 Current OU1 Conceptual Model

The geology at OU1 is typical of the Atlantic Coastal Plain, characterized by interlayered beds and lenses of sand, silt, clay, shell, and limestone. Shallow deposits (surface to 25 feet below land surface [bls]) are silty to clayey sand, silt, and clay. Deposits at depths between 25 and 150 feet consist predominantly of silty sand with shell fragments across OU1.


SITE 78
SITE 24
APPROXIMATE SITE BOUNDARY
78-GW13
78-GW20
78-GW06
78-GW19
78-GW22-2
78-GW05
78-GW07
78-GW18
78-GW31-2
78-GW31-3
78-GW30-2
78-GW30-3
78-GW32-2
78-GW32-3
78-GW22-1 (ABANDONED)
78-GW17-2
78-GW12
78-GW16
78-GW04-2
78-GW04-3
78-GW02
78-GW03
78-GW36
78-GW33
78-GW35
78-GW34
78-GW29
78-GW37
78-GW38
RW-1
RW-2
RW-3
RW-4
RW-5
RW-6
RW-7
RW-8
RW-9
RW-10
RW-11
RW-12
LEGEND
RECOVERY WELL
SHALLOW MONITORING WELL
INTERMEDIATE MONITORING WELL
DEEP MONITORING WELL
APPROXIMATE DIRECTION OF SURFACE WATER FLOW
APPROXIMATE SITE BOUNDARY
NOTE:
-WELLS SHOWN IN BLACK REGULAR FONT ARE NOT INCLUDED IN THE MONITORING PROGRAM.
SCALE IN FEET
0
500
RADIAN INTERNATIONAL
Baker
Baker Environmental, Inc.
FIGURE 3-1.
SAMPLING LOCATIONS
OPERABLE UNIT No. 1
CAMP LEJEUNE, NORTH CAROLINA
DRAWING NO.
3-1.dwg
CONTRACT NO.
DATE
08/05/99

The surficial aquifer at OU1 within sand and clay deposits reportedly extends to depths between 50 and 100 feet below the operable unit and is unconfined. Deeper water-bearing deposits greater than 100 feet but less than 400 feet bls comprise the Castle Hayne aquifer; however, the absence of a laterally continuous confining layer between the surficial and Castle Hayne aquifers results in direct hydraulic communication beneath OU1.

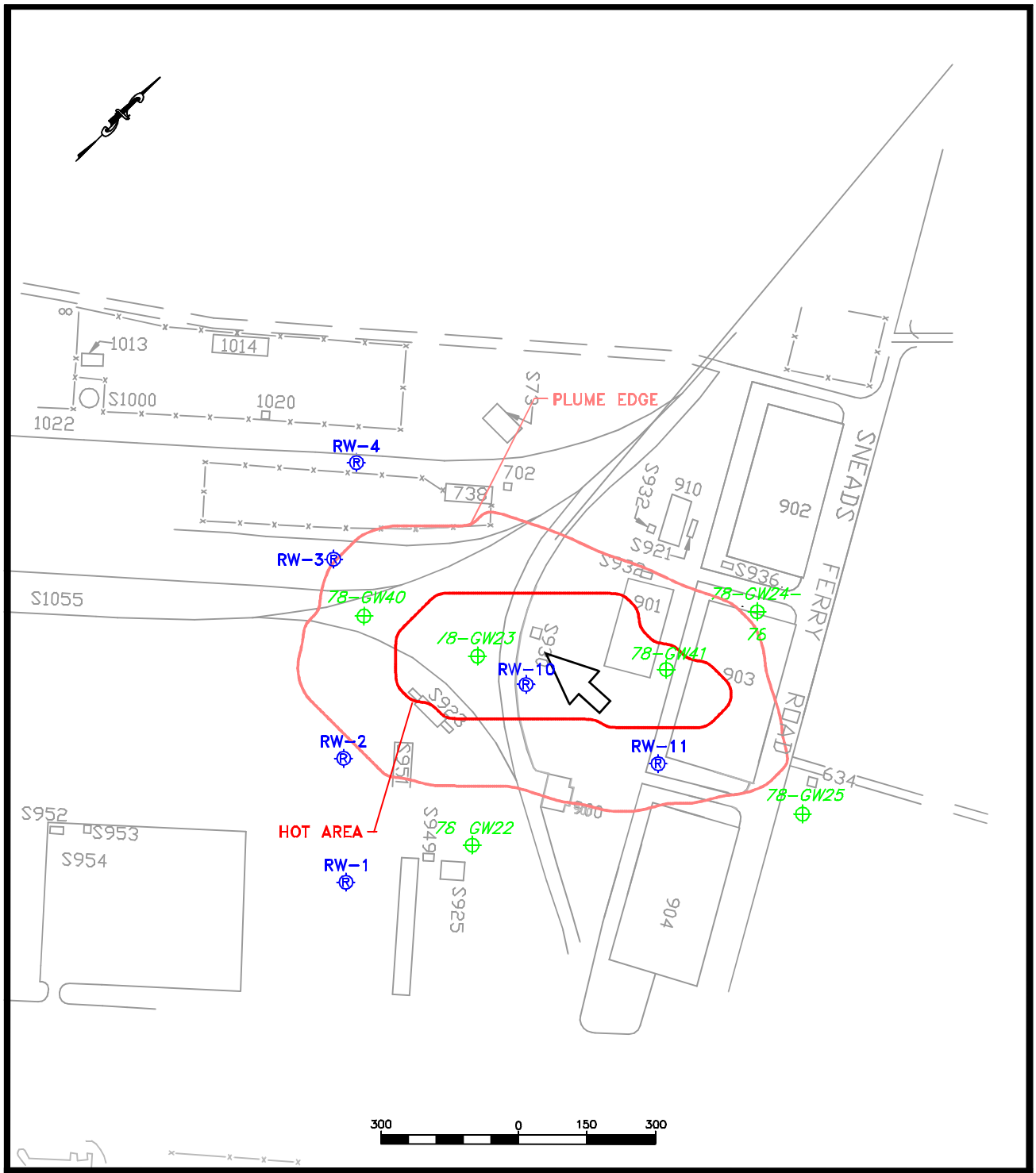
The transmissivity of the upper portion of the surficial aquifer is approximately 75 square feet per day (ft^2/day) and provides well production rates of less than two gallons per minute. Conversely, the transmissivity of the Castle Hayne aquifer ranges from 4,300 to 7,300 ft^2/day and provides production rates ranging from 50 to 150 gallons per minute to wells screened between 140 and 194 feet bls.

In general, the water table beneath OU1 occurs 4 to 14 feet bls and exhibits seasonal fluctuation. The northeast portion of OU1 is a groundwater recharge area. Groundwater flow across OU1, in both the surficial and Castle Hayne aquifers, is to the west-southwest toward discharge points in Cogdels Creek and the New River.

Former operations and disposal practices at the Hadnot Point Industrial Area have resulted in the contamination of soil and groundwater at OU1 as summarized in Table 3-1. In particular, groundwater in the surficial and Castle Hayne aquifers underlying Site 78 contains halogenated VOCs. Groundwater beneath the northern portion of Site 78 also contains nonhalogenated VOCs that originate from petroleum products. The highest concentrations of VOCs are reported in the upper portion of the surficial aquifer at two locations: the northeastern portion of Site 78 near Building 900 and in the southwestern portion of Site 78 near Building 1601. Figures 3-2a through 3-2c illustrate the estimated extent of the contaminant plume at OU1 North in the upper portion of the surficial aquifer over time. As shown in these figures, the OU1 North plume does not appear to be migrating, and in fact may be decreasing in size.

Limited information is available regarding contaminant distribution in the lower portion of the surficial aquifer and in the Castle Hayne aquifer underlying Site 78. Based on the results of a Remedial Investigation (RI), Baker concluded that contaminants have migrated vertically into the lower portion of the surficial aquifer and into the Castle Hayne aquifer. However, recent groundwater monitoring results have not had VOC concentrations above groundwater standards at these depths. Results of the RI indicated that concentrations of metals in groundwater were uniformly distributed across Site 78. Subsequent development of a database for metals detected in groundwater indicates that the concentration of metals detected at OU1 are similar to background concentrations.

As part of the RI, a human health risk assessment (HRA) incorporating multiple potential receptors and pathways was performed. The exposure routes evaluated included ingestion, dermal contact, and inhalation of surface soil; ingestion and dermal contact of subsurface soil; future ingestion, dermal contact, and inhalation of VOCs in groundwater; and ingestion and dermal contact of surface water and sediments. Potentially exposed populations included current military personnel and future on-site adult and child residents



LEGEND

⊕ - SHALLOW MONITORING WELL

- GROUNDWATER RECOVERY WELL

⇦ - GROUNDWATER FLOW DIRECTION

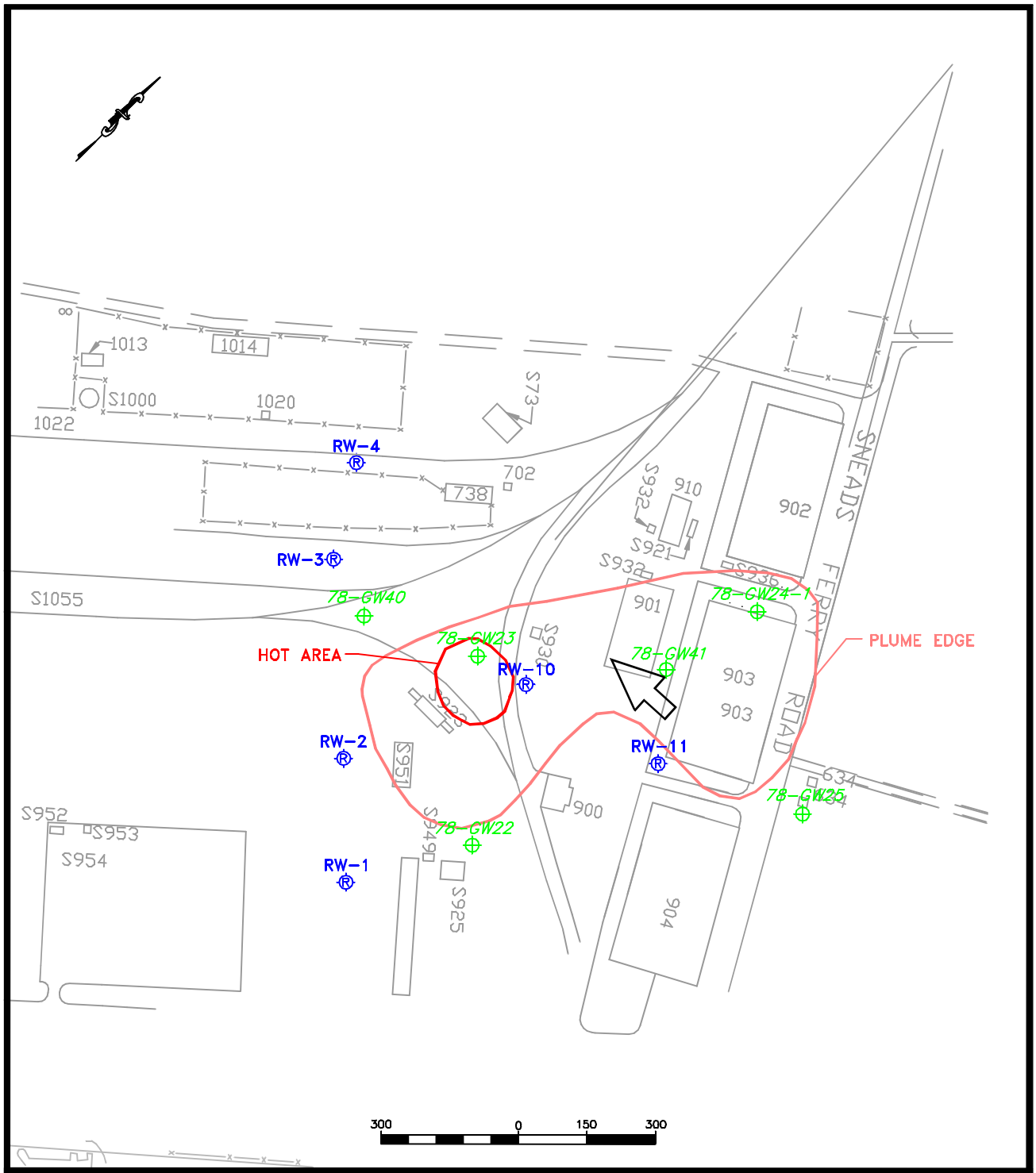
NOTE: PLUME EDGE ~ 10 µg/L
HOT AREA ≥ 5000 µg/L

SOURCE: BAKER

Figure 3-2a. VOC Contaminant Plume at OU1 North Plant, July 1996

RADIAN INTERNATIONAL
A DAMES & MOORE GROUP COMPANY

990103C-KL-RTP



LEGEND

- SHALLOW MONITORING WELL
- GROUNDWATER RECOVERY WELL
- GROUNDWATER FLOW DIRECTION

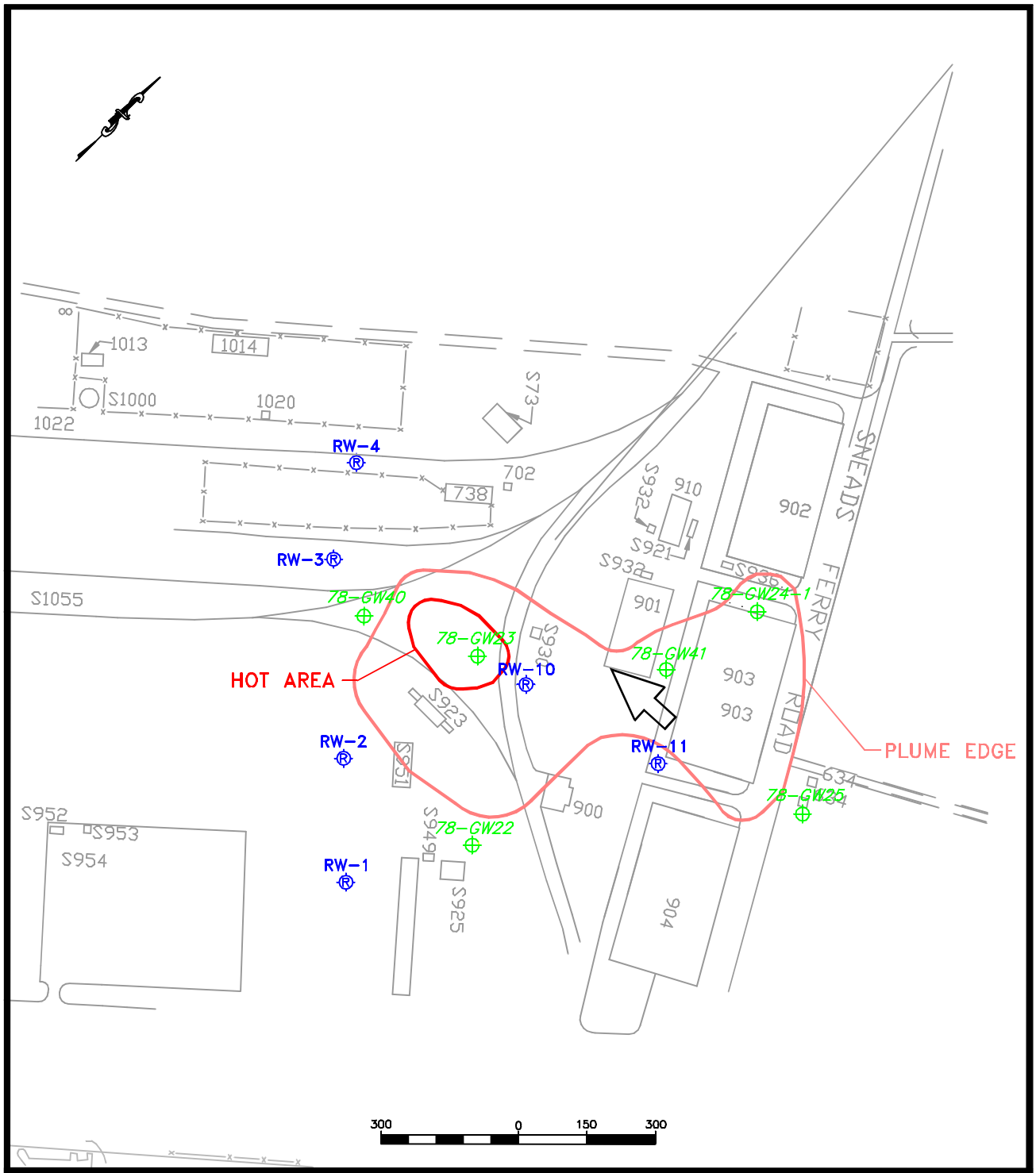
NOTE: PLUME EDGE ~ 10 µg/L
HOT AREA ≥ 5000 µg/L

SOURCE: BAKER

Figure 3-2b. VOC Contaminant Plume at OU1 North Plant, July 1997

RADIAN INTERNATIONAL
A DAMES & MOORE GROUP COMPANY

990103C-KL-RTP



LEGEND

- SHALLOW MONITORING WELL
- GROUNDWATER RECOVERY WELL
- GROUNDWATER FLOW DIRECTION

NOTE: PLUME EDGE ~ 10 µg/L
HOT AREA ≥ 5000 µg/L

SOURCE: BAKER

Figure 3-2c. VOC Contaminant Plume at OU1 North Plant, January 1998

RADIAN INTERNATIONAL
A DAMES & MOORE GROUP COMPANY

990103C-KL-RTP

for surface soil and groundwater, site construction workers for subsurface soil, and future adults and adolescent residents for surface water and sediment. Human health risk at OU1 was determined to be associated with groundwater only. A cancer risk above $1x10^{-4}$ and a Hazard Index greater than 1.0 were estimated for potential future receptors. The risk was associated with ingestion and dermal contact of groundwater and was driven by vinyl chloride, arsenic, vanadium, and chromium. COCs and remediation levels for groundwater at OU1 are listed in Table 3-4. Results for all other receptors and pathways were within acceptable risk ranges.

Table 3-4. Remediation Levels for Contaminants of Concern at OU1 (Site 78) MCB Camp Lejeune, North Carolina

Media	Contaminant of Concern	Remediation Goal	Units
Groundwater	Benzene	1.0	µg/L
	1,2-Dichloroethene (total)	70	µg/L
	Ethylbenzene	29	µg/L
	Heptachlor Epoxide	0.2	µg/L
	Tetrachloroethene	0.7	µg/L
	Toluene	1,000	µg/L
	Trichloroethene	2.8	µg/L
	Vinyl Chloride	0.015	µg/L
	Xylenes (total)	400	µg/L
	Arsenic	50	µg/L
	Barium	1,000	µg/L
	Beryllium	4	µg/L
	Chromium	50	µg/L
	Manganese	50	µg/L
	Vanadium	110	µg/L

NOTES:
µg/L = microgram per liter
µg/kg = microgram per kilogram

The following data gap in the conceptual site model (CSM) was identified:

- The potential for vertical migration of halogenated and nonhalogenated VOCs in groundwater has not been adequately established. RI results indicate that VOCs were present in the lower portion of the surficial aquifer and in the Castle Hayne aquifer. However, recent groundwater monitoring results do not confirm this conclusion.

3.3 OU1 North P&T System Description and Design Basis

The groundwater extraction and treatment system at OU1 North has been in operation since January 1995 (OHM, 1998c). The system was designed to collect and treat contaminated groundwater from the uppermost portion of the surficial aquifer in the northern portion of Site 78 at OU1 and to prevent off-site contaminant migration. Contaminated groundwater, extracted via a network of wells, is treated and discharged to the sanitary sewer.

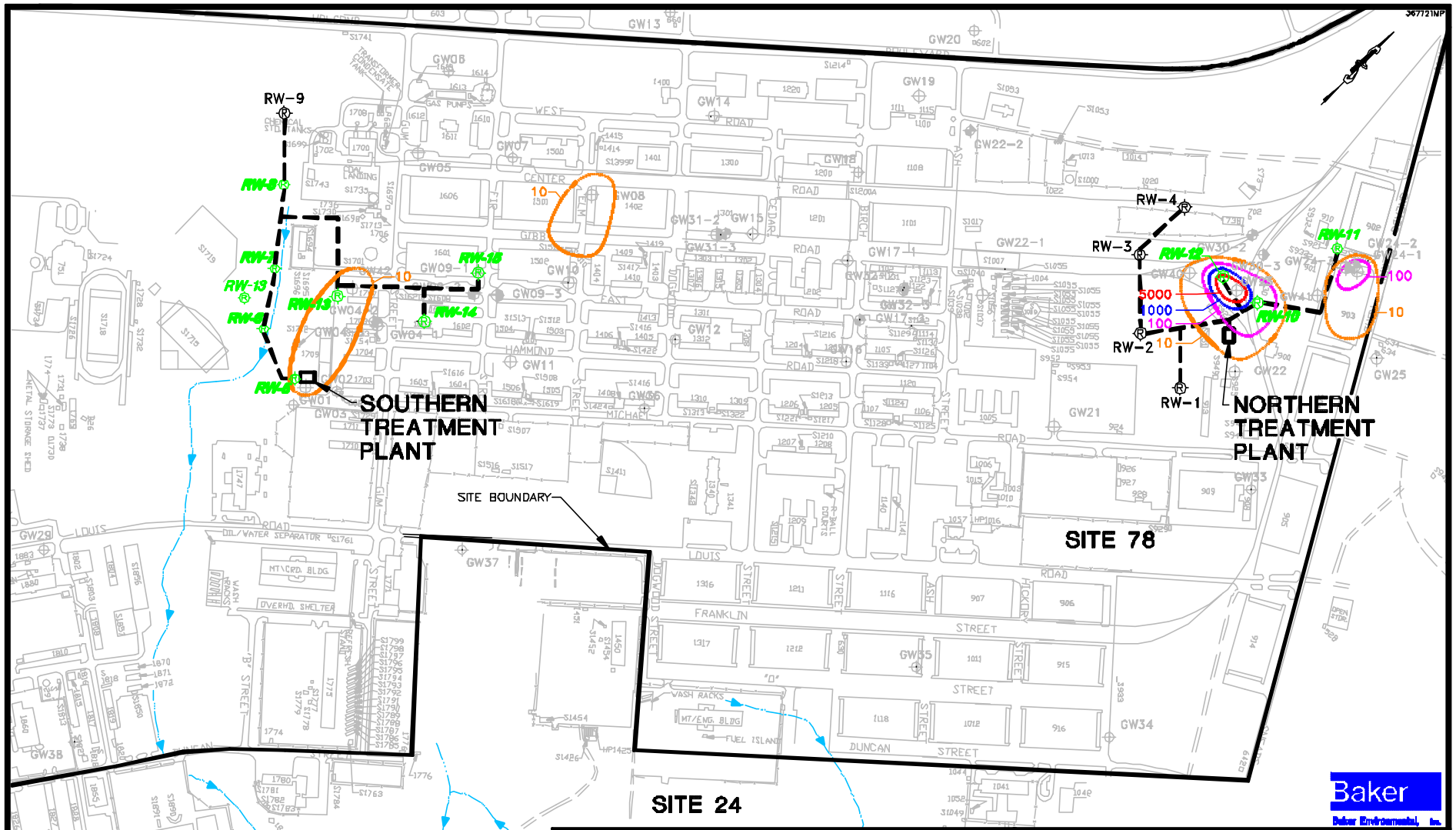
In addition to the VOC plumes addressed by the OU1 North P&T system, fuel contamination exists in the soil and groundwater at OU1. This area is known as the Hadnot Point Fuel Farm (HPFF). Currently, a soil vapor extraction/air sparge system and a bioventing system are in place to address this contamination. The HPFF is not addressed in this report except as it relates to the north and south VOC plumes at OU1. Figure 3-3 is a plan view of OU1 indicating the location of both the northern and southern P&T systems as well as the HPFF systems.

In addition to treating groundwater extracted at OU1, the northern treatment system is also used to treat investigation derived waste (IDW) and Aggressive Fluid Vapor Recovery (AFVR) wastes.

3.3.1 Description of Extraction and Monitoring Well Networks at OU1 North—The North P&T system at OU1 currently includes three active extraction wells (RW-10, RW-11, and RW-12) and four inactive extraction wells (RW-1, RW-2, RW-3, and RW-4). The network was initially designed as part of an interim remedial action. Four wells (RW-1 through RW-4) were installed downgradient of the contaminant plume to intercept and recover groundwater from the upper portion of the surficial aquifer as the plume migrated toward the southwest in the direction of groundwater flow. However, as shown in Figures 3-2a through 3-2c, the plume appears to have stabilized, and thus never reached wells RW-1 through RW-4. Wells RW-1 through RW-4 were removed from service in 1996 due to the low concentration of contaminants present in the extracted groundwater.

Subsequently, two additional wells (RW-10 and RW-11) were installed in areas of the plume where high concentrations of VOCs were detected. In 1998, wells RW-10 and RW-11 were reinstalled to increase extraction effectiveness, and well RW-12 was installed within another area of the plume where high concentrations of VOCs were detected.

All wells are screened in the upper portion of the surficial aquifer. The wells are constructed with six-inch diameter stainless steel casing and wire-wrap screen. Each well is 35 feet deep with 25 feet of 10- or 20-slot screen surrounded by a quartz sand filter pack. A pneumatically operated submersible pump is set within three feet of the bottom of each well. Measurements made in the latter half of 1998 indicate that a pumping rate of approximately one-gallon per minute was resulting in a drawdown of about one foot in each well.



LEGEND

- RW-1 OFF-LINE RECOVERY WELL
- RW-4 ON-LINE RECOVERY WELL
- APPROXIMATE DIRECTION OF SURFACE WATER FLOW
- SITE BOUNDARY
- 10 ISOCONCENTRATION LINE (ug/L)

500 0 250 500
1 inch = 500 ft.

FIGURE 3-3.
NORTHERN AND SOUTHERN TREAMENT SYSTEMS
OPERABLE UNIT No. 1 – SITE 78
MONITORING AND O&M SUPPORT, CTO-0367
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

A network of 18 shallow monitoring wells (screened at depths between 5 and 25 feet), two intermediate depth monitoring wells (screened at depths between 55 and 75 feet), and two deep monitoring wells (screened at depths between 130 and 150 feet) monitors groundwater quality throughout Site 78 to determine if groundwater contaminants are still present, have migrated, are degrading naturally, or have been removed by extraction wells (Baker, 1999a). The monitoring well locations at Site 78 are illustrated on Figure 3-1.

3.3.2 Description of Aboveground Treatment Train at OU1 North—A schematic of the aboveground groundwater treatment plants at OU1 is presented in Figure 3-4. The following describes the treatment process at the northern plant.

Groundwater Influent Flow. Groundwater from the wells is pumped to an oil/water separator where light non-aqueous phase liquids (LNAPL) can be separated from the water. The LNAPL may be transferred to a storage tank. No LNAPL has been collected to date. Since initial operation, a calcium sequestering system has been added to the process stream to control scaling.

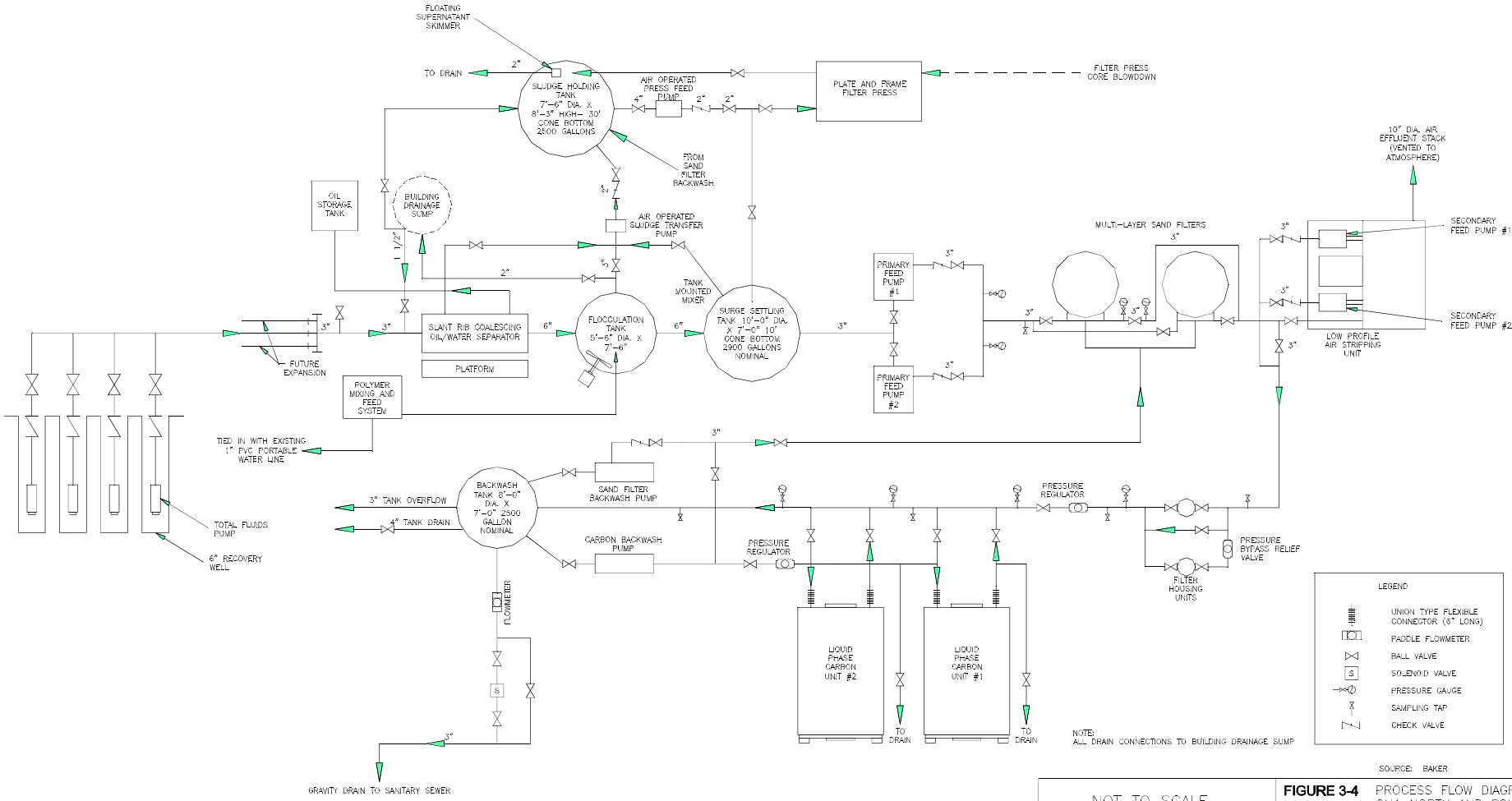
Flocculation and Filtration. Water from the oil/water separator is then directed to a flocculation tank where a polymer may be added to aid in the removal of suspended soils. The polymer system is not currently being used. Sludge generated from the settled solids may be transferred to a sludge holding tank while the groundwater is pumped through dual multi-media sand filters for removal of solids greater than 20 microns.

Air Stripping. Water from the sand filters is pumped to a low profile air stripper to remove VOCs. The stripper vapor is discharged directly to the atmosphere.

Filtration and Granular Activated Carbon (GAC) Adsorption. The water effluent from the air stripper is directed through a cartridge filtration system to remove additional fines greater than 10 microns. Following filtration, the water is sent through GAC for polishing.

Treated Effluent Storage and Discharge. The treated water is stored in the treated water/backwash tank. From this tank, water is stored for use in backwashing the multi-media filters and carbon units, or the water is discharged to the sanitary sewer.

Instrumentation and Control System. The system is designed to operate with minimal operator attention. A programmable logic controller (PLC) is used to control the OU1 treatment plant. During normal operation, most of the equipment functions automatically based on level sensor input. The PLC contacts the operator via an autodialer when an alarm is triggered. Audible and visible alarms are in place to alert operators to changes in the process that are considered critical. These critical alarms may also be transmitted via autodialer. A summary of the normal operation and status of the instrumentation and control system (manual and/or controlled by the PLC) is provided in Table 3-5.



SOURCE: BAKER

NOT TO SCALE

RADIAN INTERNATIONAL
A DAMES & MOORE GROUP COMPANY

FIGURE 3-4 PROCESS FLOW DIAGRAM OU1 NORTH AND SOUTH GROUNDWATER TREATMENT PLANT

OPERABLE UNIT NO. 1

DRAWING NO.	CONTRACT NO.	DATE
lej99088.dwg	803016.0402	06/23/99

990112C-KL-RTP

Table 3-5. Summary of the OU1 Groundwater Treatment Plants Instrumentation and Control System

Process	Normal Operation
Polymer feed system	Automatic with manual adjustments.
Oil/water separator and oil recovery	Automatic with no adjustments required.
Flocculation tank	Automatic with manual adjustments to mixer.
pH probe	Automatic with periodic calibration.
Surge settling tank and primary feed pumps	Automatic with no adjustments required.
Multi-media filters	Automatic with automatic backwash (timer).
Air stripper and secondary feed pump	Automatic with adjustments required.
Cartridge filters	No adjustments required; manual change-out.
Liquid phase GAC	Manual backwash.
Sludge holding tank	Manual transfer of solids from the flocculation tank and surge settling tanks; automatic feed from multi-media filter backwash. Manual transfer of sludge to the dewatering press.
Sludge dewatering press	Manual activation.
Building drainage sump	Automatic.

3.3.3 Design Specifications and Parameters for OU1 North—The system was designed to collect and treat contaminated groundwater and to mitigate the potential for off-site contaminant migration. The remedial objective for this system as stated in the ROD is to restore groundwater quality. The treatment plant was designed to run automatically with the help of the instrumentation and controls built into the system. The design maximum flow for the north system is 80 gallons per minute (gpm). The design normal flow for each well was 5 gpm from a maximum of 16 extraction wells (present and future). The treatment plant is designed to remove free product, VOCs, and metals concentrations to below the federal and/or North Carolina groundwater standards for discharge into the sanitary sewer system. The standards for each COC are listed in Table 3-6.

Table 3-6. Effluent Standards for the OU1 Treatment Plants

Contaminant of Concern	North Carolina* Water Quality Criteria for Groundwater (µg/L)	Federal Primary Drinking Water MCLs (µg/L)	North Carolina* Water Criteria for Fresh Surface Water (µg/L) Class C Waters	North Carolina* Water Quality Criteria for Tidal Salt Waters (µg/L) Class SC Waters
TCE	2.8	5	92.4(4)	92.4(4)
1,2-DCE	--	70	--	--
Vinyl Chloride	0.015	2.0	--	--
Benzene	1	5	71.4(4)	71.4(4)
Antimony	--	6	--	--
Arsenic	50	50	50(1)	50(1)
Beryllium	--	4	.117(4) 6.5(1)	.117(4)
Chromium	50	100	50(1)	20(1)
Iron(5)	300	300(6)	1000(7)	--
Lead	50	15(3)	25(1)	25(1)
Manganese	50	50(6)	--	--
Mercury	1.1	2	0.012(1)	.025(1)
Nickel	150	100	88(1)	

* From NC Administrative Code 15A NCAC 2B.0200.
(1) Protection of aquatic life.
-- = No standard established.
(3) MCL is action level for public water supply systems.
(4) Protection of human health through consumption of fish/shellfish.
(5) The background levels of iron within the Camp Lejeune area are between 160,000 and 684,000 µg/L.
(6) Secondary MCL.
(7) NC Action Level for discharge to fresh waters.

To monitor the performance of the OU1 North treatment plant, samples are collected monthly as shown in Table 3-7.

Table 3-7 Monthly Performance Monitoring for the OU1 Groundwater Treatment Plants

Analytes	Plant Influent	Oil/Water Separator Effluent	Sand Filter Effluent	Air Stripper Effluent	GAC (final) Effluent
VOCs	x			x	x
Metals	x		x		x
TDS	x		x		x
TSS	x		x		x
pH	x				x
Oil & Grease	x	x			x

NOTES:
VOCs = Volatile organic compounds
TDS = Total dissolved solids
TSS = Total suspended solids
pH = Hydrogen Potential

3.3.4 System Upgrades and Modifications for OU1 North—Since initial operation, a calcium sequestering system has been added to the process stream to control scaling. Upon assuming responsibility of the OU1 North groundwater P&T system in December 1996, the operation and maintenance (O&M) contractor conducted a comprehensive system review and repair project to restore treatment efficiency and minimize long-term operation and maintenance costs. North treatment plant repairs included:

- Replacing coalescing media for the oil/water separator with larger media;
- Cleaning bag filters, discharge tank, flocculation tank and surge tank;
- Repair of flow meters;
- Repair of air compressors;
- Repair of transfer pump seals and impellers;
- Replacement of sand and cleaning of sand filters;
- Cleaning and repair of air stripper;
- Modification and repair of filter press;
- Replacement of pneumatic pump controllers;
- Replacement of activated carbon media;
- Repair of electric heaters; and
- Replacement of malfunctioning valves.

3.4 OU1 North Good Management Practices

This section is intended to highlight good management practices that have already been implemented by Camp Lejeune and its O&M contractors. The following are considered good O&M management practices:

- Upon assuming responsibility of the OU1 North P&T system in December 1996, the O&M contractor conducted a comprehensive system review and repair project to restore treatment efficiency and minimize long-term operation and maintenance costs. System repairs included repair of flow meters, repair of the air compressors, repair of transfer pump seals, cleaning of sand filters, cleaning and repair of the air stripper, replacement of activated carbon media due to clogging, and replacement of malfunctioning valves.
- The O&M contractor replaced piston-type air compressors with rotary screw type compressors to achieve improved uptime and reduced maintenance cost.
- The treatment system at OU1 North is used to treat IDW and AFVR wastes. This results in cost savings over off-site disposal of these wastes.
- The O&M contractor has added one new extraction well in the hot spot zone within the OU1 North area to allow for more aggressive contaminant mass removal.

3.5 OU1 North System Performance Evaluation

The overall technical and cost-effective performance for the OU1 North treatment system in comparison to its design and remedial action objectives is relatively poor. As described in subsequent Sections 3.5.1 and 3.5.2, the OU1 North plant and associated extraction system demonstrate the following characteristics:

- Influent flowrates of less than 10% of design capacity;
- Extremely low contaminant mass removal, i.e., approximately 12 pounds of cumulative mass removed over 2.5 years of operation;
- Poor cost-effectiveness, as evidenced by an average cost per pound of contaminant removed of $27,000;
- Significant system downtime and associated maintenance and repair costs; and
- Little evidence to suggest that aquifer restoration to ROD-specified cleanup levels can be achieved by the system in its current configuration and mode of operation.

3.5.1 OU1 North System Performance Plots— Figures 3-5 through 3-9 are cost and performance plots for the period of September 1996 through March 1999 for the OU1 North treatment system. Taken collectively, they provide valuable information on the current and historical performance baseline for this system, and are discussed below:

- **Figures 3-5 and 3-6, "Influent VOC Concentrations vs. Time":** As shown in Figure 3-5, the monthly total VOC influent concentration has remained below 1.0 mg/l with the exception of three months where concentrations spiked, probably due to discrete "slugs' of contamination entering the extraction well network. Figure 3-6 shows the influent trends with these three events removed. Although the influent concentration appears to be trending upward, this effect is due to the installation of new extraction wells in areas of higher concentration in mid-year 1998. In reality, the total VOC influent concentrations have remained relatively low and stagnant, i.e., in the range of 100-400 ppb.
- **Figure 3-7, "Cumulative Mass Recovered vs. Time":** The total mass removed by the OU1 North system is approximately 12 pounds, and approximately half of this amount was removed in only 3 months time (October through December 1998). This removal coincides with the influent concentration spike shown in Figure 3-5. When this factor is considered, it took the OU1 North System some 27 months to remove the remaining 6 pounds of contamination, or approximately 0.22 pounds per month.

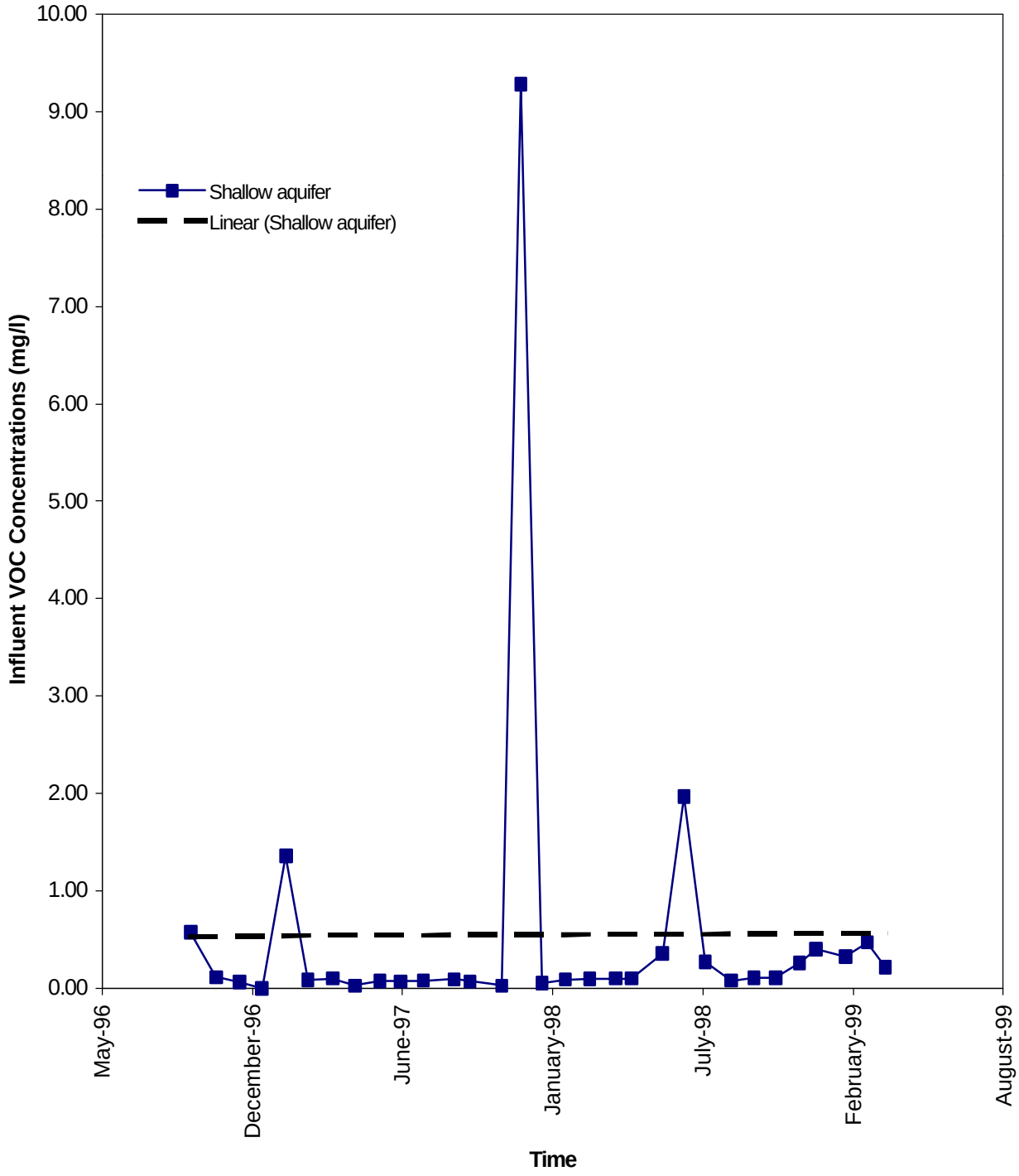


Figure 3-5. Influent VOC Concentrations vs. Time OU1 (Site 78) - North Plant

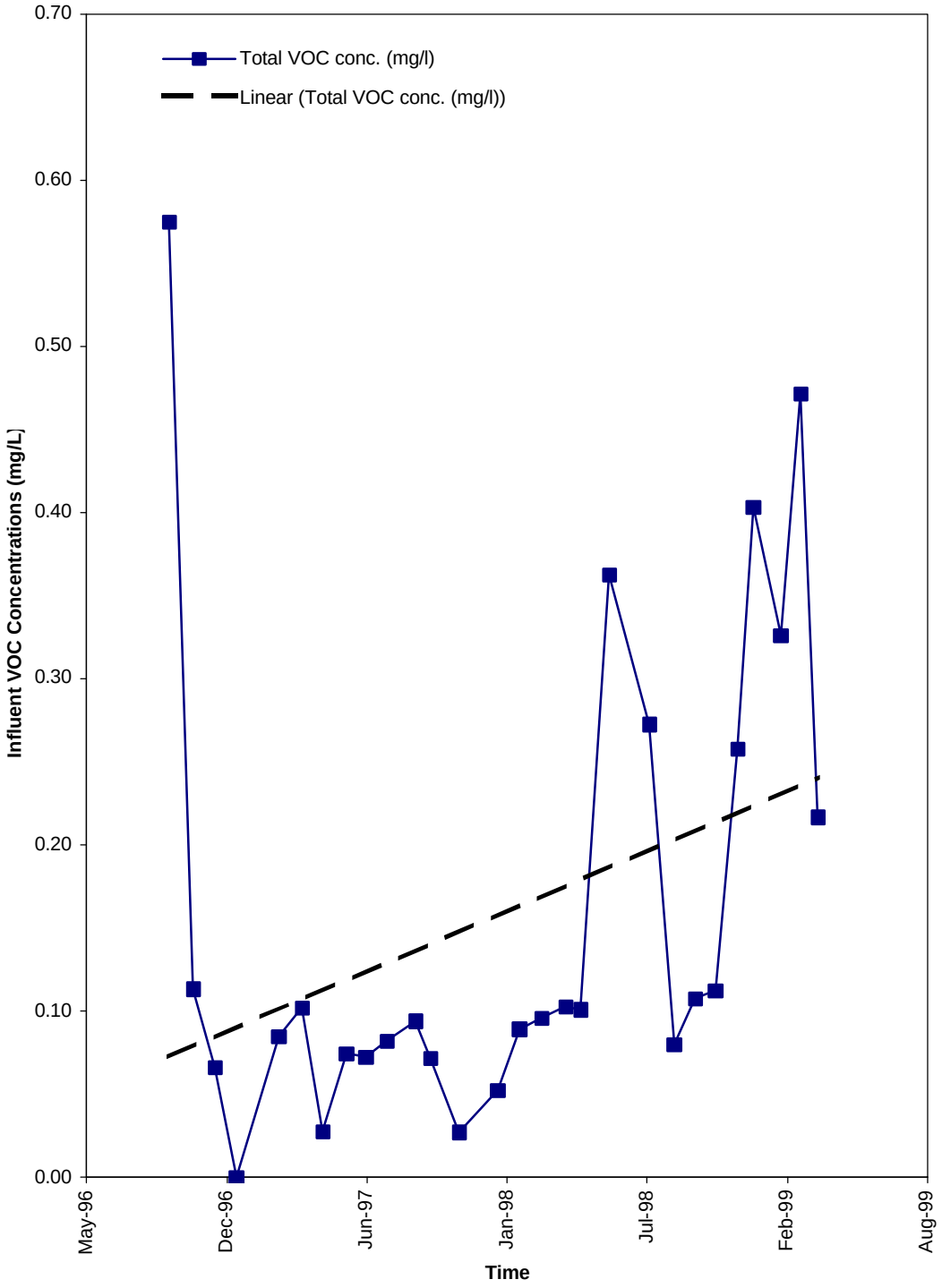


Figure 3-6. Influent VOC Concentrations vs. Time OU1 (Site 78) - North Plant. (concentration spikes removed)

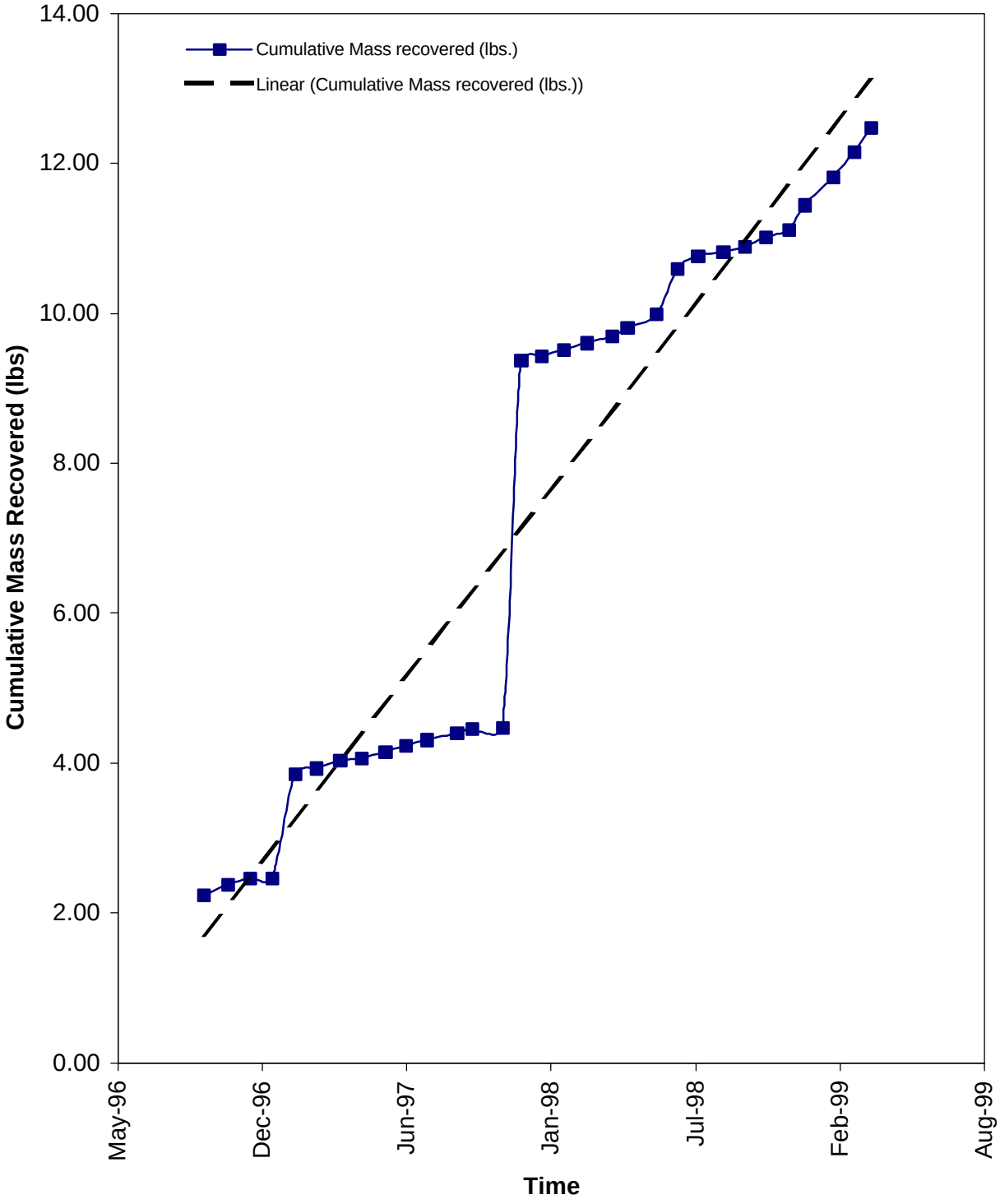


Figure 3-7. Cumulative Mass Recovered vs. Time OU1 (Site 78) - North Plant

- **Figure 3-8, "Cumulative Costs vs. Cumulative VOCs Recovered":** Figure 3-8 graphically demonstrates the minimal cost effectiveness of the OU1 North system. Two portions of this graph show areas where cumulative costs increase rapidly for very little mass removal. In particular, the following observations can be made: (a) approximately $200,000 of cumulative costs were expended to remove the first four pounds of contamination, (b) six more pounds of contamination were removed for less than $10,000, and (c) $220,000 were expended to remove an additional 2.5 pounds of contamination. In summary, more than $400,000 was expended to remove only 6.5 pounds of contamination.
- **Figure 3-9, "Average Cost Per Pound Recovered vs. Time":** The OU1 North system's average cost per pound of contaminant removed for the entire operating period is approximately $27,000. As shown in the figure, the average monthly cost increased from $5000 to $42,000 per pound during the first year of operation; and then dropped dramatically to $20,000 per pound due to the concentrated mass removal associated with the "spike" influent event in late 1997. Since January 1998, the cost per pound removed has steadily increased to the March 1999 value of almost $35,000. The high cost per pound removed is a direct result of low influent flowrates and contaminant concentrations.

Table 3-8 summarizes selected performance parameters for the system.

Table 3-8. OU1 North System Design Versus Performance Data

Parameter	Design	Actual Average[a]	Actual Median[a]
Aquifer Average Flowrate (gpm)	15	2.74	2.87
Monthly Aquifer Volume (gallons)	3,456,000	115,431	113,810
Monthly Mass removed (lbs)	N/A	0.40	0.09
Average cost per mass removed ($/lb)[b]	N/A	$27,217	$28,277

[a] Based on performance data from September 1996 through March 1999.
[b] Capital costs were not included.

NOTES:
gpm = gallons per minute
lbs = pounds
N/A = not applicable

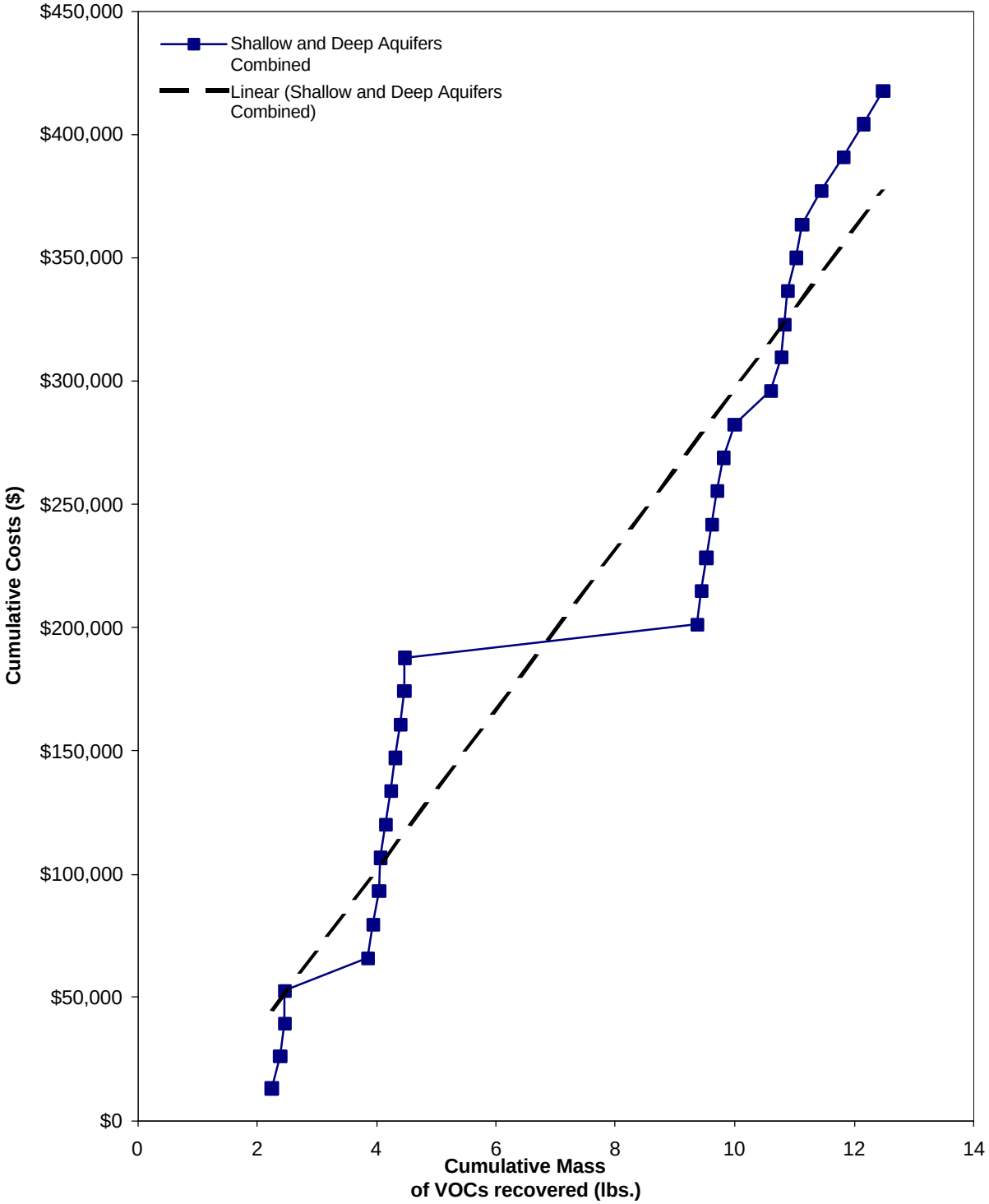


Figure 3-8. Cumulative Costs vs. Cumulative VOCs Recovered OU1 (Site 78) - North Plant.

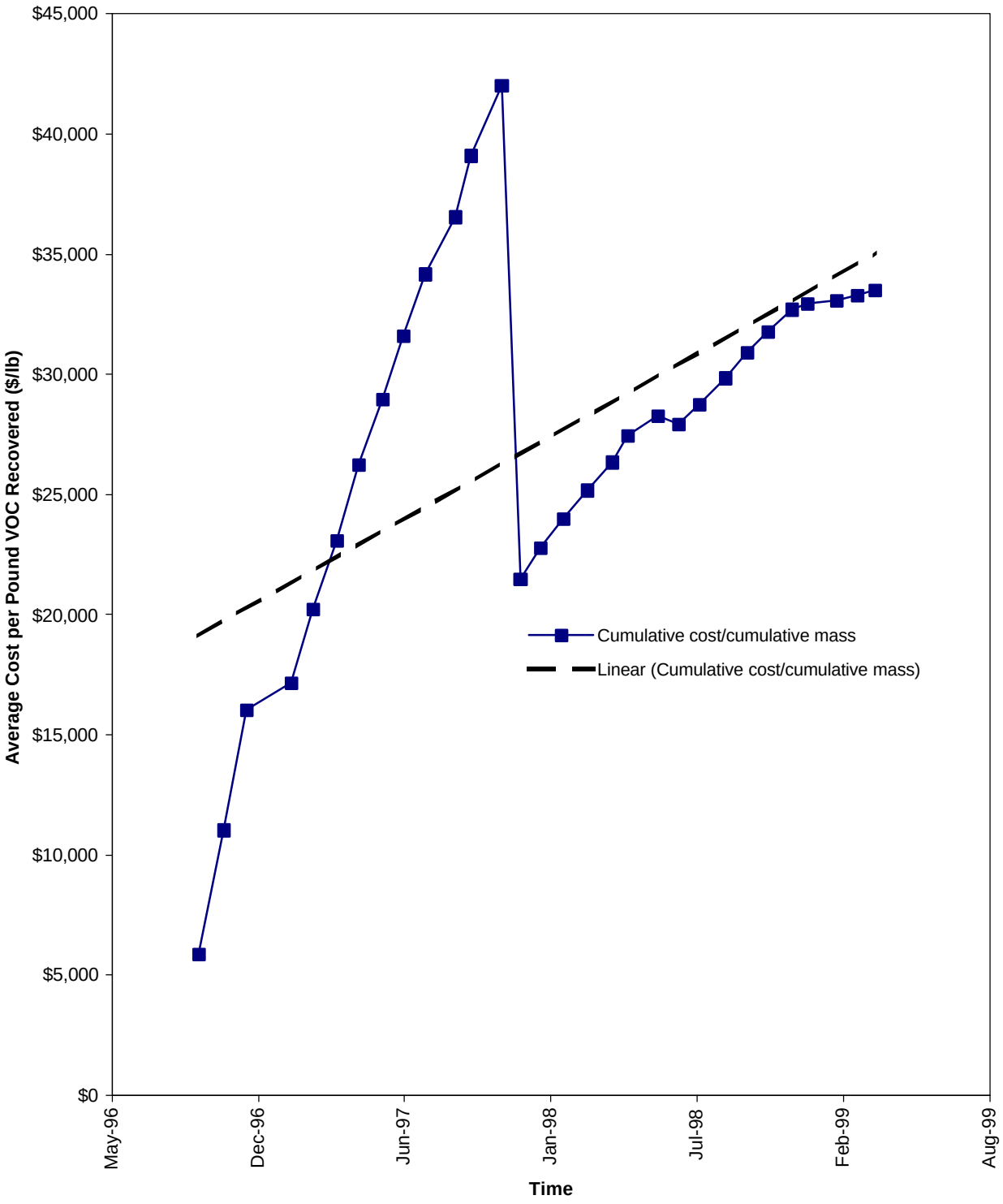


Figure 3-9. Average Cost Per Pound Recovered vs. Time OU1 (Site 78) - North Plant

3.5.2 OU1 North Extraction and Monitoring Well Network Performance—The ROD for OU1 specifies that the pump and treat systems at Site 78 operate until the remediation levels for the groundwater COCs are met. Inherent to any pump and treat system designed to restore groundwater quality are the dual objectives: to hydraulically contain contaminated groundwater and to remove sufficient contaminant mass to achieve remediation levels. Progress toward meeting the objectives is a measure of extraction well network performance that can be quantified by measuring the following parameters:

- Hydraulic heads and gradients;
- Extraction rates;
- Extracted water quality; and
- Contaminant concentration.

This section addresses the performance of the extraction well network at the OU1 North treatment system against these parameters. It also identifies data gaps in the current monitoring well network which hinders effective performance monitoring.

Data Gaps

The following data gaps were identified in evaluating the performance of the extraction and monitoring well networks at the OU1 North P&T system. Although these data gaps may be significant within the performance criteria framework of the OU1 ROD, their presence does not hinder or alter the OU1 North system performance conclusions and recommendations contained in this report.

- The number and location of LTM points for water level measurements is inadequate to verify plume containment in three dimensions;
- The number and location of LTM sampling points is inadequate to define complete extent of the contaminant plume;
- Pumping rates for the individual extraction wells are not measured; and
- Contaminant concentrations have not been measured in samples from the individual extraction wells. However, we understand that samples will be collected from individual wells beginning January 2000.

Hydraulic Head and Gradients

Water levels measured at OU1 in July 1998 did not demonstrate that the North P&T system has established a capture zone in three dimensions within the surficial aquifer. Rather, the measurements available indicate that groundwater in the area of the North contaminant plume was flowing in the general direction of the natural gradient across Site 78. In addition, the only well cluster installed near the North plume (wells 78-GW24-1, 78-GW24-2, and 78-GW24-3) indicates that a downward gradient exists between the surficial and the Castle Hayne aquifers.

Extraction Rates

Based on the volume of water extracted in the last half of the year, the North P&T system removed approximately 0.03 pore volumes of groundwater in 1998. This performance is poor when compared to typical extraction well-field design criteria of 0.3 to 2 pore volumes per year (Cohen et. al., 1994).

The inability of the extraction well network to meet the minimum design criterion is attributed primarily to the low permeability of the surficial aquifer, which precludes pumping at higher rates. The feasibility study for the North P&T system estimated that each extraction well in the network would yield three to five gallons per minute (Baker, 1994a). However, during the last six months of 1998, the average yield of RW-10 was slightly more than two gallons per minute. Due to the limited potential of the surficial aquifer to yield water, approximately 10 additional extraction wells would be required to remove 0.3 pore volumes of contaminated water per year.

Groundwater extraction and treatment at the North treatment plant has been inconsistent. In the latter half of 1998, extraction well RW-11 was inactive due to the production of excessive clay, leaving only extraction well RW-10 operational. Reinstallation of wells RW-10 and RW-11 plus routine maintenance of the system also resulted in 636 hours of downtime during the latter half of 1998. These operations and maintenance problems combined with already low pumping rates have further limited the effectiveness of the system.

Extracted Water Quality

Historical data from the North treatment plant indicate that the median VOC concentration of the influent is about 0.1 mg/L. However, several peaks in the record contribute to a higher mean concentration of 0.57 mg/L. Excluding the peaks, the influent concentration exhibits a range between 0.07 and 0.11 mg/L. The low influent concentration over much of the period of record indicates that the extraction wells are not located in the most contaminated areas of the plume and, therefore, are inefficient in removing contaminants. More effective well placement requires installing extraction wells in the areas of highest contamination; along the plume axis; and in areas of the least mobile contaminants to collectively maximize mass removal, reduce the pumping of clean water, and minimize contaminant travel time.

Contaminant Concentration and Distribution

The areal extent of VOCs in the surficial aquifer, depicted by isoconcentration contour maps (Figures 3-2a through 3-2c) that represent different sampling events, appears to be constant. The concentrations of total VOCs and individual compounds in 78-GW23, the most contaminated well in the North contaminant plume, also appear relatively constant but well above remediation levels. Consequently, little progress toward achieving active groundwater restoration is evident in the data. However, a plume that is unchanging in size and position is one line of evidence that natural attenuation processes may be occurring.

Potential Evidence of Natural Attenuation

As stated above, natural attenuation is potentially occurring if a plume is stable or receding. Another line of evidence that natural attenuation may be occurring can be found in several geochemical indicators. Of these, the best evidence that natural attenuation is occurring at the North contaminant plume is the presence of 1,2-dichlorethene and vinyl chloride in samples collected from site monitoring wells. Both compounds are sequentially reduced from trichloroethene in the anaerobic biodegradation process of reductive dechlorination.

The presence of BTEX, which can serve as a carbon source, in the North contaminant plume is a second indicator that reductive dechlorination can potentially occur. However, a third indicator, dissolved oxygen, is present in the North contaminant plume at concentrations that exceed levels generally accepted as the minimum for reductive dechlorination. The measured concentrations are, nevertheless, favorable for the oxidation of vinyl chloride. Other geochemical indicators used in screening natural attenuation potential are not included in the LTM program, but should be measured during the MNA assessment that is recommended in Section 4.

3.5.3 OU1 North Aboveground Treatment Train Performance—Since upgrades by the O&M contractor, the equipment in the aboveground treatment train for the northern plant at OU1 has been performing at a level that meets requirements of the design basis. However the plant is operated at less than 5% of full capacity due to the limited number of wells and low groundwater extraction rate from the aquifer. In addition, all extracted groundwater is routed through the oil/water separator and the flocculation tank; however, this routing is unnecessary because of the absence of free product or high levels of suspended solids. The polymer system is also not used for suspended solids flocculation.

Over the last 31 sampling events (September 1996 to March 1999) presented in the “Groundwater Treatment Plant (OU1) Monthly Monitoring Results” (OHM, 1996-1999), with the exception of one instance in May 1998, every sample collected from the air stripper effluent had concentrations below the effluent standards presented in Table 3-6. Because the air stripper effluent sample exceeded samples for both OU1 North and South during the same month (May 1998), this indicates that a sampling or analysis error may have occurred. All samples collected over this same period from the GAC effluent have been below the effluent standards. Two 2,000-pound GAC units are currently used to provide polishing of the groundwater effluent prior to discharge to the sanitary sewer. Cartridge filters are used to remove fines from the groundwater prior to the GAC units to avoid clogging the units. However, the amount of contaminant removal by these units is minimal, as the air stripper removes all detectable amounts of the VOCs. The GAC units (and cartridge filters) are not necessary for the removal of contaminants from the effluent, but are required only by the current NPDES permit requirements.

During the O&M contractor’s comprehensive system review in 1996, the autodialer alarm for the air stripper blower was malfunctioning. At that time, this alarm was disconnected. The PLC alarm for the air stripper blower was still functioning and would shut down the system and trigger other active autodialer alarms. This arrangement is considered adequate for alerting operators of system problems.

A calcium sequestering system has been added to the process stream to control scaling. In addition to treating groundwater extracted at OU1, the northern treatment system is also used to treat IDW and AFVR wastes.

Based on records beginning in January 1997, the O&M contractor has performed routine monthly maintenance on the OU1 northern treatment plant as required in the *Hadnot Point Shallow Aquifer Groundwater Treatment System Operations and Maintenance Manual* (OHM, 1997a). During 1997 and 1998, the treatment plant operated a total of 319 days each year for an annual operating percentage of 87%. However, this percentage of uptime does not take into account the fact that the treatment system routinely cycles on and off throughout each operating day due to low groundwater extraction rates. There is not enough flow to keep the air stripper running continuously, so the flocculation tank is used as a surge tank, and the system cycles on and off as needed to treat the accumulated groundwater. Consequently, the treatment system actually runs for only 5% of the time.

Downtime during 1997 and 1998 resulted from a variety of events including redrilling of extraction wells, malfunction of valves, cleaning of the air stripper, and the circuit breaker being tripped.

A review of the existing sampling and analysis plan indicates that the oil and grease analysis of the oil/water separator effluent is not required as the oil/water separator has not removed any product to date. Also noted is that the plan does not call for the individual influent from each well to be sampled. Note that the individual wells will be sampled beginning January 10, 2000 (Baker, 2000).

The annual operations and maintenance costs for the OU1 North Groundwater P&T system are provided in Table 3-9. Detailed line item operation and maintenance costs, along with system capital costs, were not available for review.

Table 3-9. Annual Operations and Maintenance Costs for the OU1 North Groundwater P&T System

Fiscal Year	Annual Operations Costs (North & South)	Annual Maintenance Costs (North & South)	North Plant Annual Utilities	North Plant Annual Costs	North Plant Monthly Costs
1999	$225,000	$50,000	$10,111	$147,611	$12,301
1998	$223,083	$333,497	$8,929	$287,219	$23,935
1997	$117,497	NA	$9,069	$67,818	$5,651
1996	$115,000	$171,586	$14,593	$157,886	$13,157
1995	$94,850	NA	$6,096	$53,521	$4,460

NA = not applicable

4.0 CONCLUSIONS AND RECOMMENDATIONS FOR OU1 NORTH P&T SYSTEM

A major obstacle to meeting ROD-specified remediation levels at OU1 North through active groundwater extraction is the low permeability of the surficial aquifer. Although the aquifer's permeability has apparently limited the migration of the plume, it also limits the capability of the extraction wells to remove contaminant mass through active pumping. Even with recent modifications to two extraction wells and the installation of a third, the likelihood of restoring groundwater quality through active pumping is minimal. Given this physical limitation of the site, increasing the number of extraction wells will provide only marginal improvement toward mass removal. Furthermore, a decision to install additional extraction wells should not be made unless it can be proven that the plume is still increasing in size. As previously indicated, it is likely that the North plume has already stabilized due to natural attenuation processes in the surficial aquifer. Consequently, the following recommendations for the OU1 North System are made.

4.1 OU1 North Optimization Recommendations

Based on the information reviewed and presented in Section 3.0, several primary recommendations can be made for the OU1 North P&T system. Complete implementation of these recommendations will likely require an Explanation of Significant Difference (ESD) or a ROD amendment to the current OU1 ROD.

1. Perform a monitored natural attenuation (MNA) assessment on the OU1 North plume, according to established DoD and EPA protocols.
2. In parallel with recommendation 1, continue to operate the OU1 North P&T system on an interim basis until contaminant mass removal from extraction wells RW-10, 11, and 12 reach asymptotic levels.
3. Shut down the OU1 North system upon achievement of objectives in recommendation 2.
4. Should state guidelines be changed to permit risk assessment, consider revising the baseline human health risk assessment assumptions and associated cleanup level calculations to reflect an industrial future land use category as the most probable scenario. Prior to conducting a comprehensive risk assessment, perform preliminary calculations to determine if the potential results of the risk assessment justify the effort.
5. If MNA does not prove feasible as the long-term remedy for OU1 North, consider applying remedial options currently in use at HPFF, along with enhanced biodegradation remedies. These alternative remedies could include AS/SVE and application of hydrogen releasing compound (HRC).
6. Leverage the performance assessment within this report, as well as the data and information from implementation of the above recommendations, as the foundation for the upcoming five-year review at OU1.

In addition, detailed recommendations are provided to help optimize the OU1 North P&T system during its interim operation period. Several of these recommendations may also be applicable for future remedial actions. All recommendations for the extraction and monitoring well network and the aboveground treatment trains for the OU1 North P&T system are summarized in Table 4-1.

4.1.1 OU1 North Extraction and Monitoring Well Network Recommendations—The following are recommendations for the extraction and monitoring well networks associated with the North treatment plant at OU1. Although the recommendations are likely to increase expenditures for monitoring over the short term, it is anticipated that these expenditures will result in long-term savings either by identifying actions for improving system performance or by justifying an alternative approach.

- Conduct screening for MNA by adding relevant analytical parameters to the current monitoring program.
- Evaluate the effect of new extraction well RW-12 and modified wells RW-10 and RW-11 on increased contaminant mass removal by collecting water quality samples from each well and analyzing for COCs to monitor concentrations and mass removal. Subsequently, prepare graphs of cumulative mass removed relative to recovery time and relative to cumulative pore volumes extracted.
- Continue to monitor both the lower portion of the surficial aquifer and the Castle Hayne aquifer for VOCs, as recommended by the O&M contractor, to determine if VOCs are migrating downward from the upper portion of the surficial aquifer.
- Assess whether the plume is hydraulically contained from hydraulic gradient determinations by measuring water levels in all adjacent monitoring wells, including deep wells, and in the four inactive extraction wells. Water quality samples should also be collected from these wells and analyzed to evaluate effects on VOC migration from active hydraulic containment or stabilization by natural attenuation processes.
- On the basis of the routine sampling results, prepare contour maps that illustrate the concentration and extent of individual COCs in groundwater relative to their remediation levels. A map of total VOC concentration distributions provides a general perspective of the plume, but can not be used to compare with remediation targets.
- Prepare time series graphs of individual COC concentration changes with time to examine trends in water quality within and outside the plume.

Table 4-1. OU1 North Evaluation and Optimization Summary

System Component	Consideration	Cost Impacts	Effectiveness Impacts
North Extraction System	Evaluate the effects of recent system modifications. • Continue to monitor surficial and Castle Hayne aquifers for VOCs. • Measure water levels in the four inactive extraction wells and in adjoining monitoring wells. • Add the active and inactive extraction wells to the current groundwater monitoring network.	• Increase monitoring labor and analytical costs by $5200/year.	• Determine if system modifications have satisfactorily increased contaminant mass removal rates and improved hydraulic containment; if further modifications are warranted; or, if alternate remedies and remedial goals should be considered.
North Extraction System	Improve performance evaluation database. • Prepare isoconcentration contour maps for individual COCs. • Prepare graphs of individual COC concentration changes over time. • Prepare graphs of cumulative mass removed relative to recovery time and cumulative pore volumes extracted.	• Increase data presentation and evaluation costs by $1600/year.	• Contribute to database necessary for evaluating P&T system performance.
North Extraction System	Conduct preliminary screening for natural attenuation by adding relevant analytical parameters to current monitoring programs.	• Increase labor and analytical costs by $12,000.	• Determine if monitored natural attenuation is a potential alternative remedy that merits detailed evaluation.
North Aboveground Treatment Plant	Bypass the oil/water separator and flocculation tank.	• Decrease in O&M costs by $1,800/year for OU1 North. • Decrease analytical costs by $1,000/year for system.	• Decrease labor associated with cleaning oil/water separator and flocculation tank. • The bypass will eliminate the need to perform oil and grease analysis at one point in the process stream.

Table 4-1. OU1 North Evaluation and Optimization Summary (continued)

System Component	Consideration	Cost Impacts	Effectiveness Impacts
North Aboveground Treatment Plant	Use oil/water separators and flocculation tanks for future remedial action sites at Camp Lejeune.	• No cost impact for OU1. • Potential cost savings for future remedial sites.	• Equipment not needed at OU1.
North Aboveground Treatment Plant	Use the OU1 polymer pumps at the OU2 plant.	• No cost impact for OU1. • Potential cost savings for OU2.	• Equipment not needed at OU1.
North Aboveground Treatment Plant	• Modify NPDES permits to allow GAC bypass for normal operation, or • Perform cost analysis for treatment by GAC alone vs. air stripper alone.	**Cost savings for running air stripper alone:** • Decrease in filter cartridge replacement cost of $800 to 1,000/year for system. • Decrease in labor cost of $5,600/year for OU1 North. • Decrease analytical costs by $1,200/year for system. **Cost savings for running GAC alone could not be identified.**	• Air stripper effluent samples will need to be monitored closely to ensure that effluent discharge standards are met. • Decrease costs associated with back washing and filter replacement. • The bypass will eliminate the need to perform VOC analysis at one point in the process stream.
North Aboveground Treatment Plant	Sample influent from individual wells for VOCs once a quarter. Scheduled to begin in January 2000.	• Increase analytical costs by $2,800/year for the North system.	• Determine the effectiveness of each individual well for removal of contaminants from the subsurface.
North Groundwater Treatment Plant	Recommend increasing response time to circuit breaker trips. Check that autodialer alarms are being activated to alert operator.	• No cost impact.	• Increase in treatment plant up time.

4.1.2 OU1 North Aboveground Treatment Train Recommendations—The following are recommendations for the OU1 North aboveground treatment train. These recommendations are also summarized in Table 4-1.

- As the oil/water separator and flocculation tank are not used for their design purpose, Radian recommends installing a bypass around these to avoid the expense of cleaning the coalescing media and the tanks. The cost savings in labor (approximately 40 hours) is approximately $1,800 annually. This will also reduce the analytical cost by removing the oil and grease analysis after the oil/water separator for annual savings of $1,000.
- Consider using the existing oil/water separator and flocculation tank for future remedial action sites at Camp Lejeune. There would be no cost impact on the OU1 system. Cost savings may be incurred for any future remedial system.
- Consider using an unused polymer pump at OU2. This may alleviate some of the maintenance required for the existing polymer pump at OU2. There would be no cost impact on the OU1 system.
- Based on the air stripper and GAC effluent performance discussed in Section 3.0, we recommend requesting that carbon polishing be modified in the NPDES requirements for discharge to the sanitary sewer; and that the GAC and cartridge filters be bypassed during normal operation. The GAC will be readily accessible if effluent sampling indicates that GAC is needed to reduce effluent concentrations. This will save labor and cost by reducing the amount of back flushing and by eliminating the need for cartridge filter replacement. It is estimated that the annual replacement cost of cartridge filters is $1,000. Reduction in labor (140 hours per year) to backwash carbon and manage sludge generated by back washing will create an annual savings of $5,600. This will also reduce the analytical cost by removing the VOC analysis of GAC effluent for annual savings of $1,200.
- An alternative to removing the GAC polishing is to shut down the air stripper. The flowrates and concentrations are low enough for the effluent to be treated by GAC alone. A cost analysis should be performed to determine whether the total operating cost for the air stripper alone may be more costly than using only GAC for polishing. Detailed costs for the air stripper and GAC operation were not available for this analysis.
- We recommend increasing the response time to circuit breakers being tripped. Check the Autodialer to ensure alarms are being activated to alert the operator.
- We recommend sampling the influent for VOCs from individual wells, once a quarter, to determine the removal effectiveness from each well. This represents an annual cost increase of $2,800. Note that quarterly sampling of influent from individual wells is planned to begin on January 10, 2000 (Baker, 2000).

4.2 OU1 North Recommendations Life Cycle Costs

A life cycle cost analysis was conducted for each of the RAO optimization recommendations for the OU1 North Aboveground Treatment Train. The life cycle cost analysis provides a net present value (NPV) for costs or savings incurred over the life of the operation. The NPV was calculated for operations of 5, 10, and 15 years, assuming a 6% interest rate. Results of the life cycle cost analysis are presented in Table 4-2.

Table 4-2. Life Cycle Cost Analysis for OU1 North Aboveground Treatment Train

Recommendations	Annual Costs				Net Present Value		
	Capital	Labor	Analytical	Total	5 years	10 years	15 years
Continue operation of existing P&T "as is"				$163,102	$687,045	$1,200,445	$1,584,087
Discontinue operation of P&T and implement MNA	$5,000	$15,000	$15,000	$35,000	$126,371	$220,803	$291,367
Bypass oil/water separator and flocculation tank	$0	($1,800)	($1,000)	($2,800)	($11,795)	($20,608)	($27,194)
Use existing oil/water separator and flocculation tank for future remedial action	No cost impact on OU1; cost savings may be incurred for future remedial activities						
Use unused polymer pump at OU2	No cost impact on OU1 system; potential cost savings for OU2						
Bypass the GAC and cartridge filters for discharge to sanitary sewer	($1,000)	($5,600)	($1,200)	($7,800)	($32,856)	($57,409)	($75,756)
Increase response time to circuit breakers	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sample influent for VOCs, quarterly	$0	$0	$2,800	$2,800	$11,795	$20,608	$27,194
Evaluate the effects of recent system modifications	$0	$5,200		$5,200	$21,904	$38,272	$50,504
Improve performance evaluation database	$0	$1,600	$0	$1,600	$6,740	$11,776	$15,540
Conduct preliminary screening for natural attenuation	$0	$12,000		$12,000	$50,548	$88,321	$116,547

(Figures in parenthesis indicate cost savings)

5.0 OU1 SOUTH REMEDIAL SYSTEM ASSESSMENT

5.1 OU1 South Background and Regulatory Framework

This information is identical to that provided for OU1 North in Sections 3.1.1-3.1.3.

5.2 Current OU1 South Conceptual Model and Remedial Action Status

The conceptual model for OU1 South is identical to that described for OU1 North in Section 3.2.

Figures 5-1a through 5-1c illustrate the contaminant plume in the upper portion of the surficial aquifer at OU1 South over time. As with OU1 North, the plume appears to have stabilized, and may indeed be shrinking in size. Once again, this may indicate that natural attenuation processes are at work in the surficial aquifer.

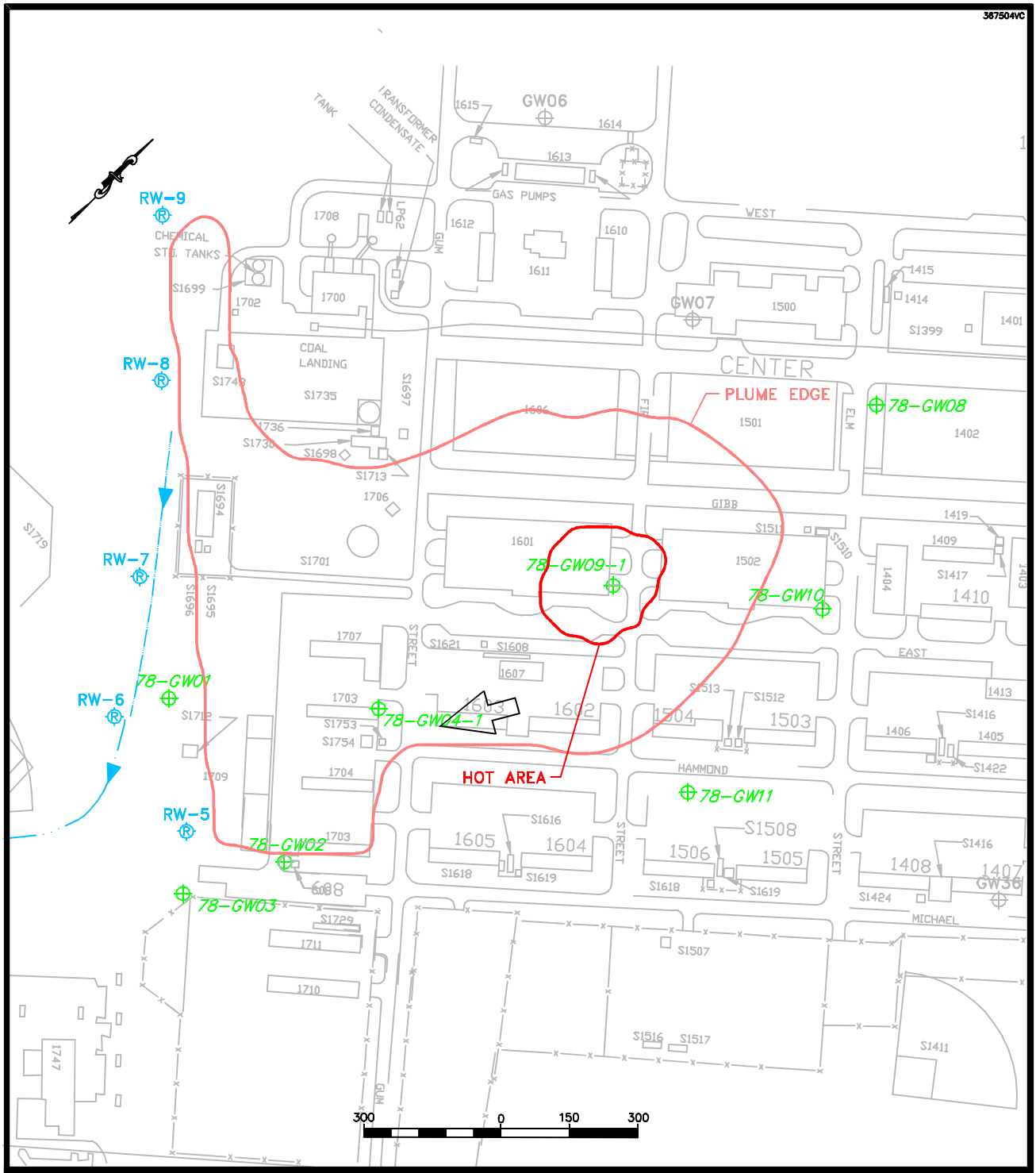
5.3 OU1 South P&T System Description and Design Basis

The groundwater extraction and treatment system at OU1 South has been in operation since January 1995 (OHM, 1998c). The system was designed to collect and treat contaminated groundwater from the uppermost portion of the surficial aquifer in the southern portion of Site 78 at OU1 and to prevent off-site contaminant migration. Contaminated groundwater, extracted via a network of wells, is treated and discharged to the sanitary sewer.

In addition to the VOC plumes addressed by the OU1 South P&T system, fuel contamination exists in the soil and groundwater at OU1. This area is known as the Hadnot Point Fuel Farm (HPFF). Currently, a soil vapor extraction/air sparge system and a bioventing system are in place to address this contamination. The HPFF is not addressed in this report except as it relates to the north and south VOC plumes at OU1. Figure 3-3 is a plan view of OU1 indicating the location of both the northern and southern P&T systems as well as the HPFF systems.

In addition to treating groundwater extracted at OU1, the southern treatment plant is also used to treat surfactant-flushing waste from the Building 25 area. (This treatment is to be terminated as of August 1999.)

5.3.1 Description of Extraction and Monitoring Well Network at OU1 South—The South P&T at OU1 includes seven active extraction wells (RW-5, RW-6, RW-7, RW-8, RW-13, RW-14, and RW-15) and one inactive well (RW-9). The configuration of the well network is illustrated in Figure 3-3. Initially, five wells (RW-5 to RW-9) were installed downgradient of the contaminant plume to intercept groundwater from the upper portion of



LEGEND

- SHALLOW MONITORING WELL
- GROUNDWATER RECOVERY WELL
- GROUNDWATER FLOW DIRECTION

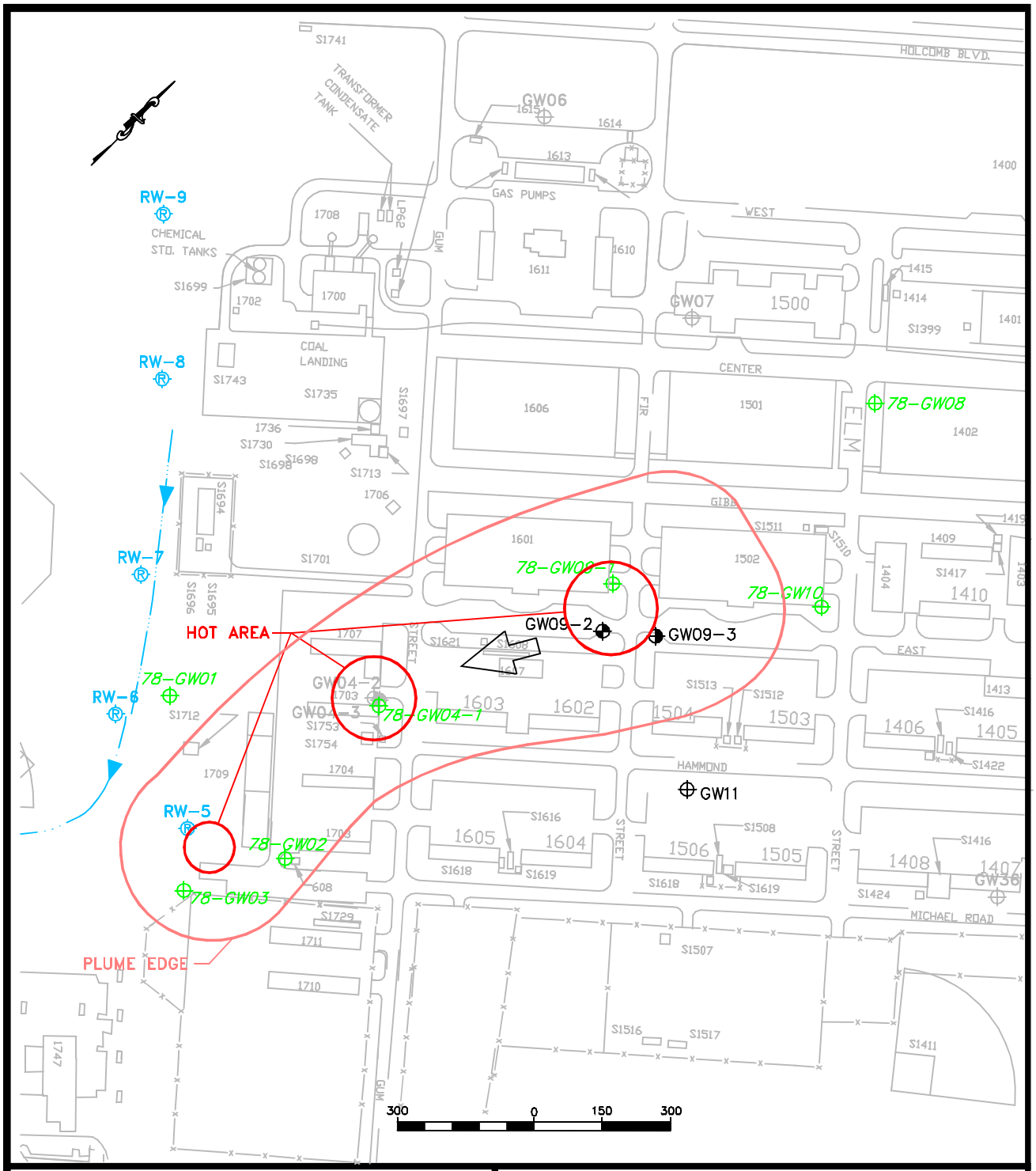
NOTE: PLUME EDGE ~ 10 µg/L
HOT AREA ≥ 1000 µg/L

SOURCE: BAKER

Figure 5-1a. VOC Contaminant Plume at OU1 South Plant, January 1998

RADIAN INTERNATIONAL
A DAMES & MOORE GROUP COMPANY

990104C-KL-RTP



LEGEND

- SHALLOW MONITORING WELL
- GROUNDWATER RECOVERY WELL
- GROUNDWATER FLOW DIRECTION

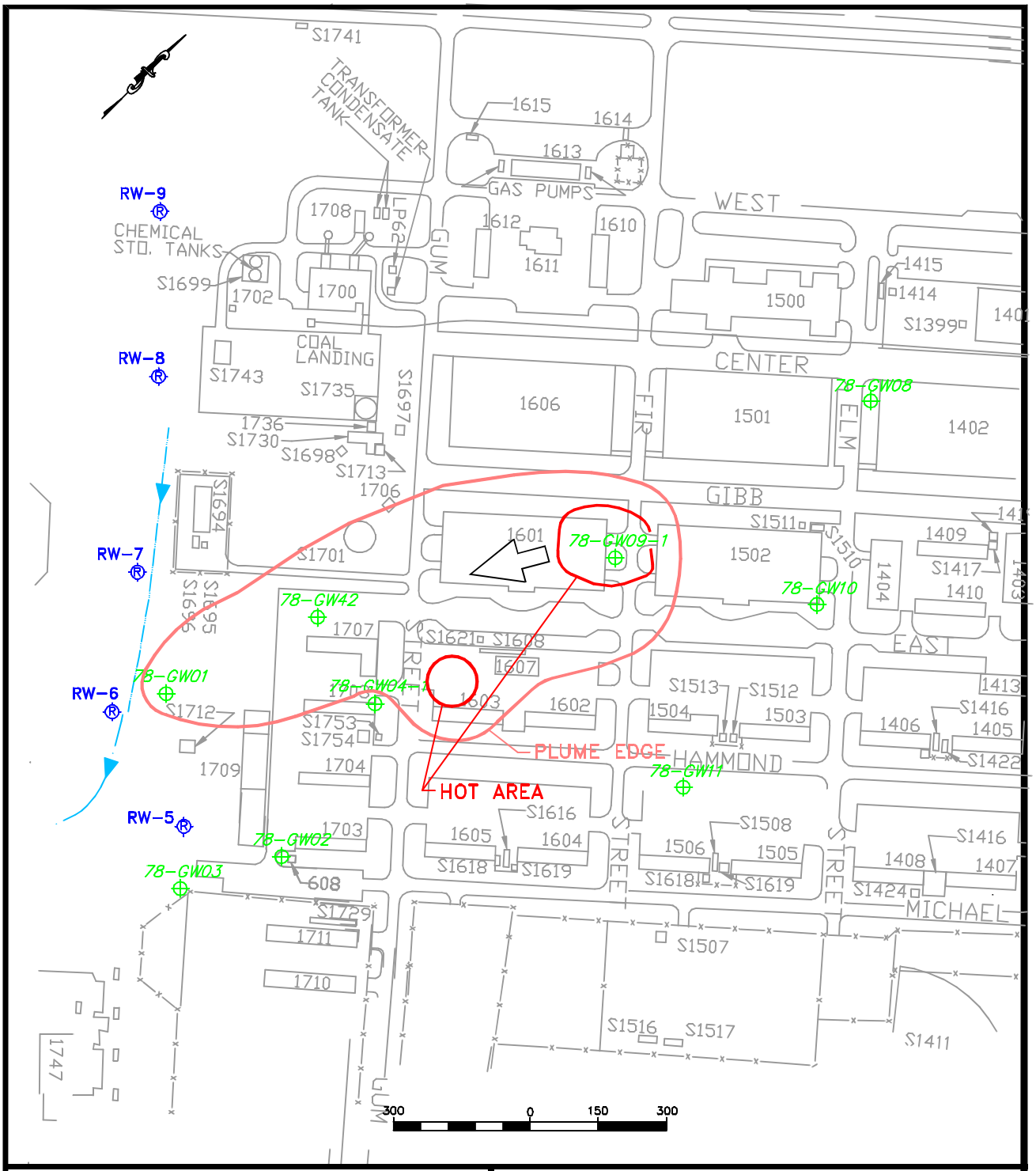
NOTE: PLUME EDGE ~ 10 µg/L
HOT AREA ≥ 1000 µg/L

SOURCE: BAKER

Figure 5-1b. VOC Contaminant Plume at OU1 South Plant, January 1997

RADIAN INTERNATIONAL
A DAMES & MOORE GROUP COMPANY

990104C-KL-RTP



LEGEND

- SHALLOW MONITORING WELL
- GROUNDWATER RECOVERY WELL
- GROUNDWATER FLOW DIRECTION

NOTE: PLUME EDGE ~ 10 µg/L
HOT AREA ≥ 1000 µg/L

SOURCE: BAKER

Figure 5-1c. VOC Contaminant Plume at OU1 South Plant, January 1998

RADIAN INTERNATIONAL
A DAMES & MOORE GROUP COMPANY

990104C-KL-RTP

the surficial aquifer as the plume migrated in the direction of groundwater flow. However, as with the OU1 North system, the plume for OU1 South also appears to be stable and no longer migrating. In 1998, three additional wells (RW-13, RW-14, and RW-15) were installed in areas of the plume with higher concentrations of VOCs in order to increase mass removal rates.

All wells are screened in the upper portion of the surficial aquifer. The wells are constructed with six-inch diameter stainless steel casing and wire-wrap screen. Each well is 35 feet deep with 25 feet of 10- or 20-slot screen surrounded by a quartz sand filter pack. A pneumatically-operated submersible pump is set within three feet of the bottom of each well. Measurements made in the latter half of 1998 indicate that the pumping rate of approximately one gallon per minute resulted in a drawdown of about one foot in each well.

Monitoring wells associated with the South P&T system are part of the well network that monitors groundwater quality throughout Site 78, as described for the OU1 North system in Section 3.3.1. The monitoring well locations at Site 78 are illustrated in Figure 3-1.

5.3.2 Description of Aboveground Treatment Train at OU1 South—The OU1 South Treatment System is identical in design and process flow as that described for OU1 North in Section 3.3.2. The one exception is that an anti-foaming agent (Foamtrol AF 721) has been added to the South plant to control foaming of the surfactant-flushing waste from the Building 25 area.

5.3.3 Design Specifications and Parameters for OU1 South—The design specifications and parameters for OU1 South are identical to those described for OU1 North in Section 3.3.3.

5.3.4 System Upgrades and Modifications for OU1 South—Since initial operation, a calcium sequestering system has been added to the process stream to control scaling and an anti-foaming agent has been added to control foaming. Upon assuming responsibility of the OU1 South groundwater P&T system in December 1996, the O&M contractor conducted a comprehensive system review and repair project to restore treatment efficiency and minimize long-term operation and maintenance costs. South treatment plant repairs included:

- Cleaning the coalescing media for the oil/water separator;
- Cleaning bag filters, discharge tank, flocculation tank and surge tank;
- Repairing and replacing flow meters;
- Repairing air compressors;
- Replacing primary and secondary feed pumps;
- Replacing sand and cleaning sand filters;

- Cleaning and repairing air stripper;
- Modifying and repairing filter press;
- Repairing autodialer alarm;
- Replacing activated carbon media;
- Repairing electric heaters; and
- Replacing malfunctioning valves.

5.4 OU1 South Good Management Practices

This section is intended to highlight good management practices that have been implemented by Camp Lejeune and its O&M contractors. The following are considered good O&M management practices:

- Upon assuming responsibility of the OU1 South P&T system in December 1996, the O&M contractor conducted a comprehensive system review and repair project to restore treatment efficiency and minimize long-term operation and maintenance costs. System repairs included repair of flow meters, repair of air compressors, repair of transfer pump seals, cleaning of sand filters, cleaning and repair of air stripper, replacement of activated carbon media due to clogging, and replacement of malfunctioning valves.
- The O&M contractor replaced piston-type air compressors with rotary screw type compressors to achieve improved uptime and reduced maintenance cost.
- The treatment system at OU1 South is also used to treat surfactant flushing waste from the Building 25 area. This results in cost savings over off-site disposal of these wastes.
- The O&M contractor has added three new extraction wells in “hot spot” zones within the OU1 South area to allow for more aggressive contaminant mass removal.

5.5 OU1 South System Performance Baseline

The overall technical and cost effective performance for the OU1 South treatment system in comparison to its design and remedial action objectives is relatively poor. As described in subsequent Sections 5.5.1 and 5.5.2, the OU1 South plant and associated extraction system demonstrate the following characteristics:

- Influent flowrates of less than 10% of design capacity;
- Extremely low contaminant mass removal, i.e., less than 11 pounds of cumulative mass removed over 2.5 years of operation;
- Poor cost effectiveness, as evidenced by an average cost per pound of contaminant removed of $31,000 for the South system;

- Significant system downtime and associated maintenance and repair costs; and
- Little evidence to suggest that aquifer restoration to ROD-specified cleanup levels can be achieved by the system in its current configuration and mode of operation.

5.5.1 OU1 South System Performance Plots—Figures 5-2 through 5-5 are cost and performance graphs for the period of September 1996 through March 1999 for the OU1 South Treatment System. Taken collectively, they provide valuable information on the current and historical performance baseline for this system, and are discussed below:

- **Figure 5-2, "Influent VOC Concentrations vs. Time":** Figure 5-2 shows that the monthly total influent VOC concentration for the OU1 South system has remained at or below 400 ug/l with one exception. The concentration spiked to a level of 1.40 mg/l during the early part of 1997. The overall influent concentration is trending slightly downward over time. The increase in concentration seen in the May-June 1998 timeframe was due to the introduction of new extraction wells installed in plume areas of higher contaminant concentrations.
- **Figure 5-3, "Cumulative Mass Recovered vs. Time":** As with the OU1 North system, the total mass removed by the OU1 South system is very low at 10.75 pounds over the 2.5 years of operation. The period of June 1997 through February 1998 saw almost no additional incremental mass removal. Additional extraction wells were installed to remedy this situation; however, the cumulative mass removal since that time has only been 4 to 5 pounds.
- **Figure 5-4, "Cumulative Costs vs. Cumulative VOCs Recovered":** Figure 5-4 demonstrates the minimal cost effectiveness of the OU1 South system. More than $400,000 of cumulative O&M costs were expended to remove 10.75 pounds of contamination. Of this amount, approximately $150,000 was expended to recover one pound of contamination during the June 1997-February 1998 timeframe.
- **Figure 5-5, "Average Cost Per Pound Recovered vs. Time":** The OU1 South system's average cost per pound of contaminant removed for the entire operating period is approximately $31,000. As shown in the figure, the average monthly cost increased from $10,000 to almost $45,000 per pound during the first 1.5 years of operation; and then dropped slightly to the March 1999 value of nearly $39,000. The recent decrease is due to the addition of extraction wells sited in areas of the plume with higher contaminant concentrations. The high cost per pound removed is a direct result of low influent flowrates and contaminant concentrations.

Table 5-1 summarizes selected performance parameters for the system.

Table 5-1. OU1 South System Design Versus Performance Data

Parameter	Design	Actual Average[a]	Actual Median[a]
Aquifer Average Flowrate (gpm)	40	7.01	5.96
Monthly Aquifer Volume (gallons)	3,456,000	307,780	229,624
Monthly Mass removed (lbs.)	N/A	0.35	0.31
Average cost per mass removed ($/lb.)[b]	N/A	$31,436	$36,964

[a] Based on performance data from September 1996 through March 1999.
[b] Capital costs were not included.

NOTES:
gpm = gallons per minute
lbs = pounds

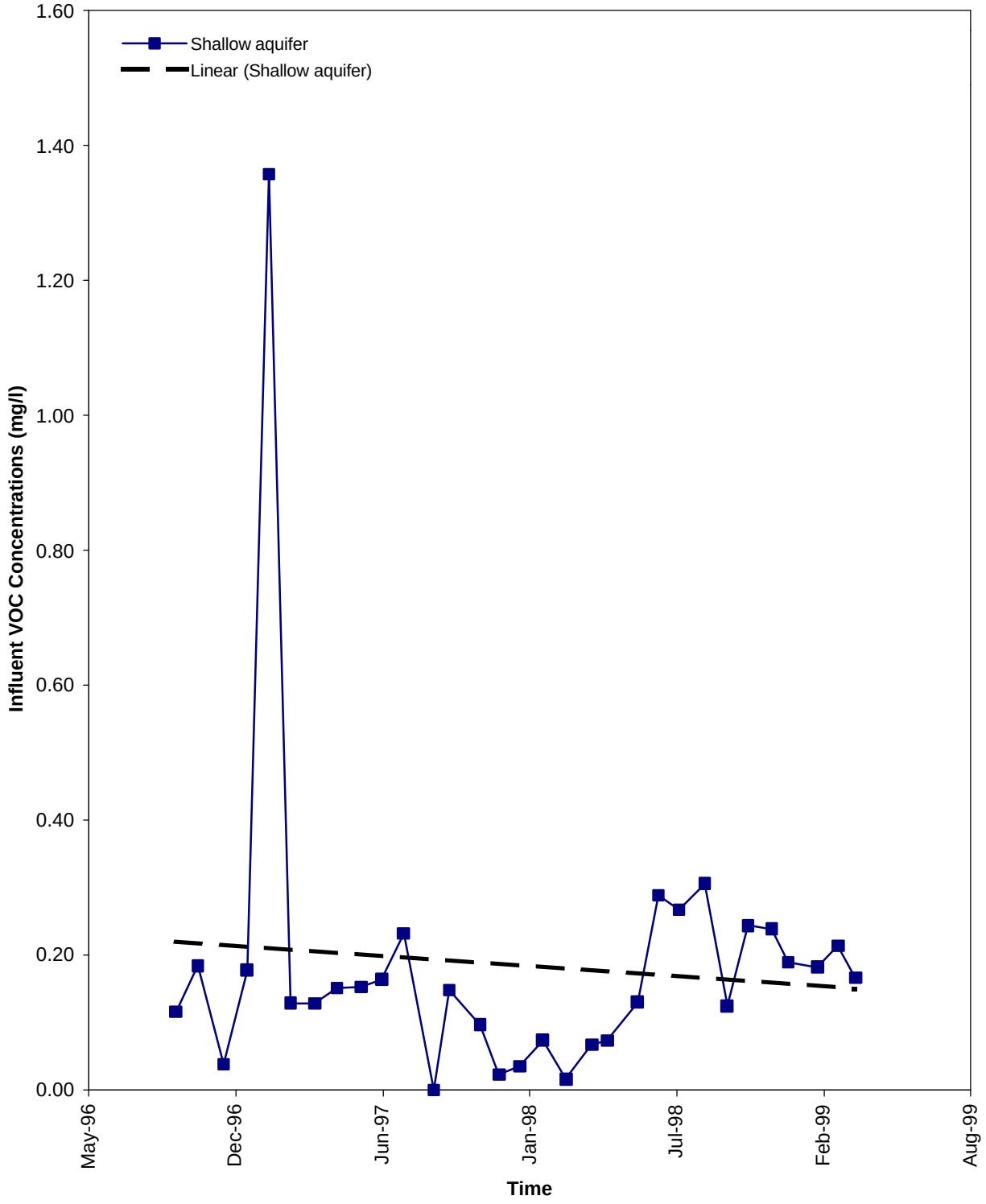


Figure 5-2. Influent VOC Concentrations vs. Time OU1 (Site 78) South Plant

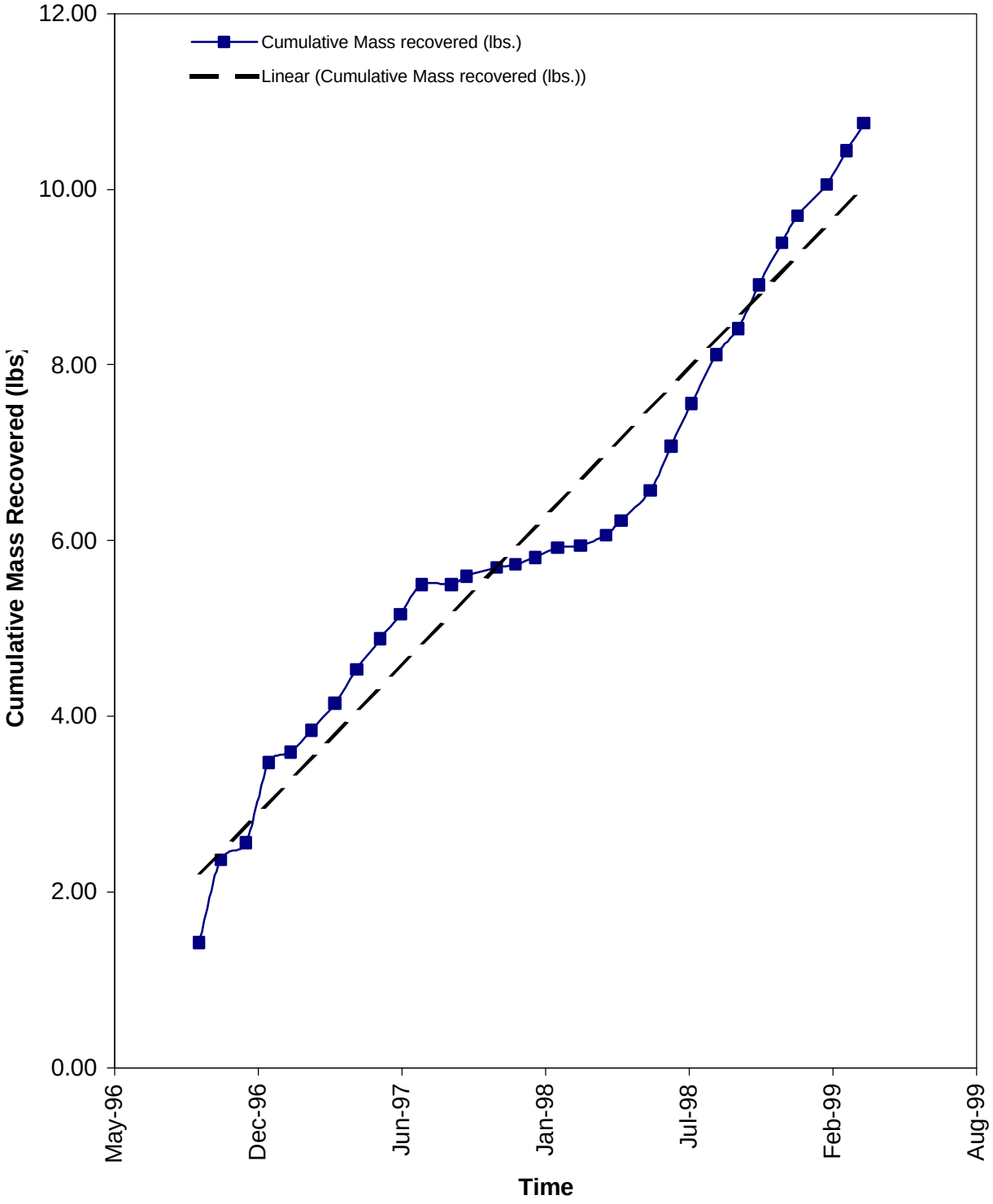


Figure 5-3. Cumulative Mass Recovered vs. Time OU1 (Site 78) South Plant

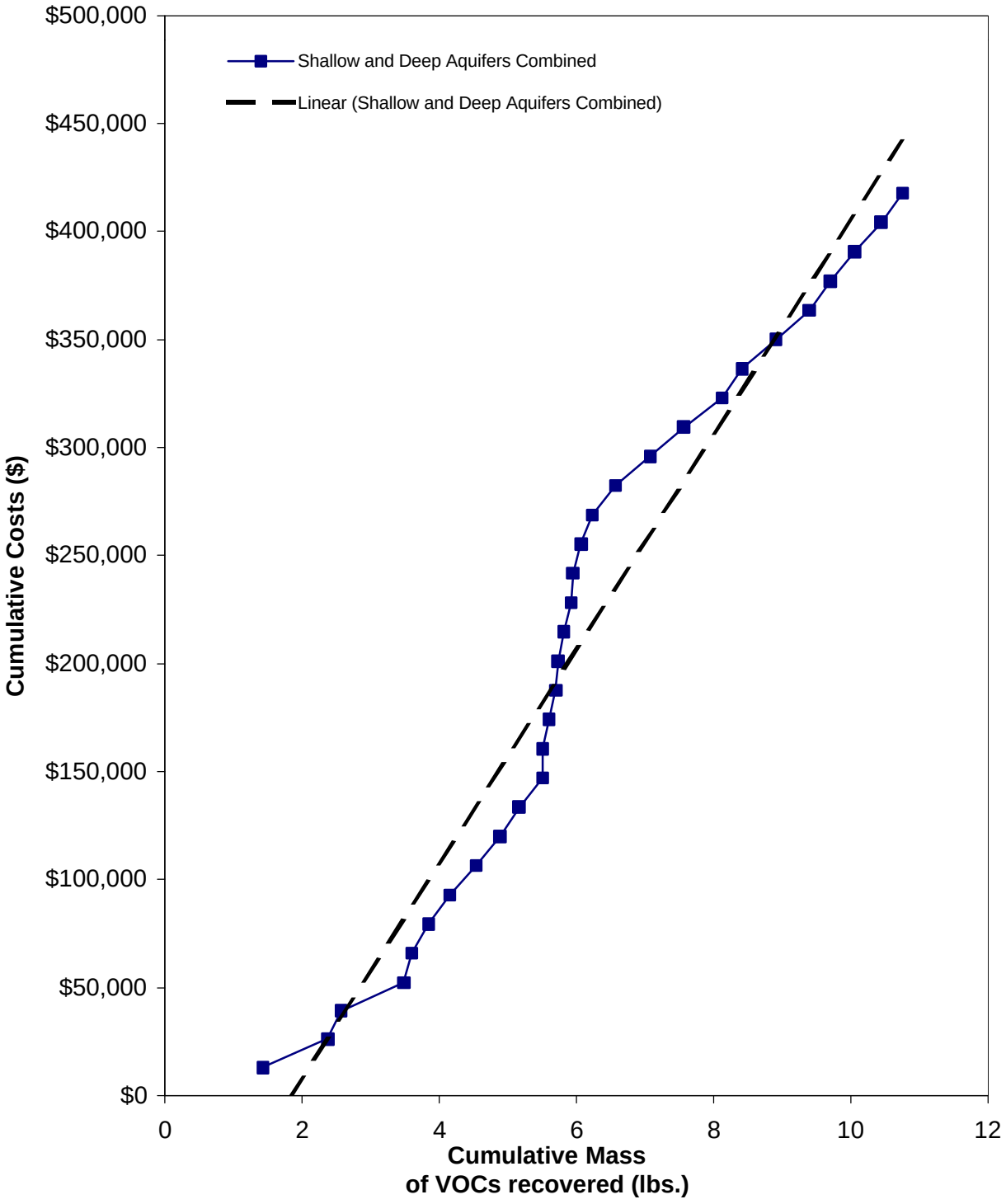


Figure 5-4. Cumulative Costs vs. Cumulative VOCs Recovered OU1 (Site 78) South Plant

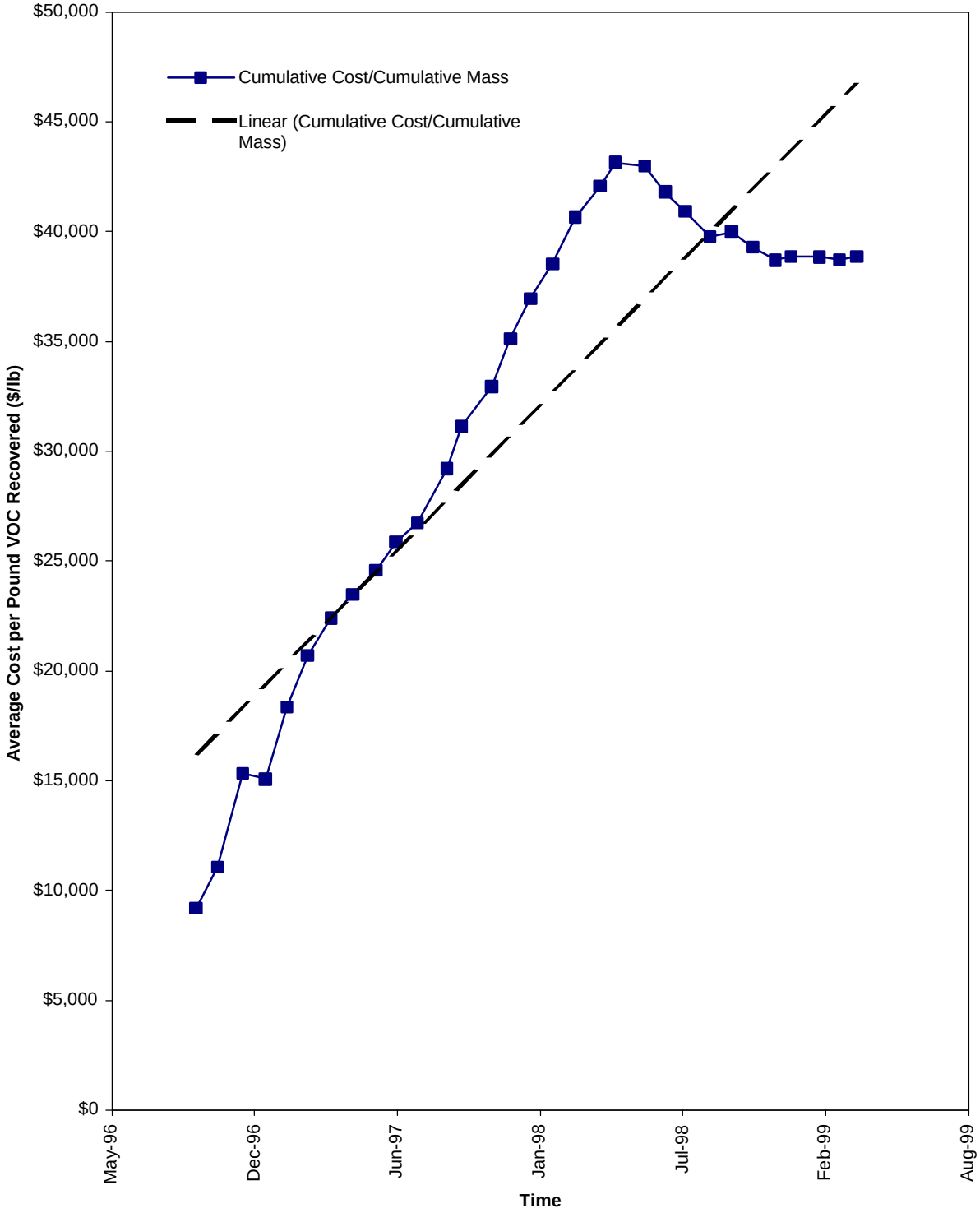


Figure 5-5. Average Cost Per Pound Recovered vs. Time OU1 (Site 78) South Plant

5.5.2 OU1 South Extraction and Monitoring Well Network Performance—This section compares the performance of the extraction well network at the OU1 South P&T system against the parameters previously discussed for the OU1 North system in Section 3.5.2.

Data Gaps

Data gaps identified in evaluating the performance of the extraction and monitoring well networks at the South P&T system are identical to those identified at the North P&T system. As with the OU1 North system, these data gaps do not affect the overall conclusions and recommendations contained herein.

- The number and location of LTM points for water level measurements is inadequate to verify plume containment in three dimensions;
- The number and location of LTM sampling points is inadequate to define the extent of the contaminant plume;
- Pumping rates for the individual extraction wells are not measured; and
- Contaminant concentrations have not been measured in the individual extraction wells. However, we understand that samples will be collected from individual wells beginning January, 2000.

Hydraulic Head and Gradients

Water levels measured at OU1 South in July 1998 do not demonstrate that the South P&T system has established a capture zone within the surficial aquifer. The measurements indicate the general direction of groundwater flow in the southern portion of OU1; however, the absence of monitoring wells downgradient of the extraction wells precludes analyzing the effects of pumping on plume containment.

Water levels measured at a well cluster (wells 78-GW09-01, 78-GW09-2, and 78-GW09-3) installed near the South plume indicate that an upward gradient exists between the lower portion of the surficial aquifer and the underlying Castle Hayne aquifer. Because of the distance between the well cluster and the extraction wells, it is unlikely that the upward gradient is related to pumping from the wells; instead it represents natural hydraulic conditions identified during the remedial investigation.

Pumping Rates

The feasibility study for the South P&T system estimated that each extraction well in the network would yield three to five gallons per minute (Baker, 1994a). However, during the last six months of 1998, the average yield of the five operating wells was slightly more than one gallon per minute. Based on estimates of the contaminant plume's size and the volume of water extracted in the last half of the year, the North P&T system flushed less than 0.1 pore volumes of groundwater through the plume in 1998. Also, the locations of the extraction wells at the edge of the plume cause the extraction of relatively

uncontaminated groundwater volumes. Due to the poor capability of the surficial aquifer to yield water, approximately 20 additional extraction wells would be required to annually remove a minimum of 0.3 pore volumes from the contaminant plume. In the latter half of 1998, well maintenance plus routine system maintenance resulted in 168 hours of downtime at the South Treatment Plant.

Extracted Water Quality

Historical data from the South Treatment Plant indicate that the median VOC concentration of the influent is approximately 0.14 mg/L. However, a single high concentration (1.3 mg/L) increases the mean VOC concentration to 0.18 mg/L. In the latter half of 1998, the influent concentration, averaging approximately 0.24 mg/L, indicated an increasing trend following a nine-month period of below average concentration. The low influent concentration over the entire period of record is expected, because the extraction wells are located at the downgradient edge of the plume and not within the areas of highest contamination. The downgradient extraction well network is the least effective configuration for achieving groundwater restoration, because contaminants must travel along the entire length of the plume to reach the wells. More effective well placement requires installing extraction wells in the areas of highest contamination; along the plume axis; and, within areas of the least mobile contaminants, to collectively maximize mass removal, reduce the pumping of clean water, and minimize contaminant travel time and distance.

Contaminant Concentration and Distribution

No monitoring wells are located downgradient of the extraction wells to verify that plume migration has been contained.

The areal extent of VOCs in the surficial aquifer, depicted by isoconcentration contour maps (Figures 5-1a through 5-1c) that represent different sampling events, appears to be relatively constant since January 1997. Excluding a recent anomalous sampling event, the concentrations of total VOCs and individual compounds in 78-GW09-1, where the most contaminated samples in the South contaminant plume have been collected, appear well above remediation levels. Consequently, little progress toward achieving active groundwater restoration is demonstrated by the data. However, since the OU1 South plume appears to be stable, and possibly decreasing in size, it is likely that passive natural attenuation processes are occurring.

Potential Evidence of Natural Attenuation

As in the North contaminant plume, natural attenuation is also potentially occurring at the South contaminant plume as evidenced by its stable size and location. Other evidence that natural attenuation is potentially occurring is the presence of 1,2-dichloroethene and vinyl chloride in samples collected from site monitoring wells. However, carbon sources are present at only trace concentrations and dissolved oxygen concentrations exceed the level necessary for optimum reductive dechlorination. Other indicators of potential attenuation are not included in the LTM program, but should be measured during the MNA assessment recommended in Section 6.

5.5.3 OU1 South Aboveground Treatment Train Performance—The performance of the OU1 South aboveground treatment train is very similar to that described for OU1 North in Section 3.5.3, with the exceptions noted in the following paragraphs.

A calcium sequestering system has been added to the process stream to control scaling and an anti-foaming agent has been added to control foaming. In addition to treating groundwater extracted at OU1, the southern treatment plant is also used to treat surfactant-flushing waste from the Building 25 area.

Based on records beginning in January 1997, the O&M contractor has performed a majority of all routine monthly maintenance on the OU1 Southern Treatment Plant as required in the *Hadnot Point Shallow Aquifer Groundwater Treatment System Operations and Maintenance Manual* (OHM, 1997a). During 1997, the treatment plant operated a total of 307 days, for an annual operating percentage of 84%. The treatment plant operated a total of 350 days, for an annual operating percentage of 96%, in 1998. The primary reason for the lower operating percentage in 1997 was due to the system being shut down in January 1997 for system optimization. Delays during 1997 and 1998 included maintenance of extraction wells, malfunction of valves, cleaning of the air stripper, and the circuit breaker being tripped. These uptime percentages do not take into account the fact that the treatment system routinely cycles on and off throughout each operating day due to low groundwater extraction rates. The groundwater extraction rate is approximately 10% of the treatment plant design capacity of 80 gpm. There is not enough flow to keep the air stripper running continuously, so the flocculation tank is used as a surge tank and the system cycles on and off as needed to treat the accumulated groundwater. The treatment system actually runs approximately 10% of the time.

The annual operations and maintenance costs for the OU1 South Groundwater P&T system are provided in Table 5-2. Line item operation and maintenance costs were not available for review.

Table 5-2. Annual Operations and Maintenance Costs for the OU1 South Groundwater P&T Systems

Fiscal Year	Annual Operations Costs (North & South)	Annual Maintenance Costs (North & South)	South Plant Annual Utilities	South Plant Annual Costs	South Plant Monthly Costs
1999	$225,000	$50,000	$11,351	$148,851	$12,404
1998	$223,083	$333,497	$11,351	$289,641	$24,137
1997	$117,497	NA	$13,052	$71,801	$5,983
1996	$115,000	$171,586	$13,925	$157,218	$13,102
1995	$94,850	NA	$2,088	$49,513	$4,126

NA = not applicable

6.0 CONCLUSIONS AND RECOMMENDATIONS FOR OU1 SOUTH P&T SYSTEM

The number, location, and limited pumping capacity of the extraction wells at the South Treatment System are inadequate to achieve groundwater restoration through active pumping. Mass removal to date has been poor, even with the recent installation of three additional extraction wells. As with the OU1 North system, a major obstacle to meeting remediation levels is the low permeability of the surficial aquifer. Given this physical limitation of the site, increasing the number of wells will provide only marginal improvement toward mass removal. More importantly, it is likely that the South plume has already stabilized due to natural attenuation processes in the surficial aquifer, and may be decreasing in size.

6.1 OU1 South Optimization Recommendations

Based on the information reviewed and presented in Section 5.0, several primary recommendations can be made for the OU1 South P&T system. As with OU1 North, complete implementation will likely require an ESD or ROD amendment to the current OU1 ROD.

1. Shut down the operation of the OU1 South system at the earliest opportunity. Continued active pumping is difficult to justify given the low permeability of the aquifer, current total VOC concentrations, and the likelihood of passive natural attenuation processes already at work.
2. In parallel with recommendation 1, perform a monitored natural attenuation (MNA) assessment on the OU1 South plume according to established DoD and EPA protocols. Data gaps to better define the extent of the plume in three dimensions can be filled as part of the MNA assessment.
3. Should state guidelines be changed to permit risk assessment, consider revising the baseline human health risk assessment assumptions and associated cleanup level calculations to reflect an industrial future land use category as the most probable scenario. Prior to conducting comprehensive risk assessment, perform preliminary calculations to determine if the potential results of the risk assessment justify the effort.
4. If MNA does not prove feasible as the long-term remedy for OU1 South, consider applying remedial options currently in use at HPFF, along with enhanced biodegradation remedies. These alternative remedies could include AS/SVE and application of hydrogen releasing compound (HRC).
5. Leverage the performance assessment within this report, as well as the data and information from implementation of the above recommendations, as the foundation for the upcoming five-year review at OU1.

In addition, recommendations are provided to optimize the OU1 South P&T system as it is currently operating if system shutdown cannot be immediately implemented. Recommendations are summarized in Table 6-1 and described in detail in the following subsections.

Table 6-1. OU1 South Evaluation and Optimization Summary

System Component	Consideration	Cost Impacts	Effectiveness Impacts
South Extraction System	Evaluate the effects of recent system modifications. • Continue to monitor surficial and Castle Hayne aquifers for VOCs. • Install two shallow monitoring wells downgradient of the plume. • Measure water levels in the inactive extraction wells and in adjoining monitoring wells. • Add the active and inactive extraction wells and two new monitoring wells to the current groundwater monitoring network.	• Labor and contractor cost of $10,000 for installing 2 monitoring wells. • Increase monitoring labor and analytical costs by $8200/year.	• Determine if system modifications have satisfactorily increased contaminant mass removal rates and improved hydraulic containment; if further modifications are warranted; or, if alternate remedies and remedial goals should be considered.
South Extraction System	Improve performance evaluation database. • Prepare isoconcentration contour maps for individual COCs. • Prepare graphs of individual COC concentration changes over time. • Prepare graphs of cumulative mass removed relative to recovery time and cumulative pore volumes extracted.	• Increase data presentation and evaluation costs by $1600/year for system.	• Contribute to database necessary for evaluating P&T system performance.
South Extraction System	Conduct preliminary screening for natural attenuation by adding relevant analytical parameters to current monitoring programs.	• Increase labor and analytical costs by $12,000.	• Determine if monitored natural attenuation is a potential alternative remedy that merits detailed evaluation.

Table 6-1. OU1 South Evaluation and Optimization Summary (continued)

System Component	Consideration	Cost Impacts	Effectiveness Impacts
South Aboveground Treatment Plant	Bypass the oil/water separator and flocculation tank.	• Decrease in O&M costs by $640/year for OU1 South. • Decrease analytical costs by $1,000/year for system.	• Decrease labor associated with cleaning oil/water separator and flocculation tank. • The bypass will eliminate the need to perform oil and grease analysis at one point in the process stream.
South Aboveground Treatment Plant	Use oil/water separators and flocculation tanks for future remedial action sites at Camp Lejeune.	• No cost impact for OU1. • Potential cost savings for future remedial sites.	• Equipment not needed at OU1.
South Aboveground Treatment Plant	Use the OU1 polymer pumps at the OU2 plant.	• No cost impact for OU1. • Potential cost savings for OU2.	• Equipment not needed at OU1.
South Aboveground Treatment Plant	• Modify NPDES permits to allow GAC bypass for normal operation, or • Perform cost analysis for treatment by GAC alone vs. air stripper alone.	**Cost savings for running air stripper alone:** • Decrease in filter cartridge replacement cost of $800 to 1,000/year for system. • Decrease in labor cost of $4,000/year for OU1 South. • Decrease analytical costs by $1,200/year for system.. **Cost savings for running GAC alone could not be identified.**	• Air stripper effluent samples will need to be monitored closely to ensure that effluent discharge standards are met. • Decrease costs associated with back washing and filter replacement. • The bypass will eliminate the need to perform VOC analysis at one point in the process stream.
South Aboveground Treatment Plant	Sample influent from individual wells for VOCs once a quarter. Scheduled to begin in January 2000.	• Increase analytical costs by $3,200/year for the South system.	• Determine the effectiveness of each individual well for removal of contaminants from the subsurface.

6.1.1 OU1 South Extraction and Monitoring Well Network—The following are recommendations for the extraction and monitoring well networks associated with the South Treatment Plant at OU1. With minor variations, they are identical to the recommendations for the North Treatment Plant.

To provide an adequate database for evaluating the progress of the modified pump and treat system toward achieving groundwater restoration, the following recommendations should be implemented:

- Conduct screening for MNA by adding relevant analytical parameters to the current monitoring program.
- Continue to monitor both the lower portion of the surficial aquifer and the Castle Hayne aquifer for VOCs, as recommended by the O&M contractor, to determine whether VOCs are migrating downward from the upper portion of the surficial aquifer.
- Collect water quality samples from the extraction wells and analyze for COCs to monitor concentrations and mass removal at specific locations within the plume. Subsequently, prepare graphs plotting cumulative mass removed against time and against pore volumes extracted.
- Install several monitoring wells downgradient of extraction wells RW-5 through RW-9. Measure water levels in these new monitoring wells and in all proximal monitoring wells, including deep wells, to determine whether inward hydraulic gradients have been established and whether the plume is hydraulically contained. Water quality samples should also be collected from these wells and analyzed to ascertain whether VOC migration has been halted either through active hydraulic containment or through stabilization of the plume by natural attenuation processes.
- On the basis of the regular sampling results, prepare contour maps that illustrate the concentration and extent of individual COCs in groundwater relative to their remediation levels. Plotting total VOC concentration provides a general perspective of the plume, but has no regulatory foundation.
- Prepare time series graphs of individual COCs to examine trends in water quality within and outside the plume.

6.1.2 OU1 South Aboveground Treatment Train Recommendations—The following are recommendations for the OU1 South aboveground treatment train. These recommendations are also summarized in Table 6-1.

- Because the oil/water separator and flocculation tank are not used for their design purpose, we recommend installing a bypass around these to avoid the expense of cleaning the coalescing media and the tanks. The cost savings in labor (approximately 16 hours) are approximately $640 annually. This will also reduce the analytical cost by removing the oil and grease analysis after the oil/water separator for annual savings of $1000.

- Consider using the existing oil/water separator and flocculation tank for future remedial action sites at Camp Lejeune. There would be no cost impact on the OU1 system; however, cost savings may be incurred for any future remedial systems.
- Consider using an unused polymer pump at OU2. This may alleviate some of the maintenance required for the existing polymer pump at OU2. There would be no cost impact on the OU1 system.
- Based on the air stripper and GAC effluent performance discussed in Section 3.0, we recommend requesting that carbon polishing be modified in the NPDES requirements for discharge to the sanitary sewer; and that the GAC and cartridge filters be bypassed during normal operation. The GAC will be readily accessible if effluent sampling indicates that GAC is needed to reduce effluent concentrations. This will save labor and cost by reducing the amount of back flushing and by eliminating the need for cartridge filter replacement. It is estimated that the annual replacement cost of cartridge filters is $800. Reduction in labor (100 hours) to backwash carbon, change filters, and manage sludge generated by back washing will create an annual savings of $4,000. This will also reduce the analytical cost by removing the VOC analysis of GAC effluent for annual savings of $1,200.
- An alternative to removing the GAC polishing is to shut down the air stripper. The flowrates and concentrations are low enough for the effluent to be treated by GAC alone. A cost analysis should be performed to determine whether the total operating cost for the air stripper alone may be more costly than using only GAC for polishing. Detailed costs for air stripper and GAC operation were not available for this analysis.
- We recommend sampling the influent for VOCs from individual wells, once a quarter, to determine the removal effectiveness from each well. This represents an annual cost increase of $3,200. Note that sampling of influent from individual wells is scheduled to begin January 10, 2000 (Baker, 2000).

6.1.3 OU1 South Recommendations Life Cycle Costs—A life cycle cost analysis was conducted for each of the RAO optimization recommendations for the OU1 South Aboveground Treatment Train. The life cycle cost analysis provides a net present value (NPV) for costs or savings incurred over the life of the operation. The NPV was calculated for operations of 5, 10 and 15 years, assuming a 6% interest rate. Results of the life cycle cost analysis are presented in Table 6-2.

Table 6-2. Life Cycle Costs for OU1 South Aboveground Treatment Train

Recommendations	Annual Costs				Net Present Value		
	Capital	Labor	Analytical	Total	5 years	10 years	15 years
Continue operation of existing P&T "as is"				$163,102	$687,045	$1,200,445	$1,584,087
Discontinue operation of P&T and implement MNA	$5,000	$15,000	$15,000	$35,000	$126,371	$220,803	$291,367
Bypass oil/water separator and flocculation tank	$0	($640)	($1,000)	($1,640)	($6,908)	($12,071)	($15,928)
Use existing oil/water separator and flocculation tank for future remedial action	No cost impact on OU1; cost savings may be incurred for future remedial activities						
Use unused polymer pump at OU2	No cost impact on OU1 system; potential cost savings for OU2						
Bypass the GAC and cartridge filters for discharge to sanitary sewer	($800)	($4,000)	($1,200)	($6,000)	($25,274)	($44,161)	($58,273)
Sample influent for VOCs, quarterly	$0	$0	$3,200	$3,200	$13,480	$23,552	$31,079
Evaluate the effects of recent system modifications	$10,000	$8,200		$18,200	$76,665	$133,954	$176,763
Improve performance evaluation database	$0	$1,600	$0	$1,600	$6,740	$11,776	$15,540
Conduct preliminary screening for natural attenuation	$0	$12,000		$12,000	$50,548	$88,321	$116,547
(Figures in parenthesis indicate cost savings)							

7.0 OU2 REMEDIAL SYSTEM ASSESSMENT

7.1 OU2 Background and Regulatory Framework

This section provides a description, regulatory information, and site activity status for OU2. The information is also summarized in Tables 7-1 to 7-3.

7.1.1 OU2 Description—OU2 covers an area of 210 acres and is located in the northern part of the base, directly north of OU1. OU2 consists of Sites 6, 9, and 82.

Site 6 includes four main areas of concern. These are Open Storage Lot 201, Open Storage Lot 203, the wooded area surrounding these storage lots, and a ravine. Open Storage Lot 201 is approximately 25 acres in size and is used to store military equipment, vehicles, lumber, oils and lubricants, non-PCB transformers, and other supplies. The current size of Open Storage Lot 203 is approximately 41 acres. It is no longer an active storage area, but was once reportedly used for disposing of PCBs, cleaning solvents, electrolytes from used batteries, waste oils, and other wastes. The lot still contains scrap materials and other debris. Fuel storage tanks and various drums have also been identified at this site.

The ravine and woods in the area of Lots 201 and 203 are littered with haphazardly distributed drums, tires, metal scrap, and other debris.

Site 9 is the Fire Fighting Training Pit at Piney Green Road. This site occupies approximately 2.6 acres and is just south of Site 6. It consists of an asphalt-lined fire training pit, an oil/water separator, four aboveground storage tanks (ASTs), three propane tanks, and a fire tower. Two of the ASTs at the site are not used, although fire training exercises are still conducted at the site.

Site 82 is the Piney Green Road VOC Site. This site is approximately 30 acres in an area located north of Site 6. This site is littered with debris such as communication wire, spent ammunition casings, and empty or rusted drums (Baker Environmental, September 1993).

7.1.2 OU2 Regulatory Framework—The ROD for OU2 was signed in September 1993. The major components of the selected remedy for OU2 are listed in Table 7-2. As shown in the table, the ROD specifies a remedial action of pump and treat for both the shallow and deep plumes located at Sites 6 and 82, along with the implementation of an LTM program. The LTM program was initiated in mid-1997.

For the groundwater media, ROD-specified cleanup levels are a combination of federal MCLs, State of North Carolina standards, and risk-based standards. The ROD states that the selected remedy will be operated until the remediation levels for COCs have been met.

Table 7-1. Summary of Site Information for OU2

Site	Description	Years of Operation	Contaminated Media	Contaminants of Concern
6	Open Storage Lot 201 and Open Storage Lot 203	1940s to 1980s	Groundwater and soil	Groundwater: VOCs Soils: pesticides, PCBs, VOCs, SVOCs, and metals
9	Fire Fighting Training Pit at Piney Green Road	1960s to present	NA	NA
82	Piney Green VOC Site	Unknown	Groundwater and soil	Groundwater: VOCs Soils: pesticides, PCBs, VOCs, SVOCs, and metals

NOTES:
NA = Not applicable
OU = Operable Unit
PCBs = Polychlorinated biphenyls
SVOC = Semivolatile organic compound
VOC = Volatile organic compound

Table 7-2. Summary of Regulatory Framework for OU2

Date of ROD	Site	Remedy Components	Cleanup Criteria for Active Systems	Criteria to Stop Monitoring
September 1993	6 and 82	• Pump and treat contaminated groundwater from the deep and shallow portions of the aquifer. • Restrict the use of nearby water supply wells and restrict the installation of new water supply wells within the OU. • Implement an LTM program. • Implement *in situ* treatment via volatilization or vapor extraction of approximately 16,500 cubic yards of VOC contaminated soil. • Excavate approximately 2500 cubic yards of soil contaminated with PCBs and pesticides for off-site disposal.	Groundwater: Federal MCLs, state groundwater standards, risk-based levels Soil: TSCA nonresidential guidance (PCBs), risk-based action levels	Three consecutive rounds in which samples have non-detect (ND) concentrations or concentrations protective of human health have been demonstrated to the satisfaction of the regulatory agencies.
	9	• No further action.		

NOTES:
LTM = Long-Term Monitoring
MCLs = Maximum contaminant level
ND = Not applicable
OU = Operable Unit
PCBs = Polychlorinated biphenyls
ROD = Record of Decision
TSCA = Toxic Substances Control Act

Table 7-3. Summary of Monitoring Status for OU2

Site	Status of Monitoring	Monitored Medium	Sampling Frequency: Initial/Current (or Final)	Current Number of Monitoring Points	Remedial Actions
6 and 82	Active, begun in 1997	Groundwater	Quarterly/ Semiannually[a]	32 wells	Pump and treat system, inactive SVE system, soil removal action completed in 1995
9	NFA	NA	NA	NA	NA

[a]Nine deep wells at OU No. 2 are monitored annually.

NA = Not applicable
NFA = No further action
OU = Operable Unit

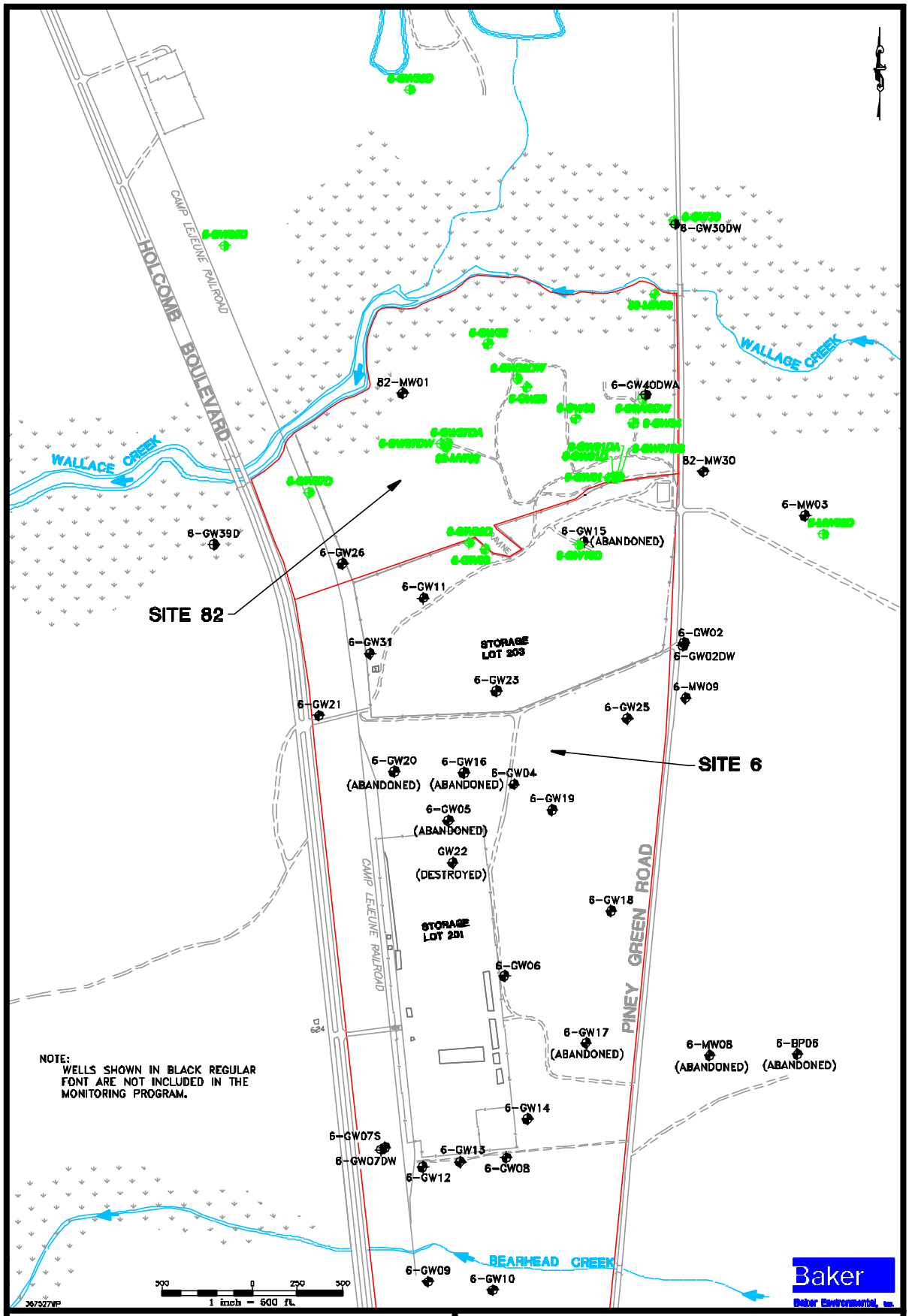
7.1.3 Activity Status—Quarterly monitoring began at OU2 in the summer of 1997, and continued until the summer of 1998. Semiannual monitoring began in the summer of 1999, and the next round is scheduled for the winter of 1999. A total of 28 wells, 16 deep and 12 shallow, are monitored as part of the LTM program for this OU. The monitoring network for Sites 6 and 82 is shown in Figure 7-1.

Contamination at this old material storage site consists of chlorinated solvents. The chlorinated solvents have affected the surficial aquifer and the deeper Castle Hayne Aquifer.

At one time, an SVE system was operated at the site as part of the ROD remedy. Currently, a pump and treat system producing 300 gallons per minute has been operating at the site since the fall of 1996. Four deep (101 to 154 feet) and six shallow (35 feet) extraction wells supply the treatment system.

7.2 Current OU2 Conceptual Model and Remedial Action Status

The geology at OU2 is typical of the Atlantic Coastal Plain, characterized by interlayered beds and lenses of sand, silt, clay, shell, and limestone. Shallow deposits are generally uniform across OU2 and consist of silty to clayey sand, silt, and clay. Deposits at depths between 40 and 140 feet, collectively described as the upper silty sand unit, consist of fine to medium-grained silty sand, silt, silty to sandy clay, and fragments of sandy limestone interbedded with thin, discontinuous layers of clay and limestone. The upper silty sand unit is underlain by a limestone unit that ranges in thickness from five feet in the southern portion of OU2 to 80 feet in the northern portion. The limestone unit is underlain by a lower silty sand unit that extends to a depth of at least 310 feet. Discontinuous clay layers are present within the lower silty sand unit at a depth of 230 feet (Baker, 1993c).



LEGEND

- SHALLOW MONITORING WELL
- DEEP MONITORNG WELL
- APPROXIMATE DIRECTION OF SURFACE WATER FLOW
- APPROXIMATE SITE BOUNDARY
- FENCING

SOURCE: LANTDIV, OCT. 1991

FIGURE 7-1.

MONITORING WELL LOCATION MAP
OPERABLE UNIT No. 2 - SITES 6 and 82
MONITORING and O&M SUPPORT, CTO-0367

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

The surficial aquifer at OU2 within sand and clay deposits that extend to approximately 50 feet below the operable unit is unconfined (Baker, undated-a). The deeper water-bearing deposits, which include the limestone unit and the upper and lower silty sand units, comprise the Castle Hayne aquifer. The surficial and Castle Hayne aquifers are hydraulically interconnected beneath the operable unit, because clay-confining beds are not continuous there (Baker, 1993c).

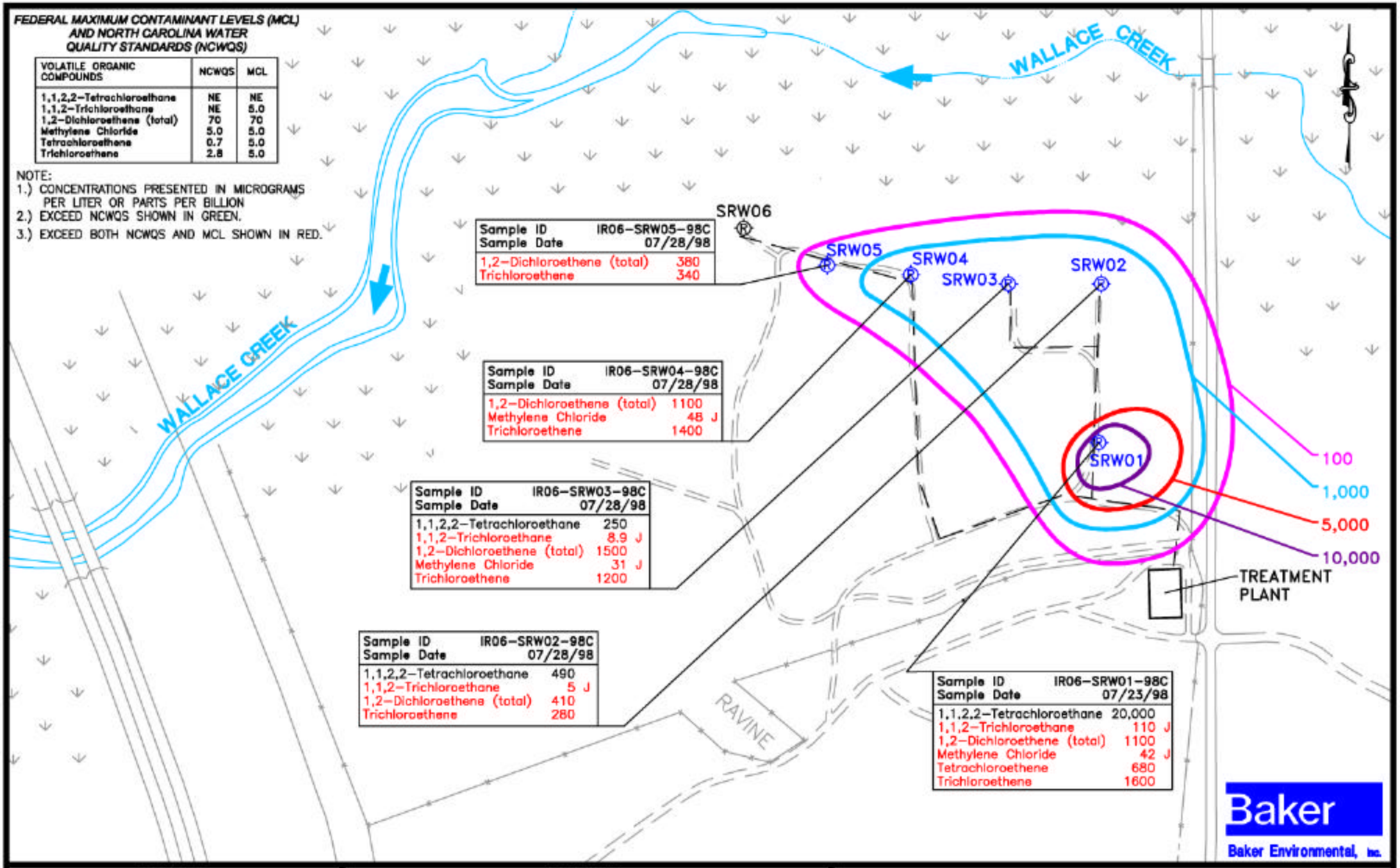
The transmissivity of the surficial aquifer is estimated to be approximately 75 ft^2/day, contributing to flowrates of one to four gallons per minute during well development. The hydraulic characteristics of the Castle Hayne aquifer underlying OU2 were not evaluated. However, the transmissivity of the Castle Hayne aquifer was calculated to be 6,900 and 7,300 ft^2/day at two water supply well locations adjoining the operable unit. One of the wells had a maximum pumping rate of 270 gallons per minute. The well was screened from 125 to 200 feet with the principal production zone located between 125 and 155 feet.

In general, the water table at OU2 occurs from less than two feet to more than 15 feet bls. A groundwater divide is located in the north central portion of OU2. Groundwater flow north of the divide (Site 82) is northwesterly toward Wallace Creek, and groundwater flow south of the divide is southwesterly toward Bear Head Creek. Prior to the commencement of groundwater remediation activities, groundwater within the Castle Hayne aquifer flowed westward with local variations of flow toward Wallace Creek and Bear Head Creek (Baker, 1993c). Currently, flow in the Castle Hayne aquifer at OU2 is toward the four deep extraction wells that were installed to remove water from depths between 95 and 120 feet (Baker, 1999b).

Former operations and disposal practices at Sites 6, 9, and 82 have resulted in the contamination of soil and groundwater at OU2 as summarized in Table 7-1. Groundwater in the surficial and Castle Hayne aquifers underlying Sites 6 and 82 contains halogenated VOCs. Groundwater in the surficial aquifer has concentrations of various metals that are similar to background concentrations. Groundwater monitoring results demonstrate that VOCs present in the surficial and Castle Hayne aquifers are similar and form a laterally and vertically contiguous contaminant plume.

Figures 7-2a and 7-2b illustrate estimated VOC plume contours within the surficial (shallow) and Castle Hayne (deep) aquifers at sites 6 and 82 at the conclusion of calendar year 1998. As shown in the figures, the extent of the shallow plume has only been defined to the 100 ppb isoconcentration contour, and the deep plume to the 1000 ppb contour. The long axis of the plume parallels groundwater flow directions resulting from conditions that existed prior to the initiation of remediation. The plume is laterally more extensive in the Castle Hayne aquifer due to that unit's greater transmissive properties.

Within the surficial aquifer, contaminant migration is toward wetland discharge areas along Wallace Creek, where empirical evidence suggests that contaminant concentrations are being reduced through natural biodegradation processes. The sum of the concentration of VOCs within parts of the Castle Hayne aquifer exceeds 100,000 µg/L, which is an order of magnitude higher than the concentration of VOCs present in the



VOLATILE ORGANIC COMPOUNDS	NCWQS	MCL
1,1,2,2-Tetrachloroethane	NE	NE
1,1,2-Trichloroethane	NE	5.0
1,2-Dichloroethene (total)	70	70
Methylene Chloride	5.0	5.0
Tetrachloroethene	0.7	5.0
Trichloroethene	2.8	5.0

SCALE

300 0 150 300

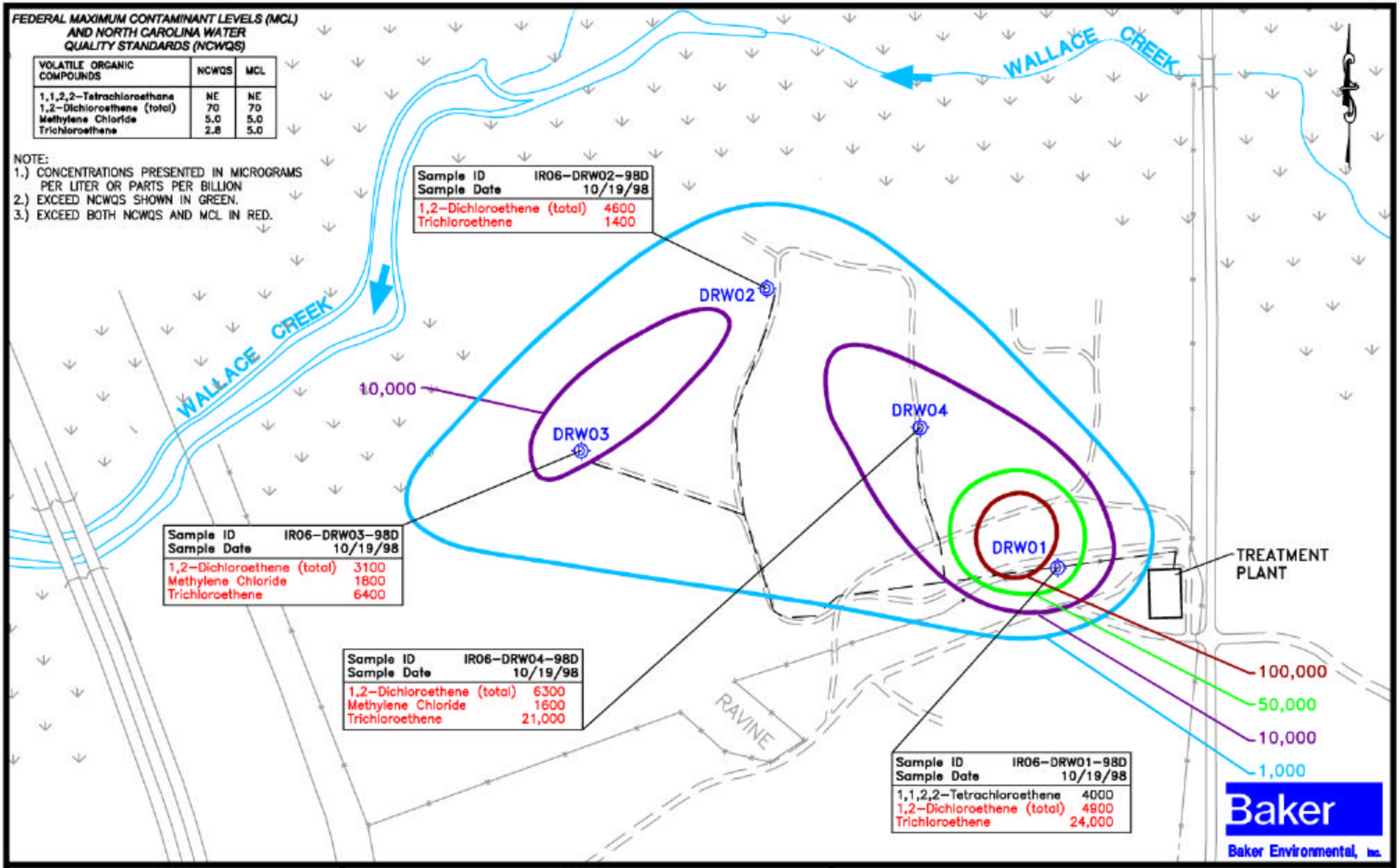
1 inch = 300 ft.

LEGEND

- ON-LINE SHALLOW RECOVERY WELL
- OFF-LINE SHALLOW RECOVERY WELL
- SURFACE WATER FLOW DIRECTION
- TOTAL VOC CONCENTRATION CONTOUR

FIGURE 7-2a
SHALLOW GROUNDWATER TREATMENT SYSTEM
THIRD QUARTER – 1998
OPERABLE UNIT No. 2 – SITES 6 and 82
MONITORING and O&M SUPPORT, CTO-0367
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

367559WP



SCALE

300 0 150 300

1 inch = 300 ft.

LEGEND

- ON-LINE DEEP RECOVERY WELL
- SURFACE WATER FLOW DIRECTION
- TOTAL VOC CONCENTRATION CONTOUR

FIGURE 7-2b
DEEP GROUNDWATER TREATMENT SYSTEM
FOURTH QUARTER – 1998
OPERABLE UNIT No. 2 – SITES 6 and 82
MONITORING and O&M SUPPORT, CTO-0367
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

367558WP

surficial aquifer. Baker (1998) attributes the contaminant concentrations in the Castle Hayne aquifer to vertical migration from the surficial aquifer caused by the hydraulic gradient from operation of a former water supply well. However, given the high concentrations detected in the groundwater, the gravity-driven migration of dense nonaqueous phase liquid (DNAPL) within the Castle Hayne aquifer is also a likely contributing factor. Vertically, the VOC plume extends to more than 200 feet bls, but the depth extent is uncertain.

As part of the RI, an HRA incorporating several potential receptors and pathways was performed. The exposure routes evaluated included ingestion, dermal contact, and inhalation of surface soil; future ingestion and dermal contact of groundwater; ingestion and dermal contact of surface water and sediments; and ingestion of aquatic biota. Potentially exposed populations included civilian personnel and future on-site adult and child residents for surface soil and groundwater; adults and adolescents for surface water and sediment; and adults for aquatic biota. Based on the HRA, an increased cancer risk (ICR) above 1×10^{-4} was calculated for future on-site residential children, civilian base employees, and future on-site residential adults exposed to groundwater (Baker, 1993d). The principal risk drivers were concentrations of vinyl chloride, arsenic, and beryllium. The Hazard Index was also above 1.0 for base employees, future on-site residential adults, and future on-site residential children who would drink the groundwater. An ICR above 1×10^{-4} was also calculated for adults who ingest fish from Wallace Creek. Results for all other receptors and pathways were within acceptable risk ranges.

Based on the results of the HRA and on a comparison of VOC concentrations to groundwater standards, remediation of the surficial and Castle Hayne aquifers at Sites 6 and 82 is warranted to protect potential future receptors (Baker, 1993d). COCs and remediation levels for groundwater at OU2 are listed in Table 7-4.

Data gaps in the CSM include the following issues:

- The vertical extent of contamination has not been determined. Monitoring results indicate that VOCs are present in the Castle Hayne aquifer to depths exceeding 200 feet, but the vertical extent of the plume has not been identified.
- No estimates of dissolved and total contaminant mass in the aquifers have been calculated to provide a benchmark to measure mass removal progress.

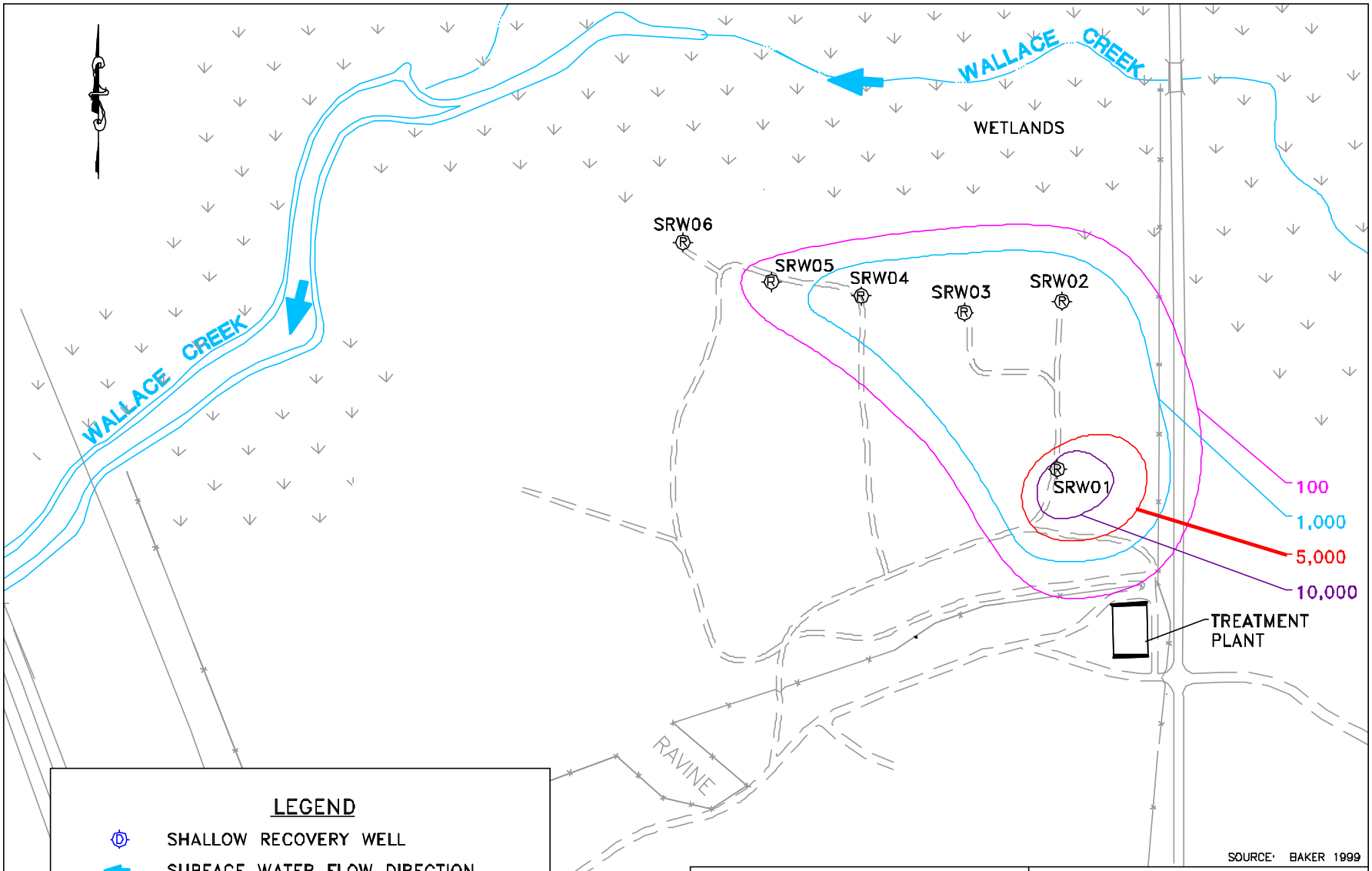
7.3 OU2 System Descriptions and Design Basis

The groundwater P&T system at OU2 has been in operation since January 1996. The system was designed to collect and treat contaminated groundwater from the central portion of Lot 203 (Site 82) at OU2 and to mitigate the potential for off-site contaminant migration. The OU2 treatment system is also used to treat wastewater derived from the nearby Bio-Cell operation. Contaminated groundwater is extracted via a network of shallow and deep extraction wells and is then treated and discharged to Wallace Creek. Figures 7-3 and 7-4 depict a plan view of the shallow and deep extraction systems.

Table 7-4. Remediation Levels for Contaminants of Concern at OU2 (Sites 6 And 82) MCB Camp Lejeune, North Carolina

Media	Contaminant of Concern	Remediation Goal	Units
Groundwater	1,2-Dichloroethene	0.38	µg/L
	Trans-1,2-Dichloroethene	70	µg/L
	Ethylbenzene	29	µg/L
	Tetrachloroethene	0.7	µg/L
	Trichloroethene	2.8	µg/L
	Vinyl Chloride	0.015	µg/L
	Arsenic	50	µg/L
	Barium	1,000	µg/L
	Beryllium	4	µg/L
	Chromium	50	µg/L
	Lead	15	µg/L
	Manganese	50	µg/L
	Mercury	1.1	µg/L
	Vanadium	80	µg/L
Soil	PCBs (total)	10,000	µg/kg
	4,4'-DDT	60,000	µg/kg
	Benzene	5.4	µg/kg
	Trichlorethene	32.2	µg/kg
	Tetrachloroethene	10.5	µg/kg
	Arsenic	23,000	µg/kg
	Cadmium	39,000	µg/kg
	Manganese	390,000	µg/kg

NOTES:
µg/L = microgram per liter
µg/kg = microgram per kilogram



LEGEND

SHALLOW RECOVERY WELL

SURFACE WATER FLOW DIRECTION

TOTAL VOC CONCENTRATION CONTOUR (ug/L)

SCALE IN FEET 0 300

RADIAN INTERNATIONAL

Figure 7–3. SHALLOW GROUNDWATER PUMP AND TREAT SYSTEM

OPERABLE UNIT 2

DRAWING NO	CONTRACT NO	DATE
lej99093.dwg	BD3016.0402	06/25/99

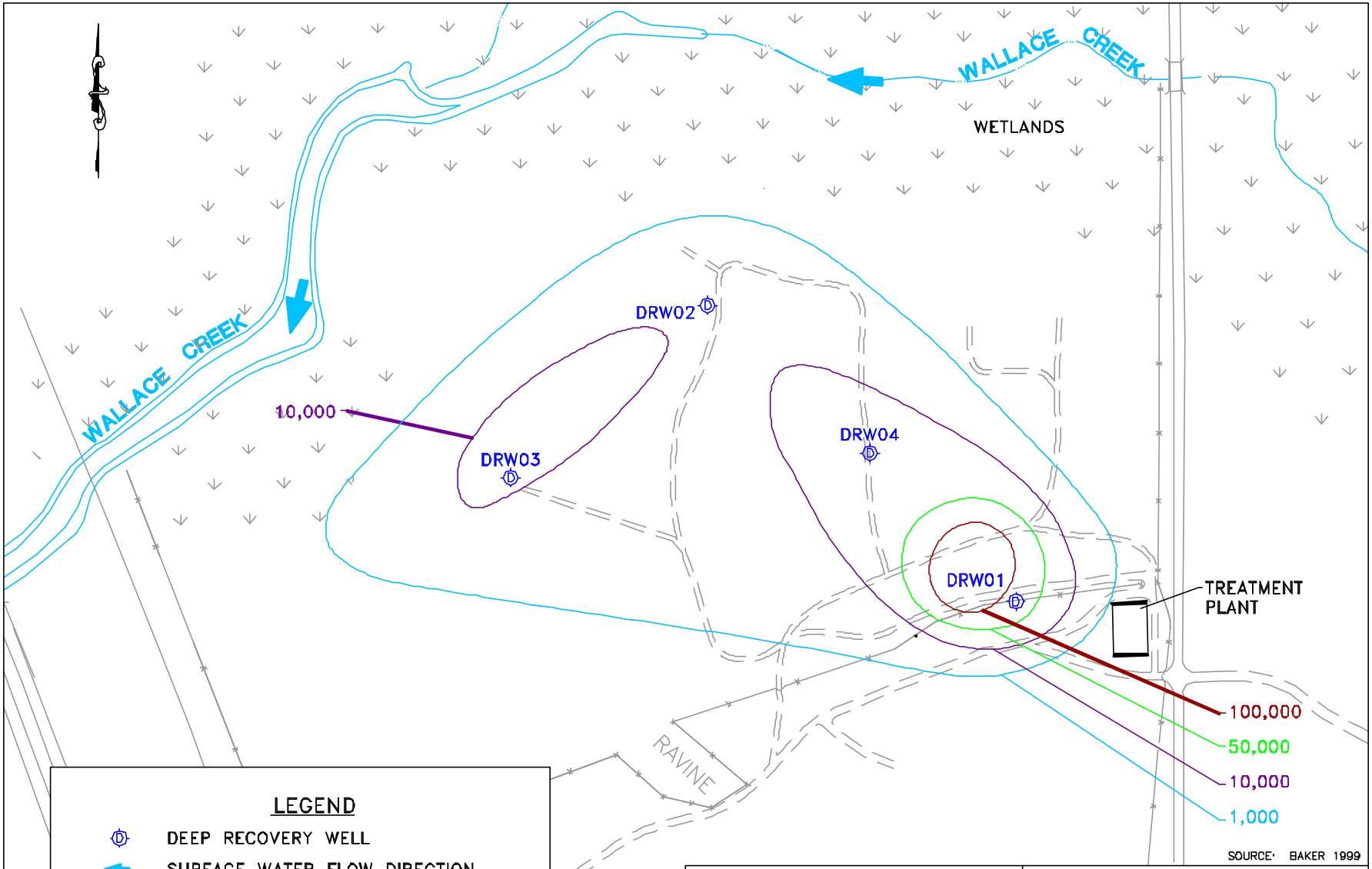


Figure 7-4. DEEP GROUNDWATER PUMP AND TREAT SYSTEM

OPERABLE UNIT 2

DRAWING NO	CONTRACT NO	DATE
lej99092.dwg	BD3016.0402	06/25/99

7.3.1 Description of Extraction and Monitoring Well Network at OU2—The groundwater P&T system at OU2 is designed to contain and remediate contaminated groundwater from the central portion of Site 82. The system includes six shallow extraction wells (SRW01 to SRW06) and four deep extraction wells (DRW01 to DRW04); however, shallow well SRW06 is not active.

Shallow well SRW01 is located in an area of VOC concentrations exceeding 10,000 µg/L within the surficial aquifer, and the other shallow extraction wells are located downgradient to limit contaminant migration (Baker, 1999b). The four deep wells are located in areas of VOC concentrations exceeding 1,000 µg/L within the Castle Hayne aquifer; however, extraction well DRW01 is within the 50,000 µg/L concentration contour.

The shallow extraction wells are completed in the surficial aquifer and are constructed with six-inch diameter stainless steel casing and 10-slot wire-wrap screen. Each well is 35 feet deep with 20 feet of screen surrounded by a sand filter pack. An electric submersible pump is set within two feet of the bottom in each well. Except for SRW05, each active shallow well is pumped continuously at between four and eight gallons per minute resulting in drawdown of about ten feet. Well SRW05 is pumped intermittently on a cycle that allows adequate water level extraction.

The deep extraction wells are completed in the upper portion of the Castle Hayne aquifer and are constructed with six-inch diameter stainless steel casing and 20-slot wire-wrap screen. Well DRW04 is 154 feet deep with 30 feet of screen surrounded by a sand filter pack. Wells DRW02 and DRW03 are each 110 feet deep with 30 feet of screen surrounded by a sand filter pack. Well DRW01 is 101 feet deep, with 20 feet of screen. Well DRW01 was designed to be 110 feet deep, but flowing sands prevented its installation to that depth. Another consequence of the flowing sand problem is that the lower half of the well screen is surrounded by native sand and not a sand filter pack. An electric submersible pump is set within one foot of the bottom in three of the four deep extraction wells. The pump in DRW01 is set higher in the well to overcome pumping large amounts of sand due, at least in part, to the absence of a complete filter pack.

Total groundwater flow to the treatment system from the deep extraction wells is about 275 gallons per minute; however, pumping rates among the individual wells vary. The pumping rate of DRW01, about 30 gallons per minute, is the lowest among the four deep extraction wells in an effort to reduce pumping sand. The pumping rate for well DRW04 is the highest of the deep wells at about 150 gallons per minute. The pumping rate at both DRW02 and DRW03 is approximately 40 gallons per minute. Pumping at these rates results in about ten feet of drawdown in each of the four wells.

The groundwater monitoring network at Sites 6 and 82 in OU2 is intended to determine whether contaminants in groundwater underlying the operable unit are still present, have migrated, are degrading naturally, or have been removed by extraction wells (Baker, 1999b). The well network includes eight shallow monitoring wells and 13 deep monitoring wells. Samples are also collected from the shallow and deep extraction wells. In 1998, two new shallow monitoring wells (GW41 and GW42) and a replacement monitoring well (GW16) were installed at OU2. The monitoring well locations at Sites 6 and 82 are illustrated in Figure 7-1.

7.3.2 Description of Aboveground Treatment Train at OU2—A schematic of the aboveground groundwater treatment plant for OU2 is presented in Figure 7-5. The following describes the treatment process.

Shallow Groundwater Influent Flow and Iron Removal. Groundwater from the shallow wells is pumped to an iron removal system. The iron removal system consists of a mix tank, an incline plate clarifier, and a sludge-thickening tank. In the mix tank, compressed air is gently bubbled through the water to oxidize any ferrous iron to ferric iron. Following air injection, the pH is adjusted with caustic, followed by the addition of a polymer solution and a metal scavenger chemical to flocculate the solids. The flocculated solids then settle out in the plate clarifier while the clarified water is pumped through the head tank to the groundwater collection tank. Sludge from the clarifier is then transferred to the sludge-thickening tank. Solids from the sludge-thickening tank are pumped to a filter press for dewatering. The sludge cakes are shipped to an appropriate off-site disposal facility.

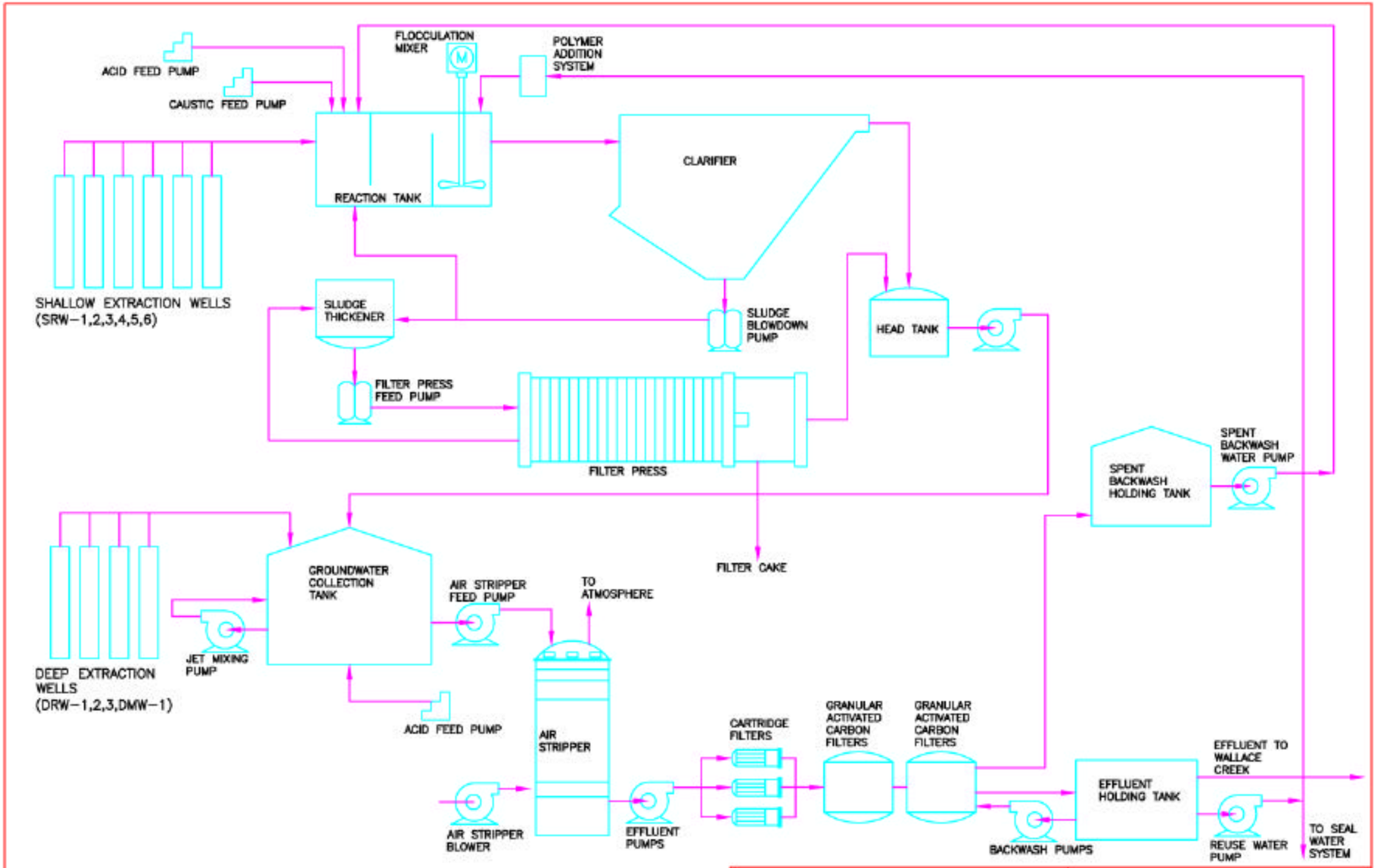
Deep Groundwater Influent Flow. Groundwater from the deep aquifer wells is pumped directly to the groundwater collection tank where it is combined with the clarified water from the shallow wells. In this tank, the pH is adjusted and then pumped to the air stripper.

Air Stripping. Water from the groundwater collection tank is pumped to a packed tower air stripper to remove VOCs. The stripper vapor is discharged directly to the atmosphere.

Filtration and Granular Activated Carbon (GAC) Adsorption. The water is pumped from the air stripper holding tank through a cartridge filtration system to remove additional fines. Following filtration, the water is sent through GAC for polishing.

Treated Effluent Storage and Discharge. The treated water is stored in the treated effluent holding tank and then discharged by gravity to the outfall at Wallace Creek. Some of the effluent water is reused for backwash or plant service.

Instrumentation and Control System. A PLC is used to control the OU2 treatment plant. The main control features are simple feedback, pH control, and cascade shut down of process operation based on tank levels. The PLC is capable of connection via telephone modem to a remote monitoring location. Manual restart of the system is required after power outages. Audible and visible alarms are in place to alert operators to changes in the process that are considered critical. These critical alarms may also be transmitted via modem. A summary of the normal operation and status of the instrumentation and control system (manual and/or controlled by the PLC) is provided below in Table 7-5.



NOT TO SCALE

RADIAN INTERNATIONAL
A DAMES & MOORE GROUP COMPANY

FIGURE 7-5. PROCESS FLOW DIAGRAM

OU2 GROUNDWATER TREATMENT PLANT

DRAWING NO.	CONTRACT NO.	DATE
lej99079.dwg	803016.0402	06/25/99

Table 7-5. Summary of the OU2 Groundwater Treatment Plant Instrumentation and Control System

Process	Normal Operation
Mix tank	Automatic with manual adjustments for air flow
Chemical storage and feed pumps	Automatic
pH probe	Automatic with periodic calibration
Clarifier	Automatic no adjustments required
Sludge blowdown pump	Automatic with manual adjustment for sludge recycle
Head tank and transfer pump	Automatic
Sludge thickener	Manual transfer of solids from sludge thickener
Sludge dewatering press and feed pump	Manual activation to process batches of sludge
Groundwater collection tanks, jet mixing pump, and acid feed pump	Automatic
Air stripper and feed pump	Automatic with adjustments required to control cycling
Cartridge filters	No adjustments required, manual change-out
Liquid phase GAC	Automatic
Effluent storage and discharge system	Automatic
Backwash holding tank and pump	Automatic backwash
Building drainage sump	Automatic

NOTES:
GAC = Granular Activated Carbon

7.3.3 Design Specifications and Parameters for OU2—The P&T system was designed to collect and treat contaminated groundwater and to mitigate the potential for off-site contaminant migration. The remedial objective for this system is to remove contaminants from the groundwater as well as contain the contaminant plume. The treatment plant was designed to run automatically with the help of the instrumentation and controls built into the system. The initial design flows for the P&T system were 5 gpm for each shallow well and between 30 and 150 gpm for each deep well with a total system capacity flow of 500 gpm (Baker, 1994b).

The treatment plant is designed to remove VOC and metals concentrations to below North Carolina limits for discharge into Wallace Creek and to remove concentrations of the inorganic compounds that could foul the treatment system. These limits for discharge are shown in Table 7-6.

To monitor the performance of the OU2 treatment plant, samples are collected monthly as shown in Table 7-7.

Table 7-6. Effluent Standards for OU2 Treatment Plant

Groundwater Contaminant of Concern	Effluent Discharge Limits (µg/L)
Trichloroethene	92.4
1,2-Dichloroethane	113,000
Trans-1,2-Dichloroethene	100
Ethylbenzene	430
Tetrachloroethene	0.8
Trichloroethane	92.4
Vinyl Chloride	525
Arsenic	50
Barium	1,400
Beryllium	0.117
Chromium	20
Lead	25
Manganese	3,500
Mercury	0.025
Vanadium	6,000

NOTES:
µg/L = micrograms per liter

Table 7-7. Monthly Performance Monitoring for OU2 Groundwater Treatment Plant

Analytes	Shallow Aquifer Influent	Deep Aquifer Influent	Air Stripper Effluent	GAC (final) Effluent
VOCs	X	X	X	X
Metals	X	X	X	X
TDS	X	X	X	X
TSS	X	X		X
pH	X	X		X

NOTES:
GAC = Granular Activated Carbon
TDS = Total Dissolved Solids
TSS = Total Suspended Solids
VOC = Volatile Organic Compounds
pH = Hydrogen Potential

7.3.4 System Upgrades and Modifications at OU2—The O&M contractor replaced the piston-type air compressor with a rotary screw-type compressor to achieve improved uptime and maintenance costs.

7.3.5 Total Capital Costs at OU2—The total capital cost of the OU2 pump and treat system was $4.66M. Given an estimated operational life of 20 years, this capital cost translates to over $400,000 per year.

7.4 OU2 Good Management Practices

This section is intended to highlight good management practices that have been implemented at Camp Lejeune by its O&M contractors. The following are considered good O&M practices:

- The treatment system at OU2 is also used to treat wastewater derived from the Bio-Cell operation. This results in cost savings over off-site disposal of these wastes.

- The O&M contractor bypasses extracted groundwater from deep wells in the OU2 area around the preliminary metals precipitation unit processes. The shallow groundwater (25 gpm) extracted from the OU2 area contains high concentrations of dissolved iron and must be pretreated to prevent fouling of downstream equipment. The groundwater extracted from the deeper unit (275 gpm) does not present an iron fouling problem. Bypassing the deep groundwater around the metals pretreatment units results in significant savings associated with capital equipment costs and chemical costs.

- The P&T system at OU2 is well designed and is operating at or above design specifications. More than 41,000 pounds of contaminants have been removed during the operating period of January 1997 to March 1999. The OU2 P&T system has been operating cost-effectively at $49 per pound of contaminant removed.

7.5 OU2 System Performance Baseline

The overall technical and cost effective performance for the OU2 aboveground treatment system in comparison to its design basis has been good. It is treating water from the shallow and deep groundwater zones at 60% of its design capacity of 500 gpm, and more than 41,000 pounds of contamination were removed during the operating period of January 1997 to March 1999. This results in an average cost per pound removed of only $49, which is considered extremely cost effective. This data is explained in more detail in section 7.5.1.

In contrast, the performance of the subsurface shallow and deep extraction well networks has several limitations and data gaps listed below and described in more detail in Section 7.5.2. These limitations raise serious doubts as to whether OU2 can be actively

remediated to the cleanup levels specified in the ROD with conventional Pump and Treat technology.

- Vertical and horizontal extent of contamination in both the shallow and deep zones is undefined;
- Average total VOC influent concentration is 21 mg/l with an increasing trend;
- Insufficient evidence to demonstrate plume capture for the shallow zone;
- Downgradient shallow zone extraction wells are diluting mass removal effectiveness;
- Presence of DNAPL in the shallow and deep zones is highly likely, and the extent of DNAPL zones is undefined; and
- Capture zone indicated by deep zone extraction well data is insufficient to prevent continued downward migration of DNAPL.

7.5.1 OU2 Treatment System Cost and Performance Baseline— Figures 7-6 through 7-9 are cost and performance plots for the period of January 1997 through March 1999 for the OU2 Treatment System. Taken collectively, they provide valuable information on the current and historical performance baseline for this system, and are discussed below:

- **Figure 7-6, "Influent VOC Concentrations vs. Time":** As shown in Figure 7-6, the monthly total VOC influent concentration for the deep zone shows a slightly increasing trend. Almost all monthly concentrations are between 10 and 27 mg/l. Concentrations in this range are indicative of DNAPL in the subsurface. By contrast, the shallow zone influent concentration is relatively stable and averages 1.6 mg/l; however, as discussed in section 7.5.2, this average concentration is biased low since five of the six shallow zone extraction wells are located in the less-contaminated downgradient portion of the plume.
- **Figure 7-7, "Cumulative Mass Recovered vs. Time":** The OU2 System removed more than 41,000 pounds of contamination during the operating period of January 1997 to March 1999. As discussed in section 7.5.2, it is likely that this removal rate could increase dramatically if additional extraction wells are installed with screened intervals targeted at discrete zones of suspected DNAPL.
- **Figure 7-8, "Cumulative Costs vs. Cumulative VOCs Recovered":** Figure 7-8 graphically demonstrates the substantial cost effectiveness of the OU2 Treatment System. The relatively flat slope of this line indicates that the amount of mass removed per dollar spent is more than adequate.
- **Figure 7-9, "Average Cost Per Pound Recovered vs. Time":** As shown in Figure 7-9, the average cost per pound removed for the OU2 system is trending slightly upward; from approximately $25 per pound in April 1997 to approximately $52 per pound in March of 1999. The average cost over the entire operating system is only $49 per pound, i.e., very cost effective.

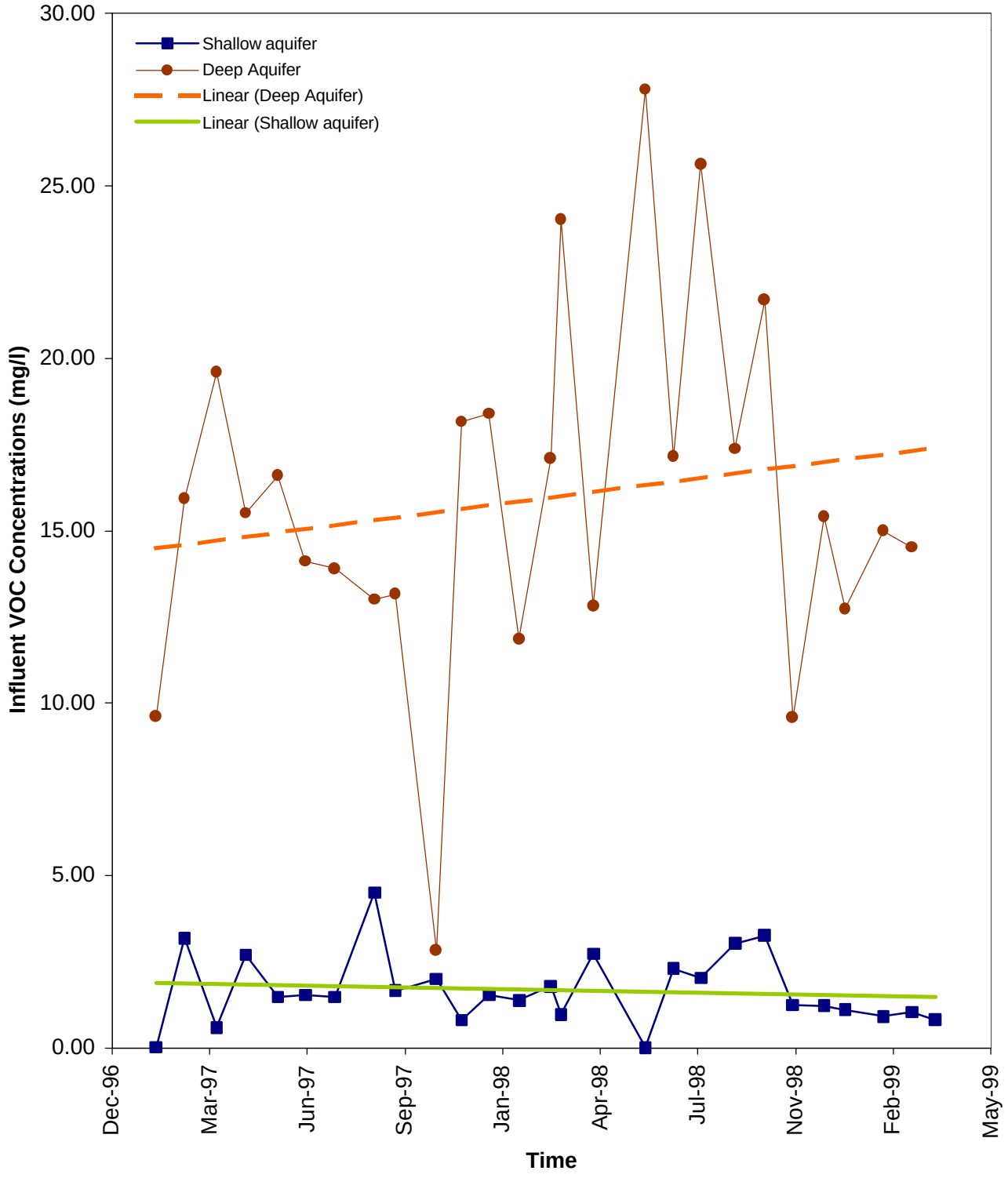


Figure 7-6. Influent VOC Concentrations vs. Time OU2 (Lot 203) - Shallow and Deep Aquifers

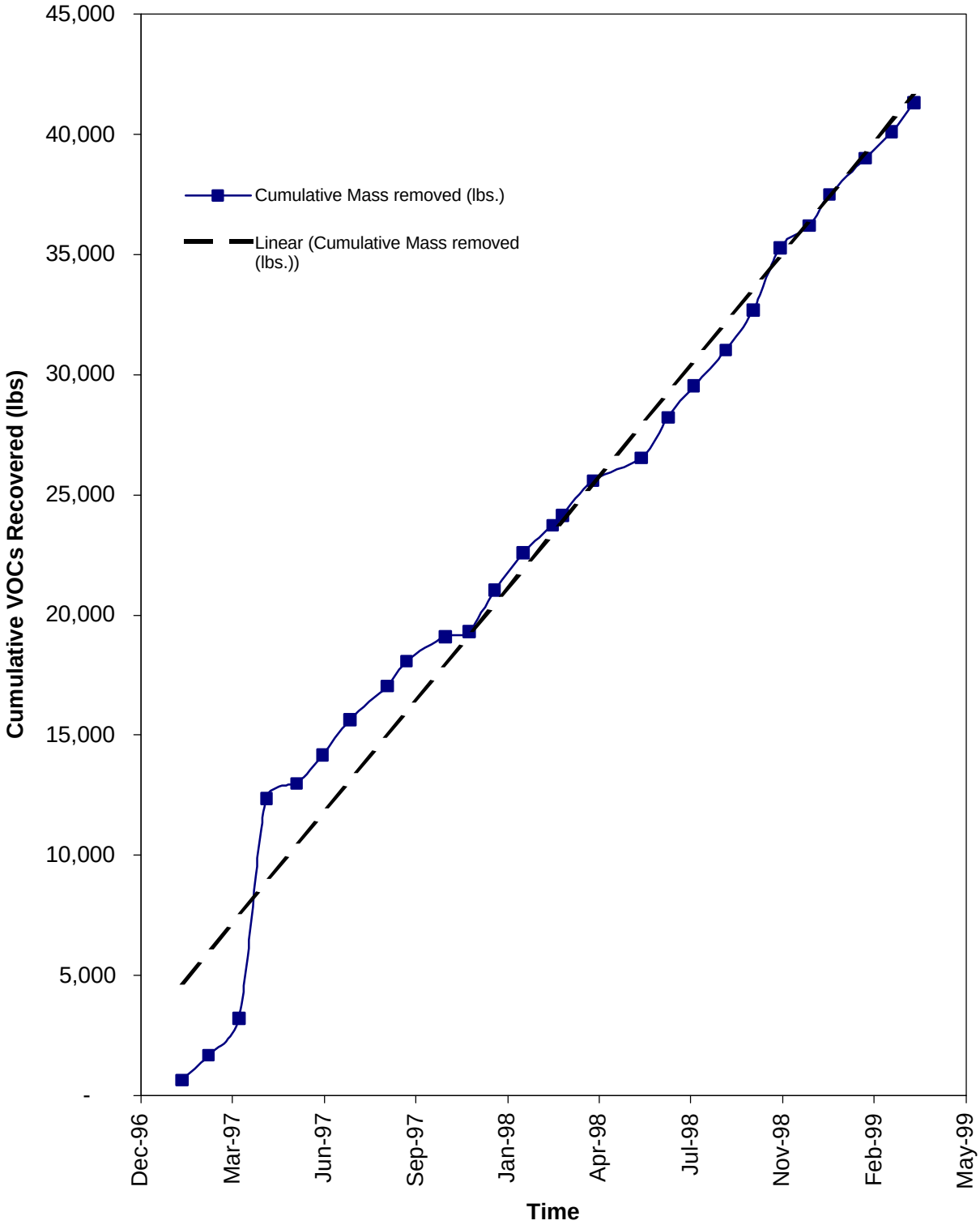


Figure 7-7. Cumulative Mass Recovered vs. Time OU2 (Lot 203) - Shallow and Deep Aquifers

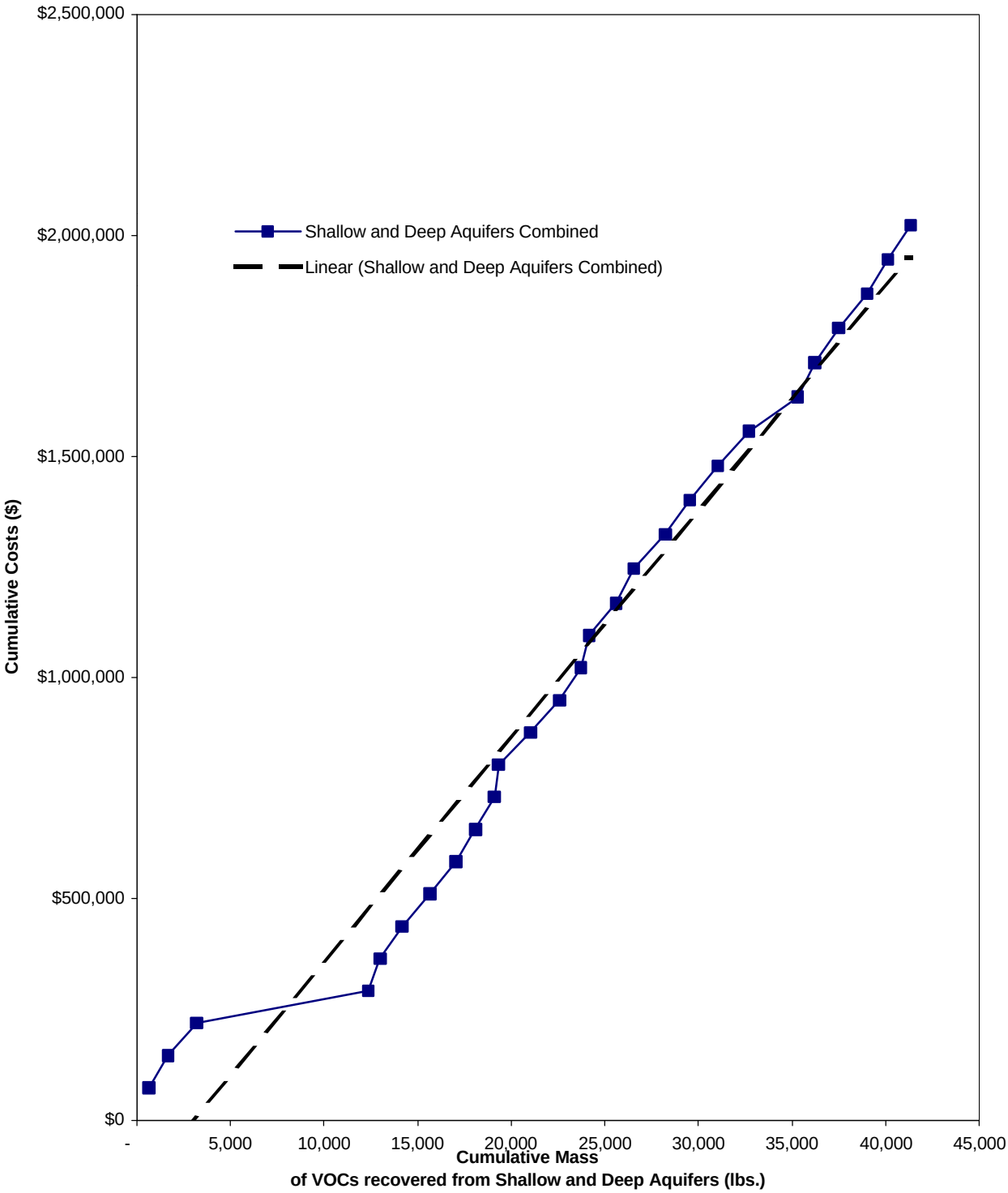


Figure 7-8. Cumulative Costs vs. Cumulative VOCs Recovered OU2 (Lot 203) - Shallow and Deep Aquifers

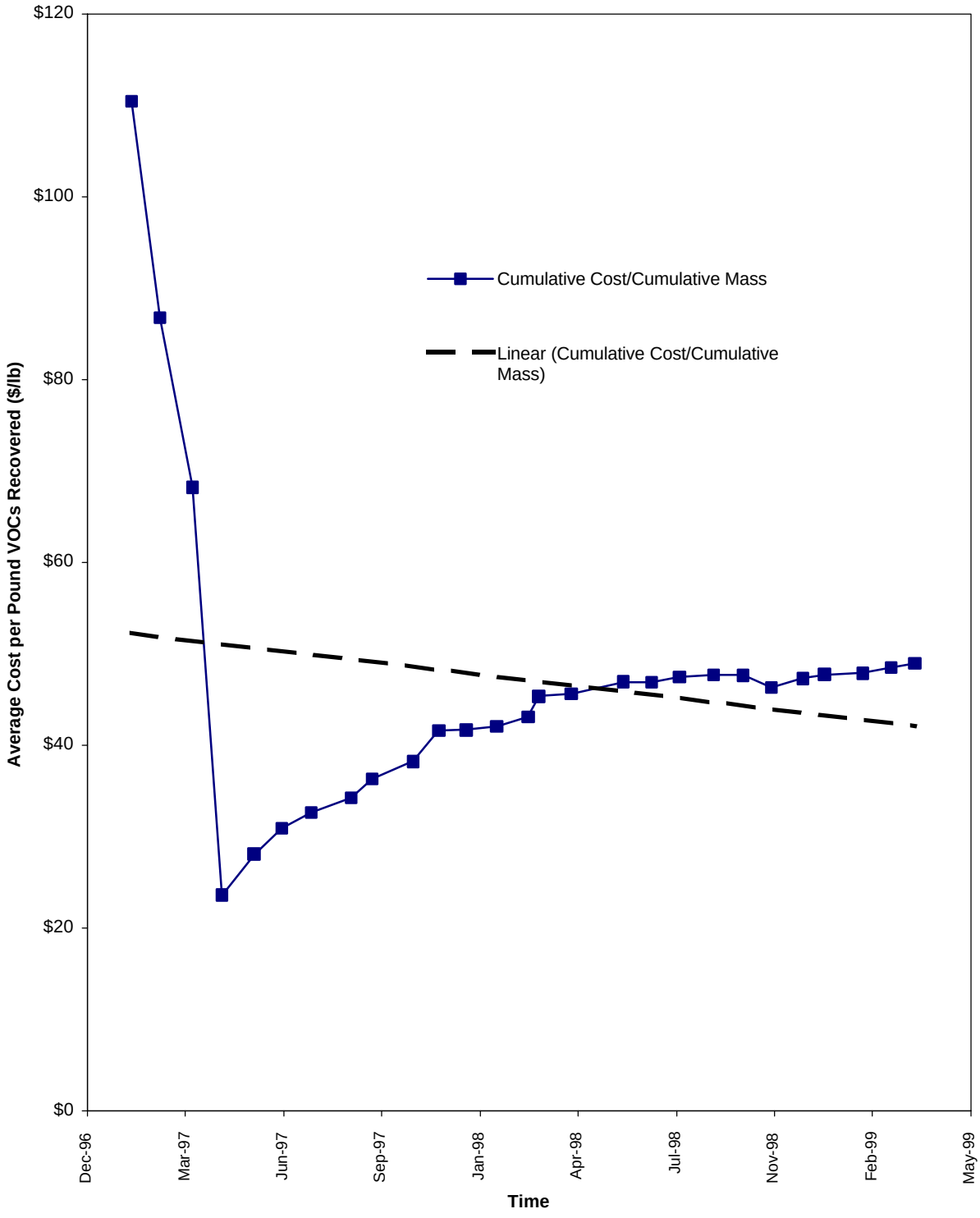


Figure 7-9. Average Cost per Pound Recovered vs. Time OU2 (Lot 203) Shallow and Deep Aquifers

Table 7-8 summarizes selected performance parameters for the OU2 system.

Table 7-8. OU2 System Design Versus Performance Data

Parameter	Design	Actual Average[a]	Actual Median[a]
Combined Aquifer Average Flowrate (gpm)	500	297.06	278.10
Monthly Aquifer Volume (gallons)	12,528,00	10,405,729	10,113,500
10% of volume for Shallow Aquifer (gallons)	1,296,000	1,040,573	1,011,350
90% of volume for Deep Aquifer (gallons)	11,232,000	9,365,156	9,102,150
Shallow - Monthly Mass removed (lbs)	N/A	14.54	14.56
Deep - Monthly Mass removed (lbs)	N/A	1,516	1,275
Total Monthly Mass removed from Both Aquifers (lbs)	N/A	1,531	1,285
Average cost per mass removed ($/lb)	N/A	$47.14	$46.35

[a] Based on performance data from January 1997-March 1999.
NOTES:
gpm = gallons per minute
mg/L = milligrams per liter
lb(s) = pound(s)
N/A = not applicable

7.5.2 OU2 Extraction and Monitoring Well Network Performance—This section compares the performance of the shallow and deep extraction well networks at OU2 against the criteria specified in Tables 7-2 and 7-4. It also identifies data gaps that represent, in part, the inability of the current monitoring well network to adequately measure performance.

7.5.2.1 OU2 Shallow Extraction and Monitoring Well Network Performance

Data Gaps

The following data gaps were identified in evaluating the performance of the shallow extraction and monitoring well networks at OU2. The significance of these data gaps is addressed in the following sections.

- The number and location of LTM points for water level measurements is inadequate to demonstrate whether or not the contaminant plume is contained in three dimensions;
- The number and location of LTM sampling points is inadequate to estimate the limits of the contaminant plume; and
- Isoconcentration contour maps of individual COCs are not available to illustrate the complete extent of the plume.

Hydraulic Head and Gradients

Hydraulic head represented by water levels measured at OU2 monitoring wells in July 1998 do not demonstrate that the shallow extraction well network has established a capture zone within the surficial aquifer. The measurements indicate the general direction of groundwater flow in the east central portion of Site 82 at OU2; however, the absence of monitoring wells downgradient of the extraction wells precludes evaluating the hydraulic effects of pumping on plume containment and the presence of a capture zone.

Water levels measured at two well cluster locations (wells 6-GW01 and 6-GW28) installed within the contaminant plume indicate that a downward gradient exists between the surficial aquifer and the underlying Castle Hayne aquifer. The downward gradient is expected because of the pumping rates associated with extraction wells completed in the Castle Hayne aquifer.

Pumping Rates

The basis of design report (Baker, 1994) for OU2 estimated that each shallow extraction well in the network would yield up to five gallons per minute. Typically, the actual yield of most of the shallow wells has been slightly higher. Baker (1999b) estimated that during the last six months of 1998, the combined yield of the five operating shallow wells was between 20 and 40 gallons per minute. Based on estimates of the contaminant plume's size and the volume of water extracted in the last half of the year, the shallow well network flushed approximately 0.35 pore volumes of groundwater through the plume in 1998. However, the location of four extraction wells, SRW02 to SRW05, near the apparent edge of the plume results in the removal of significant volumes of relatively uncontaminated groundwater.

During the five quarters that ended in December 1998, the extraction well field was operational approximately 77.5% of the time; uptime improved to 92% in the last quarter of 1998. However, during the last quarter of 1998, shallow extraction well SRW02 was not operational due to maintenance problems.

Pumped Water Quality

Historical data from the treatment plant indicate that the mean VOC concentration of the influent from the shallow extraction wells is approximately 1.54 mg/L. However, several peaks in the record contribute to a higher mean VOC concentration of 1.77 mg/L. Excluding the peaks, the influent concentration has exhibited a relatively flat trend. The relatively low influent concentration over the period of record is expected because all but one of the shallow extraction wells are located near the downgradient edge of the plume and not within the areas of highest contamination. As noted previously, a downgradient extraction well network is the least effective configuration for achieving groundwater restoration, because contaminants must travel along the entire length of the plume to reach the wells. More effective well placement requires installing extraction wells in the areas of highest contamination; along the plume axis; and within areas of the least mobile

contaminants to collectively maximize mass removal, reduce the pumping of clean water, and minimize contaminant travel time and distance.

The influent concentration combined with the shallow extraction well system's pumping rate has resulted in moderate contaminant mass removal from the surficial aquifer. Between January 1997 and December 1998, the shallow extraction wells removed approximately 365 pounds of VOCs at an average rate of 15.7 pounds per month.

Contaminant Concentration and Distribution

No monitoring wells are located downgradient of the extraction wells to indicate if plume migration has been contained.

The estimated areal extent of total VOCs less than 100 ppb in the surficial aquifer is depicted in Figure 7-2a. Isoconcentration contours illustrating the shallow plume extent at concentrations less than or equal to ROD-specified cleanup levels cannot be reliably drawn based on the density of the current monitoring well network. However, concentrations of COCs in the influent, as well as in the individual monitoring and extraction wells, appear relatively stable and well above remediation levels. Consequently, little progress toward achieving groundwater restoration is demonstrated by the data.

7.5.2.2 OU2 Deep Extraction and Monitoring Well Network Performance

Data Gaps

The following data gaps were identified in evaluating the performance of the deep extraction and monitoring well networks at OU2. The significance of these data gaps is addressed in the following sections.

- The number and location of LTM sampling points is inadequate to estimate the limits of the contaminant plume; and
- Isoconcentration contour maps for individual COCs are not available to illustrate the complete extent of the plume.

Hydraulic Head and Gradients

Water levels measured at OU2 in July 1998 suggest that the deep extraction well network has established a capture zone within the Castle Hayne aquifer. The measurements indicate that hydraulic gradients toward the extraction wells have been established and that groundwater within the Castle Hayne aquifer flows toward the deep extraction wells. However, there is no evidence that the upward gradient is of sufficient magnitude to overcome potential downward DNAPL migration.

Water levels measured at two well cluster locations (wells 6-GW01 and 6-GW40) installed within the contaminant plume indicate that an upward gradient exists between the

upper and middle portions of the Castle Hayne aquifer. The upward gradient suggests that the dissolved VOC plume is contained vertically at least in these two locations. It does not suggest that contaminants, which may have migrated down into the aquifer prior to the implementation of remediation, are within the capture zone.

Pumping Rates

The basis of design report (Baker, 1994) for OU2 estimated that each of the three proposed deep extraction wells would yield 150 gallons per minute. However, the pumping rate of well DRW-1 is only 30 gallons per minute, and the pumping rates of DRW02 and DRW03 are approximately 40 gallons per minute each. Only the pumping rate of well DRW04 achieved or exceeded its design estimate of 150 gallons per minute. Baker (1999b) estimated that during the last six months of 1998, the combined yield of the four deep extraction wells was between 254 and 274 gallons per minute. Based on estimates of the contaminant plume's size and the volume of water extracted in the last half of the year, the deep extraction well network flushed approximately 0.26 pore volumes of groundwater through the plume in 1998, compared to a recommended design minimum of 0.3 pore volumes per year. Although adding wells would increase flushing rates, potential DNAPL in the subsurface is a long-term source of dissolved contaminants that could preclude achieving restoration levels.

During the five quarters that ended in December 1998, the extraction well field was operational approximately 77.5% of the time, although uptime improved to 92% in the last quarter of 1998. In addition, well DRW01 is being pumped below its design rate to limit sand entry into the well because of incomplete filter pack emplacement. The diminished pumping rate of DRW01 is limiting mass removal, because the well is located in the most highly contaminated area of the plume.

Pumped Water Quality

Historical data from the treatment plant indicate that the mean VOC concentration of the influent from the deep extraction wells is about 16.3 mg/L. However, a peak of concentration early in the record results in a mean VOC concentration of 20.5 mg/L. The influent concentration is the result of locating the extraction wells in, or near, areas of high VOC contamination within the plume. In general, the influent concentration shows a slight upward trend suggesting that dissolved VOCs continue to be drawn toward the extraction wells from highly contaminated areas.

The influent concentration combined with the shallow extraction well system's pumping rate has resulted in high contaminant mass removal from the Castle Hayne aquifer. Between January 1997 and December 1998, the deep extraction wells removed approximately 37,125 pounds of VOCs at an average rate of 1,283 pounds per month. Contaminants continue to migrate toward the extraction wells from more distant "hot spots." A large mass of contaminant remains in the aquifer in the dissolved phase and potentially as residual and free phase DNAPL.

Contaminant Concentration and Distribution

Results from two monitoring wells (6-GW35D and 6-GW37D) that are located regionally downgradient of the extraction wells provide inconclusive information regarding plume containment in the Castle Hayne aquifer at OU2. No VOCs were detected in two samples collected from well 6-GW35D in 1998, but several VOCs were detected at concentrations exceeding remediation levels in four consecutive samples collected from well 6-GW37D between October 1997 and July 1998. The apparent trend in concentration of the four samples was upward.

The estimated areal extent of total VOCs less than 1000 ppb in the Castle Hayne aquifer is depicted in Figure 7-2b. As with the OU2 shallow zone, the current density of the monitoring well network prevents the production of a plume contour depicting the extent of the deep zone plume at concentrations less than or equal to ROD-specified cleanup limits. In addition, concentrations of COCs in the influent, as well as in the individual monitoring and extraction wells, are level or increasing, and above remediation levels. Consequently, little progress toward achieving groundwater restoration is demonstrated by the data.

Vertically, the highest concentration of VOCs has been detected in monitoring wells screened at depths between approximately 100 and 115 feet. Shallow monitoring wells, screened to approximately 35 feet, typically exhibit lower VOC concentrations. Deeper monitoring wells, screened below 220 feet, exhibit VOC concentrations that approach trace levels. In comparison, deep extraction wells DRW02 and DRW03 are screened between 80 and 110 feet, generally coinciding with the depth interval that exhibits the maximum VOC concentrations detectable by the existing monitoring network. Extraction well DRW01 is screened from 81 to 101 feet, slightly above the interval exhibiting maximum VOC concentrations, whereas DW04 is screened below the interval at 124 to 154 feet. However, there is an absence of monitoring points within the contaminant plume at depths from 35 to 75 feet and from 120 to 220 feet. These unmonitored intervals could conceivably exhibit higher VOC concentrations than have been measured. Therefore, while the screen placements in the extraction wells are effective in contaminant removal, the available data offers no assurance that the well screens target the most contaminated depths within the plume.

7.5.3 OU2 Aboveground Treatment Train Performance—Since operation began in January 1997, the aboveground treatment train for the plant at OU2 has been performing at a level that meets requirements of the design basis. In 1997 and 1998, the plant has operated at an average flowrate of 297 gpm, 60% of its design flow of 500 gpm. Most of the equipment at the plant is functioning as designed. However, according to the equipment operator, the polymer pump has required excessive maintenance to keep in operation.

Over the last 27 sampling events (January 1997 to March 1999), effluent from the GAC exceeded the effluent standards for perchloroethylene (PCE) on three occasions (February, March, and May 1998). Over this same time period, only six effluent samples (February to July 1998) from the air stripper contained concentrations over the effluent

standards for PCE in Table 7-6. The air stripper packing was cleaned in March/April 1998, improving the air stripper removal efficiencies during this period from 62 to 99.9% for PCE. However, exceedance still occurred, primarily due to the PCE effluent standards being very low (0.8 µg/l).

Two 8,000-pound GAC units are currently used to provide polishing of the groundwater effluent prior to discharge to Wallace Creek. Cartridge filters are used to remove fines from the groundwater prior to the GAC units to avoid clogging the units. However, the amount of contaminant removal by these units is minimal, as most of the VOCs are removed by the air stripper. When PCE is not present in the waste stream, the GAC units (and cartridge filters) are not necessary for the removal of contaminants from the effluent, but are required by the current NPDES permit.

Although the GAC effluent concentrations were below NPDES requirements in 1997, for the majority of the time, concentrations of VOCs in the GAC effluent were higher than the air stripper effluent. This indicates that the GAC may have been fully loaded and contributing VOCs to the effluent stream.

The detection limit for mercury (0.1 µg/l) in the performance sampling is higher than the effluent discharge limit (0.025 µg/l), making it difficult to determine if discharge limits are being exceeded on a regular basis. However, two known exceedances did occur in August and September 1997.

Based on records beginning in January 1997, the O&M contractor has performed all routine monthly, quarterly, and annual maintenance on the OU2 Treatment Plant as required in Tables 2.2 and 2.3 of the *Operations and Maintenance Manual for Camp Lejeune, Groundwater Treatment System* (OHM, 1996). During 1997, the treatment plant operated a total of 316 days, for an annual operating percentage of 87%. While in 1998, the treatment plant operated a total of 285 days, for an annual operating percentage of 78%. The main reason for the decrease in operation in 1998 was due to maintenance of the air stripper (pressure washing of packing) in March and April 1998. Delays during 1997 included malfunction of the pressure switch on the air stripper blower, cartridge filters being unavailable, and replacement of the flow transmitter.

A review of the existing sampling and analysis plan for OU2 indicates that the individual effluent from each well is not analyzed separately. However, this sampling has been occurring for several quarters.

The annual operations and maintenance costs for the OU2 Groundwater P&T system are provided in Table 7-9. The capital costs to construct the OU2 P&T system were $4,660,000. Itemized capital, and operation and maintenance costs were not available for review.

Table 7-9. Annual Operation and Maintenance Costs for the OU2 Groundwater P&T System

Fiscal Year	Annual Operations Costs	Annual Maintenance and Enhancements Costs	Annual Utilities Costs	Total Annual Costs	Monthly Costs
1999	$350,000	$50,000	$37,906	$437,906	$36,492
1998	$341,192	NA	$42,665	$383,857	$31,988
1997	$266,646	NA	$33,668	$300,314	$25,026
1996	$275,000	$38,196	$2,800	$315,996	$26,333

NA = Not applicable

8.0 CONCLUSIONS AND RECOMMENDATIONS FOR OU2 SYSTEM

The number, location, and pumping capacity of the shallow extraction wells at OU2 are inadequate to achieve groundwater restoration. Hydraulic containment of the plume may be occurring, but cannot be demonstrated by the monitoring network. Mass removal to date has been moderate compared to other P&T systems. However, the likelihood of restoring groundwater quality to cleanup standards is unlikely. A major obstacle to meeting remediation levels is the probability that DNAPL is present at the site and will be a long-term, high concentration source of contaminants to groundwater. Consequently, while increasing the number of extraction wells may improve mass removal and plume containment, there is no evidence that site closure will be any more achievable.

Similarly, the current network of deep extraction wells at OU2 is inadequate to achieve groundwater restoration. A zone of hydraulic containment has been established, and mass removal to date has been high relative to the performance of other P&T systems. However, the likelihood of restoring groundwater quality with the existing system is minimal. A major obstacle to meeting remediation levels is the probability that DNAPL is present at the site and will be a long-term, high concentration source of contaminants to groundwater.

Based on the information reviewed and presented in Section 7.0, several recommendations for the OU2 P&T system can be made. The most strategic recommendations are considered a priority for consideration and are presented below. As with OU1, complete implementation of these recommendations will require an ESD or ROD amendment to the current OU2 ROD.

- Implement a remedial strategy for OU2 which addresses the source areas and dissolved phase portions of the plume with separate but integrated approaches as discussed in Section 8.1 below;
- Define the lateral and vertical extent of contamination for the source areas and dissolved phase plumes in both the shallow and deep aquifers as discussed in Sections 8.2.1 and 8.2.2; and
- Determine whether natural attenuation processes are occurring at acceptable rates in the shallow and deep aquifer zones as discussed in Section 8.1.

8.1 Long-Term Remedial Strategy Considerations for OU2

An appropriate remedial strategy at DNAPL sites should address the DNAPL zone and the “dissolved phase” portion of the plumes with separate, but integrated approaches. Typically, this includes aggressive source removal and containment in the DNAPL zone, along with active and/or passive treatment of the “dissolved phase” portion of the plume. A recommended approach specific to OU2 should combine and integrate both active and passive treatment options, and include the following elements:

- *To the extent practicable, delineate the extent of the DNAPL source areas in the shallow and deep groundwater zones.* Per the detailed recommendations in Section 8.2.2, this would require additional site investigation activities.
- *Continue and enhance aggressive mass removal in the DNAPL source areas for both the shallow and deep groundwater zones.* This recommendation could require the installation of additional targeted extraction wells.
- *Should state guidelines allow risk assessment in the future, consider revising the baseline human health risk assessment assumptions and cleanup level calculations to reflect industrial land use as the most probable future exposure scenario.*
- *Evaluate the applicability of natural wetland biodegradation processes in treating dissolved phase VOC contamination in the shallow groundwater zone at OU2.* The wetland area downgradient of the shallow VOC plume may prove to be an effective passive treatment option for OU2.
- *Evaluate the occurrence of MNA in both the shallow and deep groundwater zones for the treatment of dissolved phase VOCs.* This will require an assessment of MNA "lines of evidence" along with predictive plume migration modeling for both the shallow and deep groundwater zones in accordance with applicable MNA guidance documents. However, treatment of the dissolved phase portion of the plume with MNA would be more cost effective than trying to contain/treat the plume with conventional P&T options. In addition, MCB Camp Lejeune is already pursuing MNA as part of feasibility studies being conducted at other sites. Upcoming RODs for sites at OU No. 6 and OU No. 14 are under negotiation and propose MNA as the final remedy. These RODs are expected to be signed in calendar year 1999. MCB Camp Lejeune should use this opportunity to pursue MNA for OU2 as well.

8.1.1 Establishment of Alternate Concentration Limits (ACLs) – Given the observation that aquifer restoration to ROD-specified cleanup levels at OU2 is unlikely, it is recommended that MCB Camp Lejeune pursue discussions with the regulatory agencies to establish less stringent groundwater cleanup criteria known as Alternate Concentration Limits (ACLs). This recommendation should be implemented as a parallel action to the strategies outlined previously. Per SARA Section 121(d), ACLs can be established when it can be shown that groundwater discharging to a surface water body does not measurably degrade the surface water body; and, there are no known points of human exposure to the contaminated groundwater prior to it reaching the surface water body. This appears to be the case for OU2, where some portion of the contaminated groundwater currently discharges to Wallace Creek.

If the above conditions are met, then the allowable ACL for the plume is the groundwater contaminant concentration discharging to the surface water body without degrading its water quality. It is expected that this allowable concentration would be significantly higher than MCLs and/or current State of North Carolina standards.

Typically, supporting data requirements to establish ACLs include simple mixing zone model results and/or sampling results from the surface water body. Similar to the approach described in Section 8.2.2, passive diffusion samplers could be placed in the bed of Wallace Creek to evaluate whether groundwater discharge from OU2 measurably impacts Wallace Creek.

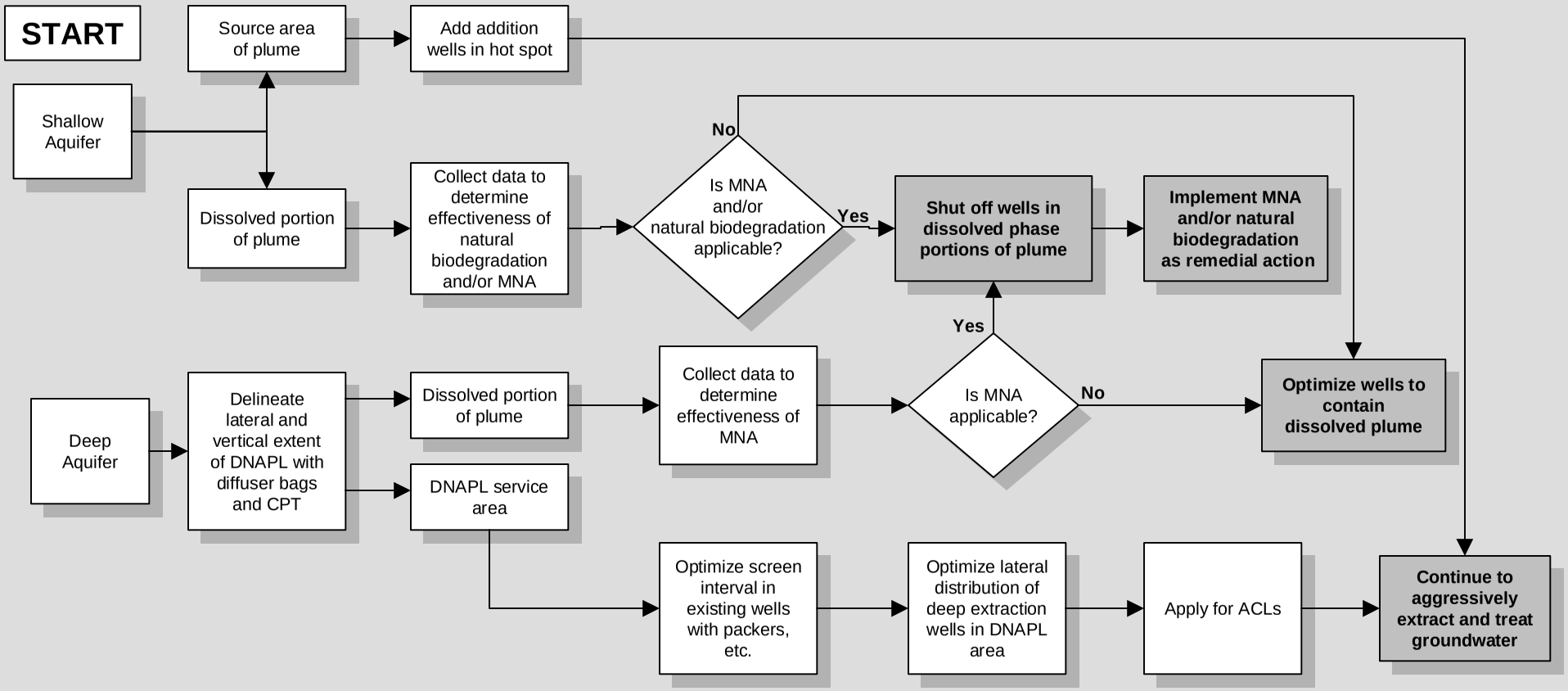
8.1.2 Innovative Technology Enhancements for OU2 – As discussed earlier, there is evidence of DNAPL associated with the OU2 plume. Pump and treat remediation in this area has been effective in removing contaminant mass, but it has been ineffective at reducing dissolved contaminant concentrations. The pump and treat system has removed over 40,000 pounds of contaminant mass over the past three years. During that time, dissolved contaminant concentrations have averaged 19.8 mg/L and remained steady. Essentially, DNAPL provides a continuing source of contaminants and continually replenishes the dissolved phase. One potential long-term remedial strategy to mitigate the effects of DNAPL on OU2 is to evaluate and implement innovative technology enhancements targeted at DNAPL reduction.

An innovative technology screening evaluation has been performed on the following types of technologies and their application to OU2:

- Flushing;
- Volatilization;
- Thermal Processes; and
- Other Treatment Technologies.

This screening evaluation is presented in detail in Appendix A. However, the primary conclusion is that none of the technologies discussed in Appendix A are well suited for remediation of DNAPL in the lower aquifer at OU2. The contaminated groundwater in that aquifer occupies a volume of over 7,000,000 cubic yards. The implementation of any of these technologies in a volume of this size would be prohibitively expensive. In addition, the location of specific pockets of DNAPL within this zone is unknown, making it impossible to focus the remedial activities in smaller target areas.

8.1.3 Decision Criteria for Remedial Strategy for OU2—As illustrated in Figure 8-1, the remedial strategy for OU2 is to continue to operate the OU2 treatment plant to aggressively treat the source area in the shallow aquifer and the DNAPL area in the deep zone, while simultaneously implementing actions to gain more complete delineation of the dissolved phase and DNAPL portions of the plume. In addition, data should be gathered to assess natural attenuation and biodegradation processes for the shallow and deep plumes. Detailed recommendations for the extraction well field and aboveground treatment plant are included in Sections 8.2 and 8.3.



Figs5-1_6-1.ppt

Figure 8-1.
Decision Criteria for Remedial Strategy for OU2 Pump and Treat Systems.

8.2 OU2 Extraction and Monitoring Well Network Recommendations

The following sections provide recommendations for the extraction and monitoring well networks in the shallow and deep aquifers at OU2. Although the shallow and deep zones are discussed separately, the recommendations should be considered in light of the fact that the site is characterized by a single plume that extends through two aquifer intervals and which apparently originates from a common source. The recommendations focus on monitoring performance during continued operation of the pump and treatment systems, in conjunction with further site characterization to estimate DNAPL distribution and assess dissolved contaminant stratification. All recommendations are summarized in Table 8-1.

8.2.1 Shallow Zone at OU2 – To provide an adequate database for evaluating the progress of the shallow zone extraction well network in achieving groundwater restoration, the following recommendations should be implemented.

- Continue to collect water quality samples from the extraction wells and analyze for COC concentrations to monitor mass removal at specific locations and near its apparent downgradient extent.
- Install several monitoring wells downgradient of extraction wells SRW02 through SRW06. Measure water levels in these new monitoring wells and in all adjacent monitoring wells to determine if hydraulic gradients toward extraction wells are being maintained and if the plume is hydraulically contained. Water quality samples should also be collected from these new monitoring wells and analyzed to evaluate VOC migration affected by active hydraulic containment, or natural attenuation processes.
- On the basis of the regular sampling results, prepare maps that illustrate the concentration and extent of individual COCs in groundwater relative to their remediation levels. Plotting total VOC concentration provides a general perspective of the plume, but cannot provide comparison with individual COC remediation goals.
- Prepare time series graphs of individual COC concentrations over time to examine trends in water quality within and outside the plume.
- Also, prepare graphs of cumulative mass removed relative to time and to cumulative pore volumes extracted.

Table 8-1. OU2 Evaluation and Optimization Summary

System Component	Consideration	Cost Impacts	Effectiveness Impacts
Shallow Zone Extraction System	Improve monitoring network for evaluating the P&T system's progress toward achieving groundwater restoration. • Install two shallow monitoring wells downgradient of the plume. • Measure water levels in any inactive extraction wells and in adjoining monitoring wells. • Add the two new monitoring wells and any inactive extraction wells to the current groundwater monitoring network.	• Labor and contractor cost of $10,000 for installing 2 monitoring wells. • Increase monitoring labor and analytical costs by $2,100/year.	• Determine if system performance is achieving objectives; if modifications are warranted; or, if alternative remedies such as monitored natural attenuation or phytoremediation should be considered.
Shallow Zone Extraction System	Perform groundwater screening to characterize contaminant distribution within the plume.	• Labor, analytical, and contractor cost of $20,000.	• Identify "hot spots" that may warrant installation of additional extraction wells for more aggressive mass removal.
Deep Zone Extraction System	Raise pump intakes above well screens.	• Cost varies with degree of access constraints. May be performed in conjunction with other well/pump maintenance.	• Protect well screens and filter packs from damage due to improper pump placement.

Table 8-1. OU2 Evaluation and Optimization Summary (continued)

System Component	Consideration	Cost Impacts	Effectiveness Impacts
Deep Zone Extraction System	Perform additional site characterization to evaluate stratigraphy, vertical contaminant distribution, and potential source areas and "hot spots," including DNAPL occurrence.	• Cost depends on the complexity of the work plan. Estimated range of $300K to $600K.	• Determine the locations and screen intervals for potential extraction wells; and, develop data to support supplementary technologies or a Technical Impracticability waiver.
Shallow and Deep Zone Extraction Systems	Improve performance evaluation database. • Prepare isoconcentration contour maps for individual COCs. • Prepare graphs of individual COC concentration changes over time. • Prepare graphs of cumulative mass removed relative to recovery time and cumulative pore volumes extracted.	• Increase data presentation and evaluation costs by $1,600/year per system.	• Contribute to database necessary for evaluating P&T systems.
OU2 Aboveground Treatment Plant	Use the OU1 polymer pumps to replace existing polymer pump at the OU2 plant. If maintenance is not reduced by borrowed pump, purchase new make of polymer pump.	• Potential decrease in maintenance cost for OU2 if borrowed pump is low maintenance. • Potential increase in cost by $6,000 if new pump is needed.	• Reduced labor associated with rebuilding existing polymer pump at OU2.

Table 8-1. OU2 Evaluation and Optimization Summary (continued)

System Component	Consideration	Cost Impacts	Effectiveness Impacts
OU2 Aboveground Treatment Plant	Modify NPDES permits to allow GAC bypass for normal operation.	• Decrease filter cartridge replacement cost of $20,000/year. • Decrease in GAC replacement cost of $9,000/year. • Decrease in labor cost of $5,700/year. • Decrease in analytical costs by $1,200/year.	• Air stripper effluent samples will need to be monitored closely to ensure that effluent discharge standards are met. • Influent samples will need to be closely monitored for PCE, so that GAC may be brought on line as needed. • Decreased costs associated with back washing, GAC replacement, and filter replacement. • The bypass will eliminate the need to perform VOC analysis at one point in the process stream.
OU2 Aboveground Treatment Plant	Monitor air stripper and GAC effluent results.	• No cost impact.	• Ensure that GAC is not fully loaded and contributing VOCs to the effluent stream.
OU2 Aboveground Treatment Plant	Achieve a lower detection limit for mercury on performance sampling and/or modify effluent discharge standards.	• Unknown if cost will be incurred to achieve lower detection limit.	• Ensure that effluent stream is meeting effluent discharge standards for mercury.

Table 8-1. OU2 Evaluation and Optimization Summary (continued)

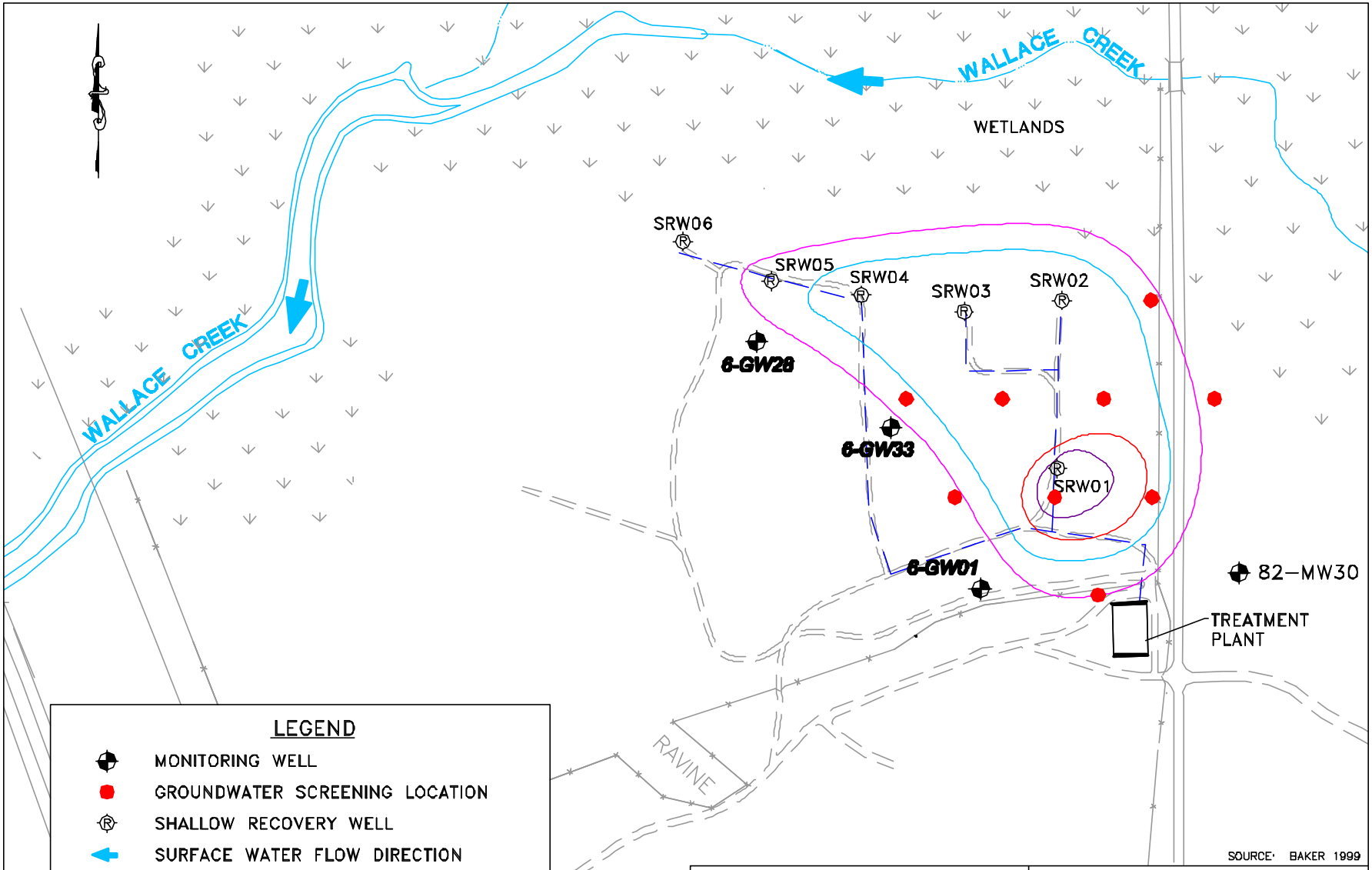
System Component	Consideration	Cost Impacts	Effectiveness Impacts
OU2 Aboveground Treatment Plant	Individual well influent flow meters have recently been installed (OHM, 2000).	• None.	• Determine flow from deep and shallow aquifers. • Determine the effectiveness of removal from the deep and shallow aquifers separately.

On the basis of the data evaluation, consider implementing the following modifications to the pump and treat system.

- Install additional shallow extraction wells within the plume to supplement mass removal from “hot spot” well SRW01. Any additional wells should be located in the areas of highest contamination, along the plume axis, and within areas of the least mobile contaminants. If hydraulic containment can be maintained by extraction wells located within the plume, terminate pumping of downgradient extraction wells SRW02 through SRW06 to preclude transporting contaminants from the source area across the entire plume.
- To assist in the placement of additional extraction wells, information regarding the distribution of contaminants in the shallow zone should be refined through groundwater screening combined with the sampling of the existing extraction wells and selected monitoring wells. Discrete groundwater samples should be collected using a screen point sampler advanced by direct push technology and analyzed for VOCs. Potential screening locations are illustrated on Figure 8-2. If possible, two samples should be collected from each screening location, preferably from 15 and 30 feet below land surface. Concurrently, samples should be collected from the six extraction wells (SRW01 through SRW06) and from the monitoring wells (6-GW01, 6-GW28, 6-GW33, and 82-MW-30).

8.2.2 Deep Zone at OU2 – The following recommendations should be implemented to evaluate and maintain or improve current pump and treat performance.

- Continue operation of the deep extraction wells to maintain hydraulic containment. Installation of additional wells to increase dissolved mass removal is not advised until source control measures are implemented.
- Raise the pumps in the deep wells so that the intakes are not located in the well screens. Intake placement within the screens increases water entrance velocities and may contribute to higher rates of corrosion, incrustation, and sand pumping. Because drawdown in the pumping wells is currently only about 10 feet, sufficient well casing is available above the screens to raise the pump intakes without decreasing yield.
- On the basis of the regular sampling results, prepare maps that illustrate the concentration and extent of individual COCs in groundwater relative to their remediation levels.
- Prepare time series graphs of individual COC concentration over time to examine trends in water quality within and outside the plume.
- Prepare graphs of cumulative mass removed relative to time and to cumulative pore volumes extracted.



RADIAN INTERNATIONAL

Figure 8–2. GROUNDWATER SCREENING AND SAMPLING LOCATIONS

OPERABLE UNIT 2

DRAWING NO	CONTRACT NO	DATE
lej99093.dwg	BD3016.0402	06/25/99

The following recommendations should be implemented to isolate production intervals in existing extraction wells, to locate and screen additional deep extraction wells, and to identify contaminant source areas:

- Use cone penetrometer testing (CPT) and direct push technology (DPT) to develop a three-dimensional model of the site stratigraphy and to identify source areas, including the presence of residual and free DNAPL.
- Obtain information regarding the vertical distribution of dissolved contaminants and DNAPL to optimize the pumping interval for the extraction wells such that aquifer zones containing the highest concentrations of COCs are targeted, and dilute or clean zones are avoided.

One method of implementing the second recommendation is to collect discrete groundwater samples using a screen point sampler advanced to selected depth intervals by DPT. Another possible method of accomplishing this task is to use an United States Geological Survey (USGS)-patented passive diffusion sampling technique in deep extraction wells, DRW01 and DRW04. The technique uses polyethylene bags filled with deionized water as a means of passively sampling contaminants in groundwater. The bags are suspended in the wells and any contaminants present diffuse through the polyethylene. After a given period (approximately 2 weeks), an equilibrium concentration in the bags is reached.

At wells DRW01 and DRW04, it is possible to suspend a number of these polyethylene bags in the wells and determine the depth of the contaminants. After identifying the depth intervals that exhibit the highest concentrations of contaminants, well packers could be used to isolate these zones in existing wells, and screens for any new wells could be installed at the optimum depths. The net effect of isolating these zones would be improved contaminant extraction and a potential reduction in the volume of cleaner water pumped to the treatment system.

Balanced against isolating the highly contaminated zones is the need to sustain adequate pumping rates to maintain a capture zone in the Castle Hayne aquifer. A significant limitation to this sampling technique is the effect of vertical groundwater gradients on the sample obtained. Vertical gradients can mask or even confound the determination of vertical contaminant distribution, because contaminants can diffuse vertically, as well as horizontally, through the bags. Consequently, it is important to determine groundwater gradients prior to implementing this technique. More importantly, to eliminate induced gradients, pumping would have to be suspended in the deep extraction wells while testing proceeded in DRW01 and DRW04.

8.3 OU2 Aboveground Treatment Train Recommendations

The following are recommendations for the OU2 aboveground treatment train. These recommendations are also summarized in Table 8-1.

- According to the equipment operator, the existing polymer pump at OU2 has been rebuilt several times. This individual pump may be faulty or the pump may not be appropriate for use at OU2. We recommend using the unused polymer pumps at OU1. If these pumps also require extensive maintenance, we recommend purchasing another brand of pump. A new polymer pump is estimated to cost $6,000.
- Based on the air stripper and GAC effluent performance discussed in Section 4.0, we recommend requesting that carbon polishing be modified in the NPDES requirements for discharge to Wallace Creek. We recommend that the GAC and cartridge filters be bypassed during normal operation. The GAC will be readily accessible if effluent sampling indicates that GAC is needed to reduce effluent concentrations. The GAC may be used to remove PCE when PCE is present in the waste stream. When PCE is not present in the waste stream, the GAC may be bypassed as the air stripper adequately removes other VOCs.

  This recommendation will save labor and cost by reducing the amount of back flushing and eliminating the need for cartridge filter and GAC replacement. It is estimated that the annual replacement cost of cartridge filters is $20,000, and the annual replacement cost of GAC is $9,000. A decrease in labor (approximately 125 hours) to change filters, backwash carbon and manage sludge generated by back washing will represent annual cost savings of $5,700. This recommendation will also reduce the analytical cost by removing the VOC analysis of GAC effluent for annual savings of $1,200.
- Recommend continued evaluation of air stripper and GAC effluent results to ensure that the GAC is not loading contaminants into the effluent stream. This loading appeared to be occurring in 1997. No cost impact is expected.
- The detection limit for mercury (0.1 µg/l) for the performance sampling is higher than the effluent discharge limit (0.025 µg/l), making it difficult to determine if discharge limits are being exceeded. We recommend trying to achieve a lower detection limit to ensure effluent standards are being met. If a lower detection limit cannot be achieved, we recommend modifying effluent discharge standards.

- Installing flow meters for the shallow aquifer influent and backwash streams is recommended. This recommendation will help determine removal effectiveness of the shallow and deep aquifers separately. Note that individual well flow meters were recently installed at OU2 (OHM, 2000) and this recommendation is completed.

8.4 OU2 Life Cycle Cost Analysis

A life cycle cost analysis was conducted for each of the RAO optimization recommendations for OU2 Aboveground Treatment Train. The life cycle cost analysis provides a net present value (NPV) for costs or savings incurred over the life of the operation. The NPV was calculated for operations of 5, 10 and 15 years, assuming a 6% interest rate. Results of the life cycle cost analysis are presented in Table 8-2.

Table 8-2. Life Cycle Costs for OU2 Aboveground Treatment Train

Recommendations	Annual Costs				Net Present Value		
	Capital	Labor	Analytical	Total	5 years	10 years	15 years
Continue operation of existing P&T "as is"				$932,881	$3,929,634	$6,866,085	$9,060,373
Discontinue operation of P&T and implement MNA	$10,500	$32,250	$32,250	$75,000	$315,927	$552,007	$728,419
Use unused polymer pump at OU1	($6,000)	$0	$0	($6,000)	($25,274)	($44,161)	($58,273)
Bypass the GAC and cartridge filters for discharge to sanitary sewer	($29,000)	($5,700)	($1,200)	($35,900)	($151,224)	($264,227)	($348,670)
Evaluate air stripper and GAC effluent results to ensure contaminant loading is not occurring	No cost impact is expected						
Achieve lower detection limits for mercury	Unknown if costs will be incurred						
Improve monitoring network for evaluating the P&T system (Shallow Zone Extraction System)	$10,000			$12,100	$50,970	$89,057	$117,518
		$2,100					
Perform groundwater screening (Shallow Zone Extraction System)	$20,000			$20,000	$84,248	$147,202	$194,245
Raise pump intakes above well screens (Deep Zone Extraction System)	Cost varies with degree of access constraints						
Perform additional site characterization (Deep Zone Extraction System)	Estimated range of $300 to $600K				$1.26 - $2.53 M	$2.21 - $4.42 M	$2.91 - $5.83 M
Improve performance evaluation database		$1,600		$1,600	$6,740	$11,776	$15,540

(Figures in parenthesis indicate cost savings)

9.0 DATA ANALYSIS, TREND EVALUATION, AND REPORTING

A review of the existing monitoring reports for the OU1 and OU2 P&T systems indicates that several steps may be taken to optimize the data analysis, trend evaluation, and reporting for these P&T systems. Each of the following items should be included in the semi-annual monitoring reports.

9.1 Performance Plots

We recommend plotting the monthly operation and cost data on performance plots similar to those found in Sections 3.0, 5.0, and 7.0 of this report (i.e., Figures 3-5 to 3-9, 5-2 to 5-5 and 7-6 to 7-9). These plots will help to visualize the cost and performance trends for each system as well as help in making appropriate optimization and remedial strategy decisions. More explanation of these plots as they relate to the past performance at the OU1 and OU2 systems are included in Sections 3.5, 5.5, and 7.5. The recommended performance plots are:

- Influent VOC Concentrations vs. Time;
- Cumulative Mass Recovered vs. Time;
- Cumulative Costs vs. Cumulative VOCs Recovered; and
- Average Cost Per Pound Recovered vs. Time.

9.2 Contaminant Migration Tracking and Plume Contours

By periodically tracking the migration of contaminants, the performance of the OU1 and OU2 remedial actions may be assessed. In addition, optimization decisions may be made as the plume changes in size or shape, or stabilizes. Use of an interactive geographic information system (GIS), along with other graphic packages will increase the visual impact of large amounts of data and will allow for data queries to easily track trends in plume and contaminant migration. Currently, the analytical database at Camp Lejeune is in the process of being linked to a GIS package so that data can be spatially displayed and analyzed. A more detailed discussion of GIS as it relates to Camp Lejeune is presented in the *Marine Corps Base Camp Lejeune Long-Term Monitoring Optimization Case Study* (NFESC 1999).

Secondly, Camp Lejeune should plot contaminant plume contours for the individual COCs. This will allow Camp Lejeune to assess how well the remedial action is addressing each contaminant compared to their individual cleanup goals. These plots facilitate optimization of remedial systems based on the most problematic COCs.

9.3 Zone of Capture

We recommend presenting the zone of capture of each extraction well operating in OU1 and OU2 in the semi-annual monitoring reports. Graphically depicting the zone of capture for each well will help determine how effective each well and the entire system is at containing and removing contaminants from the aquifer.

9.4 Operational and Performance Reporting

Currently, the semi-annual monitoring reports for OU1 and OU2 contain the following operation and performance related items: a short summary of operations, a table of performance monitoring analytical results, and a table with flow and operation time information. In addition to the information already provided, we recommend that the following information be included in the semi-annual monitoring report:

- Performance plots as mentioned above;
- Summary of operations and maintenance costs including maintenance, repairs, capital improvements, and utility costs;
- A more detailed summary of system downtime/repair actions;
- Discussion and analysis of system, plant, and extraction well performance;
- Discussion and analysis of whether the effluent is meeting discharge requirements;
- Detailed maintenance logs included as an Appendix; and
- Present individual well influent flow analytical data and mass removal.

Presentation of this information will allow the Camp Lejeune team members to have a better understanding of the performance of the P&T systems. It will also help in identifying problematic operation and maintenance issues.

10.0 REFERENCES

Baker Environmental (Baker), 1993a. *Basis of Design Report for the Hadnot Point Industrial Area Shallow Aquifer (OU1) Groundwater Treatment System.* Final. June 19.

Baker, 1993b. *Remedial Action Work Plan for the Hadnot Point Industrial Area Shallow Aquifer (OU1).* Final. July 19.

Baker, 1993c. *Remedial Investigation Report for Operable Unit No. 2 (Sites 6, 9 and 82).* Final. August 20

Baker 1993d. *Record of Decision for OU No. 2 (Sites 6, 9, and 82).* Final. September 24.

Baker, 1994a. *Feasibility Study for Operable Unit No. 1, (Sites 21,24 and 78).*Draft Final. April 29.

Baker, 1994b. *Basis of Design Report, Soil and Groundwater Remediation, Operable Unit No.* 2. Final. May 10

Baker, 1994c. *Record of Decision for OU1 (Sites 21, 24, and 78).* Final. September 8.

Baker, 1998. *Basewide Remediation Assessment Groundwater Study*. Final. April 20.

Baker, 1999a. *Monitoring Report , OU1 –Site 78. Reporting Period July 1998-December 1998.* March 25.

Baker, 1999b. *Monitoring Report , Operable Unit (OU) No 2-Sites 6 and 82. Reporting Period July 1998-December 1998.* March 26.

Baker, 2000. Telephone Discussion with Ken Tilla (Baker) and Suzanne Sellers on January 7, 2000 (Radian).

Baker, date unknown-a. Feasibility Study for Operable Unit No. 2 (Sites 6, 9, and 82). Final.

Baker, date unknown-b. *Hadnot Point Industrial Area (OU1), Shallow Aquifer Groundwater Treatment System Drawings.*

Baker, date unknown-c. *Remedial Investigation Report, Operable Unit No. 1, (Sites 21, 24 & 78).* Draft Final.

Cohen et al., 1994. *Methods for Monitoring Pump and treat Performance.* EPA/600/R-94/123. June.

Fountain, John C., 1998. *Technologies For Dense Non-aqueous Phase Liquid Source Zone Remediation*, Groundwater Remediation Technologies Analysis Center, Pittsburgh, PA. December.

Naval Facilities Engineering Service Center, (NFESC) 1999. *Marine Corps Base Camp Lejeune Long-Term Monitoring Optimization Case Study*. Draft. January.

OHM Remediation Services Corp., (OHM) 1996. *Operation and Maintenance Manual Camp Lejeune Groundwater Treatment System (OU2).* September.

OHM, 1997a. *Hadnot Point Shallow Aquifer Groundwater Treatment System (OU1), System Operation and Maintenance Manual.* Revised. November.

OHM, 1997b. *Remedial System Operation, Review and Repair, North and South Water Treatment Plants, OU No. 1, Site 78, Hadnot Point Industrial Area.* Final Report. November

OHM, 1998a. Soil Vapor Extraction, Air Sparge, and Biosparge Drawings for the Hadnot Point Fuel Farm. June.

OHM, 1998b. *North and South Extraction Systems (OU1), System Expansion Drawings.* September.

OHM, 1998c. *Remedial System Operation, Review and Repair, North and South Water Treatment Plants, OU No. 1, Site 78, Hadnot Point Industrial Area.* Final Repair Report. September.

OHM, 1998d. *Work Plan for Construction of New Wells at Hadnot Point Industrial Area (OU1), North and South Groundwater Treatment Plants.* September.

OHM, 1999a. Groundwater Treatment Plant (OU1) Monthly Monitoring Results, North and South Plants, July 1996 through March 1999.

OHM, 1999b. Groundwater Treatment Plant (OU2) Monthly Monitoring Results, January 1997 through March 1999.

OHM, 1999c. Maintenance Checklist and Maintenance Sheets for Northern and Southern OU1 Treatment Plants for 1997 and 1998.

OHM, 1999d. Maintenance/Lubrication Checklists and Maintenance Records for OU2 Groundwater Treatment Plants for 1997 and 1998.

OHM, 1999e. Monthly/Quarterly Reports, Site 78 Hadnot Point (OU1), MCB Camp Lejeune, North Carolina, July 1996 through March 1999.

OHM, 1999f. Monthly Reports, Groundwater Treatment Plant , Lot 203 (OU2), January 1997 through March 1999.

OHM, 2000. E-mail form Jim Donn (OHM) to Suzanne Sellers (Radian) on January 6, 2000.

INNOVATIVE TECHNOLOGY EVALUATION OF OU2

Appendix A
Innovative Technologies for Removing DNAPL Contamination

Technology	Description	General Applicability to DNAPL Source Zone Remediation	Applicability to OU2
Flushing Technologies			
Alcohol or Co-solvent Flushing	A mixture of water and one or more solvents is pumped via injection wells through the contaminated zone to remove contaminants by dissolution and/or mobilization. (The solvent increases the solubility of hydrophobic organic compounds and causes a reduction in interfacial tension, drawing contaminants, such as DNAPLs, into solution.) The dissolved contaminant is then recovered with the groundwater in extraction wells and can be treated.	• Capable of rapid DNAPL removal at sites with moderate to good permeability; extraction efficiency will be lower in low permeability zones and at heterogeneous sites. • Reagent costs may be a factor because co-solvent flushing requires high concentrations of reagents and solvents recycling methods have not yet been demonstrated. • Co-solvents lower interfacial tension with DNAPL, raising the potential for downward mobilization. • No controlled field tests have been conducted to determine the ultimate cleanup potential for the technology.	The permeability of the lower aquifer is favorable. The volume of the potentially contaminated zone would result in a high cost for co-solvent.
In-Situ Oxidation	An oxidizing compound (e.g., potassium permanganate, hydrogen peroxide) is injected into a DNAPL source zone to react with organic compounds and ultimately destroy them. Excess oxidizer is extracted by flushing water through the treatment zone.	• Can rapidly destroy readily oxidized contaminants (e.g., PCE and TCE). • Performance may be limited by the presence of oxidation-resistant contaminants, large amounts of oxidizable material in the soil, low permeability, and subsurface heterogeneities. • Effectiveness may be limited in carbonate-rich units. • Field data are insufficient for determining cleanup levels or the range of conditions under which the technology is suitable; however, additional field tests are underway.	The permeability of the lower aquifer is favorable. The volume of the potentially contaminated zone would result in a high cost for chemical oxidants.

Appendix A
Innovative Technologies for Removing DNAPL Contamination

Technology	Description	General Applicability to DNAPL Source Zone Remediation	Applicability to OU2
Surfactant Flushing	A water/surfactant mixture is injected into the source zone to remove contaminants via dissolution and displacement. (The surfactant lowers interfacial tension and increases the solubility of hydrophobic organic compounds, allowing them to dissolve into solution.) The extracted groundwater is treated aboveground.	• Several field tests have demonstrated the technology's effectiveness for rapid mass removal of DNAPL at sites with good to moderate permeability. • Recycling of surfactants has been demonstrated. • Extraction is less efficient in low permeability or heterogeneous sites; mobility control using polymer or foam can lessen the effect of heterogeneties. • Attainable groundwater cleanup levels have not yet been established. • Since surfactants lower the interfacial tension between water and DNAPL, the risk of vertical mobilization of DNAPL must be assessed at each site.	The permeability of the lower aquifer is favorable. The volume of the potentially contaminated zone would result in a high cost for surfactant.
Volatilization Technologies			
Soil Vapor Extraction (SVE)	Air is pumped from the vadose zone via extraction wells using vacuum pumps. (Air or oxygen may also be injected to stimulate aerobic biodegradation.) The gases emitted typically must be treated aboveground to remove/destroy the volatilized contaminants. SVE is a proven technology for NAPL mass removal in the vadose zone and has been widely implemented.	• Can provide rapid, relatively inexpensive mass removal of volatile DNAPL components in permeable, relatively homogeneous, low water content soils. • Performance limited by low permeability, high soil water content, and heterogeneities. • May be augmented by thermal techniques to remove semivolatile compounds and increase effectiveness for low permeability layers. • When used in conjunction with biodegradation, removal of hydrocarbons and other aerobically degraded compounds can be enhanced.	Not appropriate for remediation of contaminants below the water table.

Appendix A
Innovative Technologies for Removing DNAPL Contamination

Technology	Description	General Applicability to DNAPL Source Zone Remediation	Applicability to OU2
Air Sparging	A variant of SVE, air sparging injects air below the water table. (In SVE, the air is injected at the ground surface.) The air then flows upward through the contaminated groundwater, extracting contaminants as they are volatilized. The offgas may be captured with an SVE system in the overlying unsaturated zone for treatment; in this manner, contaminants in both the vadose and saturated zones can be treated.	• Capable of reducing dissolved volatile compounds to target levels in the saturated zone. • Performance is optimum in moderately permeable conditions; results are not as great in low and high permeability units and under heterogeneous conditions. • Due to the tendency of DNAPLs to accumulate on low permeability lenses, it is unlikely that an entire DNAPL source zone would be effectively sparged, although significant success has been reported in one field test. • Better performance occurs in thicker saturated zones.	The permeability of the lower aquifer is favorable. The low permeability of the surficial aquifer is unfavorable. The volume of the contaminated zone is large and the locations of DNAPL pockets are unknown.
In-well Stripping	This type of air sparging technique strips contaminated groundwater in treatment wells instead of *in situ*. Water from the contaminated zone is pumped into a well, where it is sparged by pumping air from the surface, removing the contaminants by volatilization within the well casing. The water is then pumped out through separate screens higher in the wall.	• Treats only dissolved, volatile compounds; consequently, DNAPL removal would only occur indirectly by dissolution as the dissolved phase is stripped. • Long treatment times would probably be necessary.	The permeability of the lower aquifer is favorable. The volume of the contaminated zone is large and the locations of DNAPL pockets are unknown.
Thermal Processes			
Electrical Heating	A number of techniques for heating soils has been demonstrated, including resistance heating, microwave heating, and radio frequency heating. In each method, electrical energy is applied to heat the soil. Heat increases the volatility of contaminants, which are	• Volatile compounds and perhaps semivolatile compounds (depending on the temperatures achieved) can be volatilized; to volatilize DNAPLs, the soil must be heated to near the DNAPL boiling point. • Most applicable to fine-grained soil.	The volume of the contaminated zone is large. Costs would be prohibitive.

Appendix A
Innovative Technologies for Removing DNAPL Contamination

Technology	Description	General Applicability to DNAPL Source Zone Remediation	Applicability to OU2
	then driven out of the source zone by volatilization and thermally induced vapor phase transport. The technology is normally coupled with other technologies (e.g., SVE or steam flushing) to recover the volatilized contaminants.	• No data are available to determine ultimate cleanup levels at DNAPL sites; the results will depend on site heterogeneities.	
In-Situ Vitrification	Electrical energy is applied to soil (via electrodes), heating it to a temperature high enough to vitrify (greater than 1,100°C). Upon cooling, the soil forms a glass-like substance.	• Soil vitrification technology has been demonstrated; however, no controlled results for DNAPL destruction have been reported. • Operation at or near the water table may pose problems.	The volume of the contaminated zone is large. The contaminated zone is below the water table. Costs would be prohibitive.
Steam Injection	Steam is injected via injection wells into the contaminated zone. The steam volatilizes and mobilizes contaminants, including DNAPLs, and the condensed steam/contaminants are recovered in extraction wells for treatment. The technology has been widely used in enhanced oil extraction with considerable success.	• Can provide rapid DNAPL mass removal in either the vadose or saturated zones if permeability is adequate and DNAPL mobilization is not a concern or can be controlled. • May be used to remove lower volatility compounds that can be extracted with soil vapor extraction. • Limitations included poorer performance in low permeability units and at heterogenous sites; the technology can be used in conjunction with electrical heating of fine-grained layers to improve performance at heterogeneous sites.	The volume of the contaminated zone is large. Costs would be prohibitive.

Appendix A
Innovative Technologies for Removing DNAPL Contamination

Technology	Description	General Applicability to DNAPL Source Zone Remediation	Applicability to OU2
		• Risk of DNAPL mobilization due to vapor condensation at the thermal front is not well known. • Several feet of overburden are required to provide adequate containment; otherwise, some type of seal may be necessary.	
Other Treatment Technologies			
Bioremediation	Use of biologically mediated reactions to break down contaminants. It may occur under existing conditions or with the addition of oxygen, nutrients, and/or other chemicals. Bioremediation may be used in addition to other technologies (e.g., steam injection, SVE, air sparging) to optimize remediation.	• Demonstrated to be effective for treating the most common DNAPL compounds (except PCBs) in the dissolved phase; however, it is unlikely to be effective for remediating DNAPLs, because DNAPL treatment is indirect, by dissolution, as the dissolved phase is degraded. • Extensive treatment times would probably be required.	More appropriate for dissolved phase treatment and zones of lower contaminant concentrations. Time to achieve cleanup would be lengthy.
Electrokinetics	An electric potential is applied across the contaminated zone by electrodes in the ground. This mobilizes water and contaminants and allows them to be recovered at the electrodes. Alternatively, the process can be coupled with an *in-situ* treatment method.	• Promising technology for removing DNAPLs from low permeability, fine-gained soils; however, more information is needed to determine effectiveness for DNAPL source zones. • Achieves mobilization of dissolved phase contaminants (and possibly DNAPLs) when used in conjunction with a removal or destruction technology.	More research and development is needed to design and implement this technology in full-scale applications.

Appendix A
Innovative Technologies for Removing DNAPL Contamination

Technology	Description	General Applicability to DNAPL Source Zone Remediation	Applicability to OU2
		• Pilot test suggests DNAPLs can be treated. • Mechanism for DNAPLs can be treated.	
Reactive Barrier Walls	As groundwater flows through these treatment walls, dissolved contaminants are destroyed or sorbed to the wall surface.	• Reactive Barriers using zero-valent iron have been proven effective for treating dissolved plumes of some chlorinated solvents, especially TCE. • Only dissolved phase contamination is treated; thus, DNAPL source zones cannot be directly addressed. • The effective life of treatment walls has not been determined.	More appropriate for downgradient interception of migrating dissolved contaminants. The depth of OU2 contaminants (>150 feet) is prohibitive for construction barrier walls.

DNAPL = dense nonaqueous phase liquid
NAPL = nonaqueous phase liquid
OU = Operating Unit
PCB = polychlorinated biphenyl
PCE = tetrachloroethylene
SVE = soil-vapor extraction
TCE = trichloroethylene

Source: Adapted from J. Fountain, December 1998.