04.07-09/01/95-01534

Final

Treatability Study Work Plan
Operable Unit No. 14
(Site 69)
Marine Corps Base, Camp Lejeune
North Carolina

Prepared For:

Department of the Navy
Atlantic Division
Naval Facilities
Engineering Command
Norfolk, Virginia

Under the

LANTDIV CLEAN Program

Comprehensive Long-Term
Environmental Action Navy

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

Baker	Baker Environmental, Inc.
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFM	cubic feet per minute
CFR	Code of Federal Regulations
CLEAN	Comprehensive Long-Term Environmental Action Navy
CWM	Chemical Warfare Material
DoN	Department of the Navy
DCE	1,2-dichloroethene
DNAPL	dense non-aqueous phase liquid
ECBSOPQAM	Environmental Compliance Branch (USEPA) Standard Operating Procedures and Quality Assurance Manual
FFA	Federal Facilities Agreement
FMP	Field Monitoring Plan
FSP	Field Sampling Plan
GAC	granular activated carbon
GC/MS	gas chromatography/mass spectometry
gpm	gallons per minute
HASP	Health and Safety Plan
HDPE	high density polyethylene
HTH	high test hypochlorite
ID	inside diameter
IDW	investigative derived wastes
IEG	IEG Technologies Corporation
KGB	(German acronym for "Coaxial Groundwater Ventilation")
LANTDIV	Naval Facilities Engineering Command, Atlantic Division
LNAPL	light non-aqueous phase liquid
MCB	Marine Corps Base
MDL	method detection limit
MEK	methyl ethyl ketone
MIK	methyl isobutyl ketone
MS/MSD	matrix spike/matrix spike duplicate
NC DEHNR	North Carolina Department of Environment, Health and Natural Resources
NCP	National Oil and Hazardous Substances Contingency Plan

NEESA	Naval Energy and Environmental Support Activity
NYSDEC	New York State Department of Environmental Conservation
ORD	Office of Research and Development (USEPA)
OU	Operable Unit
OUL	Ozard Underground Laboratories
PAH	polynuclear aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PID	photoionization detector
PPC	personal protective clothing
PPE	personal protective equipment
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RAC	Remedial Action Contract
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study
RPD	relative percent difference
RREL	Risk Reduction Engineering Laboratory
SAP	Sample and Analysis Plan
SARA	Superfund Amendments and Reauthorization Act
SBP	SBP Technologies, Inc.
SCH 40	Schedule 40
SOPs	standard operating procedures
TAL	target analyte list
TCA	trichloroethane
TCE	thrichloroethene
TCL	target compound list
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
TEU	Army Technical Escort Unit
TRC	Technical Review Committee
TSS	total suspended solids
USEPA	United States Environmental Protection Agency
UVB	(German acronym for "Vacuum Vaporizer Well")
UXO	unexploded ordnance
VOA	volatile organic analyte
VOCs	volatile organic compounds
ZOI	zone of influence

1.0 PROJECT DESCRIPTION

This Treatability Study Work Plan has been prepared by Baker Environmental, Inc. (Baker) under the United States Department of the Navy (DON), Atlantic Division, Naval Facilities Engineering Command (LANTDIV) Comprehensive Long-Term Environmental Action Navy (CLEAN) Program for Contract Task Order 0212 for Site 69, the Rifle Range Chemical Dump, Marine Corps Base (MCB), Camp Lejeune, North Carolina. The treatability study is being conducted as part of the Remedial Investigation/Feasibility Study (RI/FS) for Site 69. This document has been prepared in accordance with the requirements of the National Oil and Hazardous substances Contingency Plan (NCP) for remedial actions [40 Code of Federal Regulations (CFR) 300.430]. The NCP regulations were promulgated under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly referred to as Superfund, and amended by the Superfund Amendments and Reauthorization Act (SARA) signed into law on October 17, 1986. The USEPA's document Guide for Conducting Treatability Studies Under CERCLA (USEPA, 1992) has been used as guidance for preparing this document.

MCB Camp Lejeune was placed on the CERCLA National Priorities List (NPL) on October 4, 1989 (54 Federal Register 41015, October 4, 1989). The United States Environmental Protection Agency (USEPA) Region IV, the North Carolina Department of Environment, Health and Natural Resources (NC DEHNR) and the DON then entered into a Federal Facilities Agreement (FFA) for MCB, Camp Lejeune. The primary purpose of the FFA is to ensure that environmental impacts associated with past and present activities at the MCB, Camp Lejeune are thoroughly investigated and appropriate CERCLA response/Resource Conservation and Recovery Act (RCRA) corrective action alternatives are developed and implemented as necessary to protect public health and the environment.

Site 69 was originally included under Operable Unit (OU) No. 4. However, Site 69 has since been separated into its own operable unit, OU No. 14, to allow the nature and extent of groundwater contamination to be better defined, through additional field work and independent of work being performed at other sites under OU No. 4. The primary concern at Site 69 is the presence in groundwater of chlorinated volatile organic compounds (VOCs) such as 1,2-dichloroethene (DCE). A Draft FS was completed for Site 69 (Baker, October 1994) in which several groundwater treatment alternatives were evaluated. Of the groundwater treatment technologies evaluated, the innovative technology known as in-well aeration, or "in situ air stripping," appears to offer the most advantages with respect to effectiveness, implementability, and cost. A Draft Final RI Report was completed in June 1995, which contains the most current site characterization data (Baker, June 1995).

1.1 Purpose and Organization

This Treatability Study Work Plan provides the objectives, scope, and schedule of the proposed treatability study activities for the UVB/KGB System Pilot-Scale Treatability Study at Site 69. The UVB and KGB technologies are innovative in-well aeration treatment systems for contaminated groundwater. The technologies were developed and patented by IEG Technologies Corporation (IEG) of Charlotte, North Carolina. SBP Technologies, Inc. (SBP) of Gulf Breeze, Florida represents the sole source of the UVB and KGB technologies in the United States. SBP will be performing the treatability study under subcontract to Baker.

The main objectives of the UVB/KGB treatability study are to:

- Determine if the technologies are effective, implementable, and economical for remediation and/or containment of contaminants of the shallow and upper Castle Hayne Aquifers at Site 69.
- Provide engineering parameters and other design-related information necessary to design and implement a full-scale UVB/KGB remediation system.

The treatability study scope of work has been developed jointly by Baker and SBP in accordance with USEPA's "Guide for Conducting Treatability Studies under CERCLA" (USEPA, October 1992).

Sections 2.0 through 12.0 describe the treatability study technical scope of work. Sampling and analysis for the treatability study will be performed by three off-site laboratories. Quality Assurance Project Plans (QAPPs) for these laboratories are provided in Appendices A through C. Standard Operating Procedures (SOPs) for all field-related activities are provided in Appendix D. These SOPs comply with the USEPA Region IV Environmental Compliance Branch Standard Operating Procedures and Quality Assurance Manual (ECBSOPQAM) February, 1991. The theory of the UVB system operation is provided in Appendix E, specifications for the major equipment are provided in Appendix F, and referenced publications in Appendix G. All on-site work will be performed in accordance with the site-specific Health and Safety Plan (HASP) prepared by SBP under separate cover.

1.2 Site Background

Site 69, the Rifle Range Chemical Dump, is located west of the New River in the area of MCB Camp Lejeune known as the Rifle Range (see Figure 1-1). The site is approximately 14 acres in size and is situated in a topographically high area (see Figure 1-2). During the period 1950 to 1976, the area was used to dispose chemical wastes including polychlorinated biphenyls (PCBs), solvents, pesticides, calcium hypochlorite, high-test hypochlorite (HTH), and drums of "gas", which possibly contained Chemical Warfare Material (CWM), such as "mustard gas." The area is overgrown to the point that the boundary of the former dump is not readily noticeable. Three surface water bodies are located within a quarter mile of the site: the New River to the west, an unnamed tributary of the New River to the north, and Everett Creek to the south. The site area is rather secluded; however, training exercises are conducted throughout the surrounding area. Currently, a fence surrounds the site to restrict access.

The site is underlain by silty sands from the ground surface to a depth of approximately 18 feet. Beneath the silty sand is a fairly continuous sandy clay, and sand and clay unit, to a depth of approximately 27 feet. This unit could potentially act as a retarding layer. The upper unit of the Castle Hayne Aquifer, which was encountered below the sand and clay retarding layer, consists of silty sand with shell and limestone fragments.

In general, shallow groundwater appears to flow radially from the center portion of the site to the outer low lying areas, as shown in Figure 1-3. As depicted in Figure 1-4, groundwater in the upper portion of the Castle Hayne Aquifer appears to flow in a general eastern direction towards Everett Creek. Groundwater levels at Site 69 range from 0.34 to 3.3 feet below ground surface (bgs) for the perched water zone, and from 23.83 to 26.33 feet below ground surface (bgs) for the water table aquifer. The estimated horizontal hydraulic conductivity for the site is 1.0×10^{-4} cm/sec and the

estimated vertical hydraulic conductivity for the site is 1.0×10^{-5} cm/sec. The water table gradient has been determined to be 0.065.

Groundwater contamination at Site 69 primarily consists of chlorinated VOCs such as 1,2-DCE, TCE, and vinyl chloride. Concentrations of VOCs detected during the last three sampling rounds in excess of federal maximum contaminant levels (MCLs) and North Carolina Water Quality Standards (NCWQS) are shown in Figures 1-5 and 1-6 for the shallow and deep (Castle Hayne) wells, respectively. As shown in Figures 1-5 and 1-6, the highest levels of contamination are centered around monitoring wells 69-GW15 and 69-GW15IW. Monitoring well 69-GW15IW is screened from 45 to 60 ft below grade. Since a deeper well does not exist near wells 69-GW15 and 69-GW15IW, the vertical extent of contamination is currently not defined in this area. As will be discussed in Section 4.2.1, installation of a 120-ft deep well, 69-GW15DW will be required prior to performance of the treatability study to evaluate and monitor the vertical extent of groundwater contamination in the source area.

Information about the geology, hydrogeology, site contamination, and estimated risks to human health is included in the Draft Final Remedial Investigation for Operable Unit No. 4, Marine Corps Base, Camp Lejeune, North Carolina (Baker, June 1995).

SECTION 1.0 FIGURES

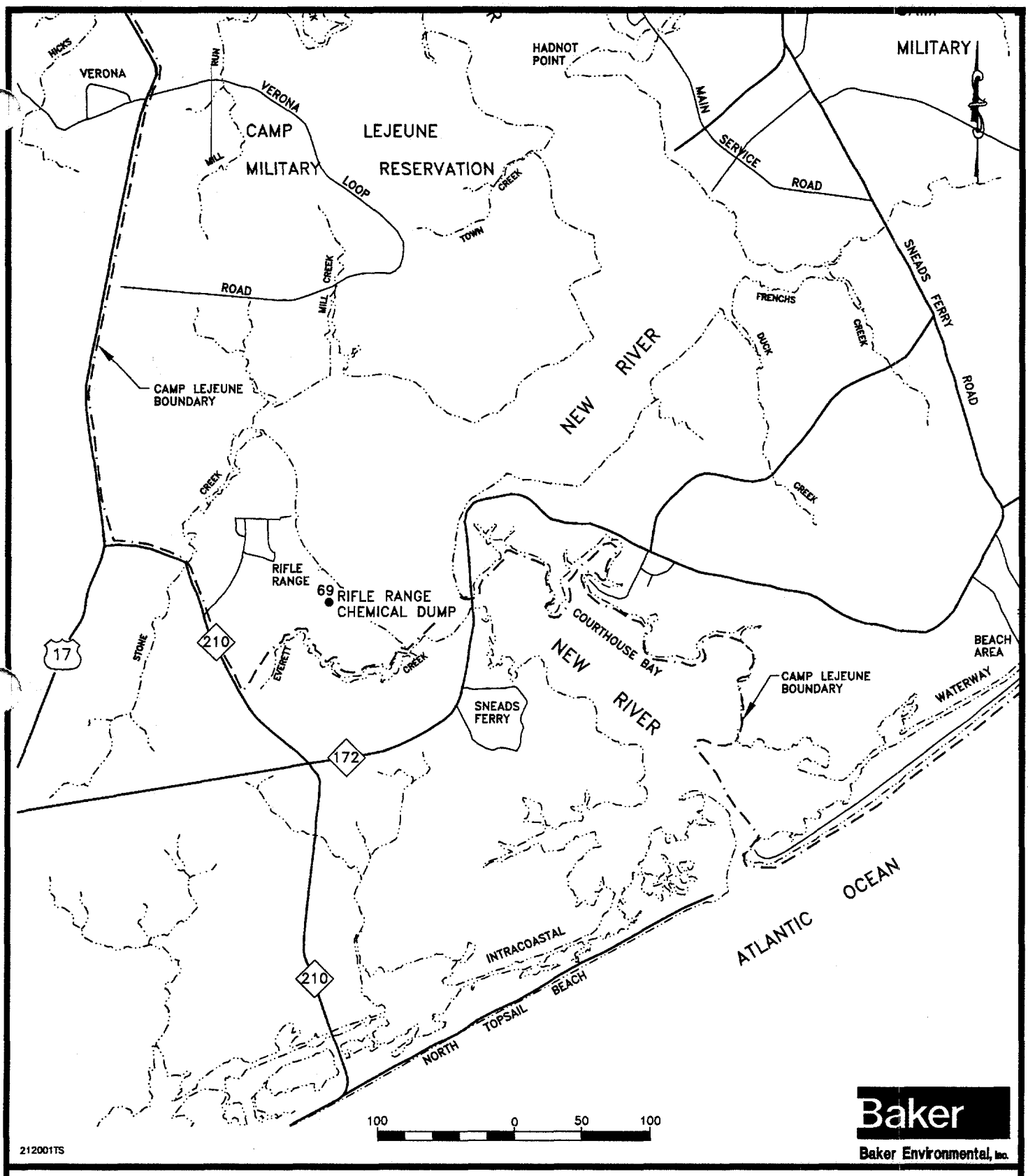
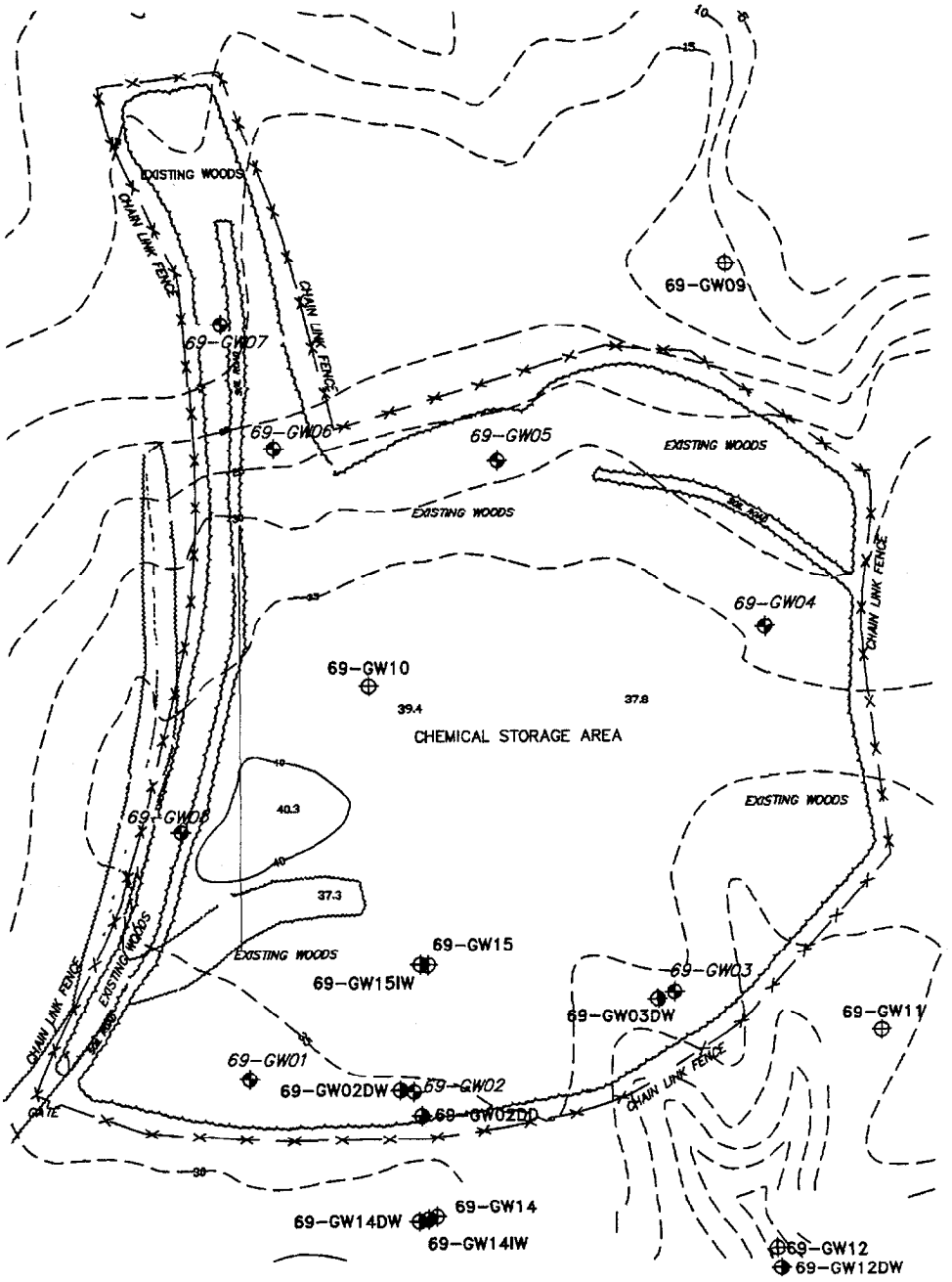


FIGURE 1-1
LOCATION MAP
SITE 69 – RIFLE RANGE CHEMICAL DUMP
CTO-0212
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

212002TS



200 0 100 200 400

1 inch = 200 ft.

Baker

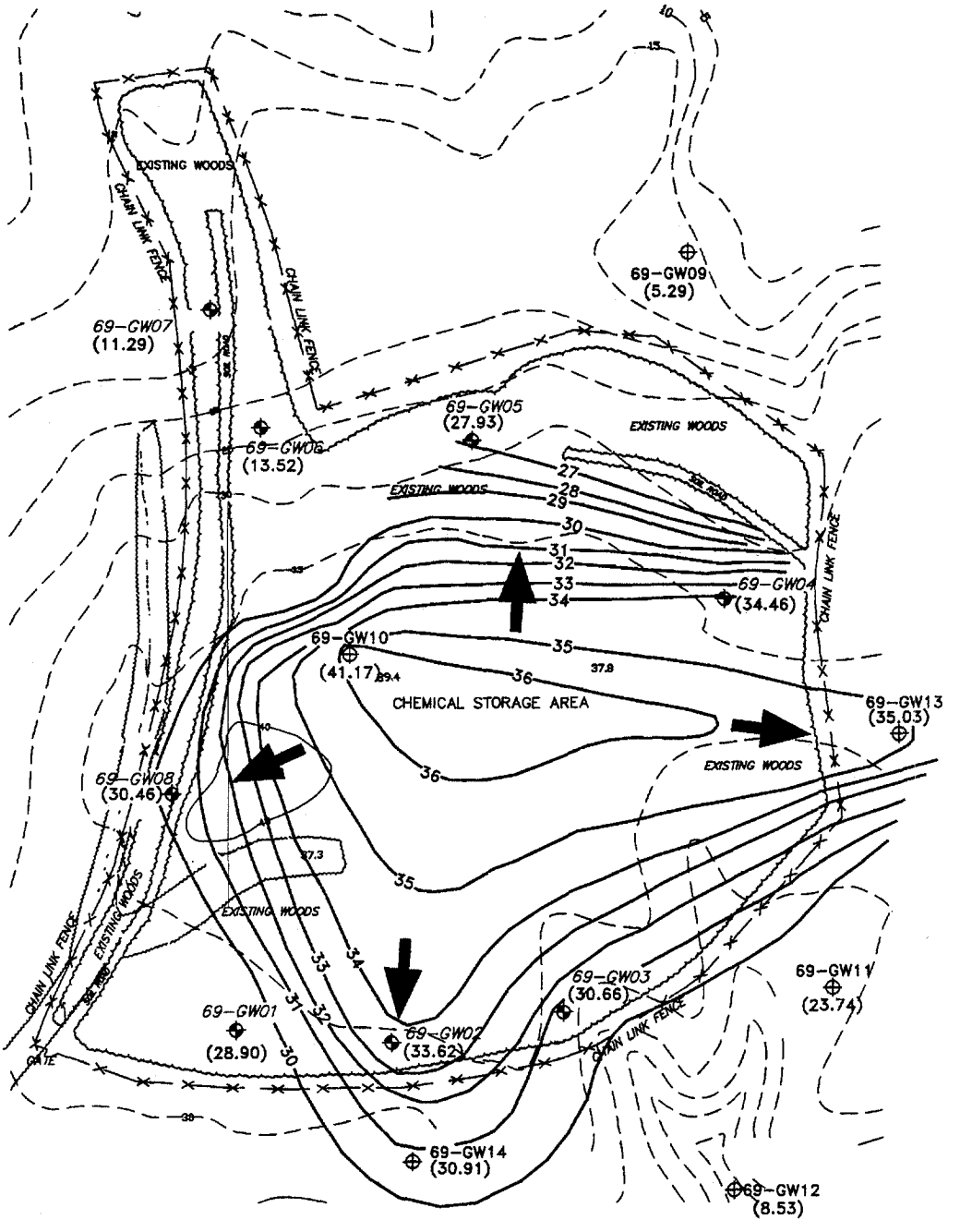
Baker Environmental, Inc.

LEGEND

- 69GW2 — EXISTING SHALLOW WELLS (ESE)
- 69GW09 — EXISTING SHALLOW WELLS (BAKER)
- 69GW02DW — EXISTING DEEP WELLS (BAKER)
- TOPOGRAPHIC ELEVATION LINES (FEET, MSL)

SOURCE: REVISED FROM LANTDIV, OCT. 1991

FIGURE 1-2
GENERAL ARRANGEMENT MAP
SITE 69 - RIFLE RANGE CHEMICAL DUMP
CTO-0212
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



200 0 100 200 400

1 inch = 200 ft.

Baker

Baker Environmental, Inc.

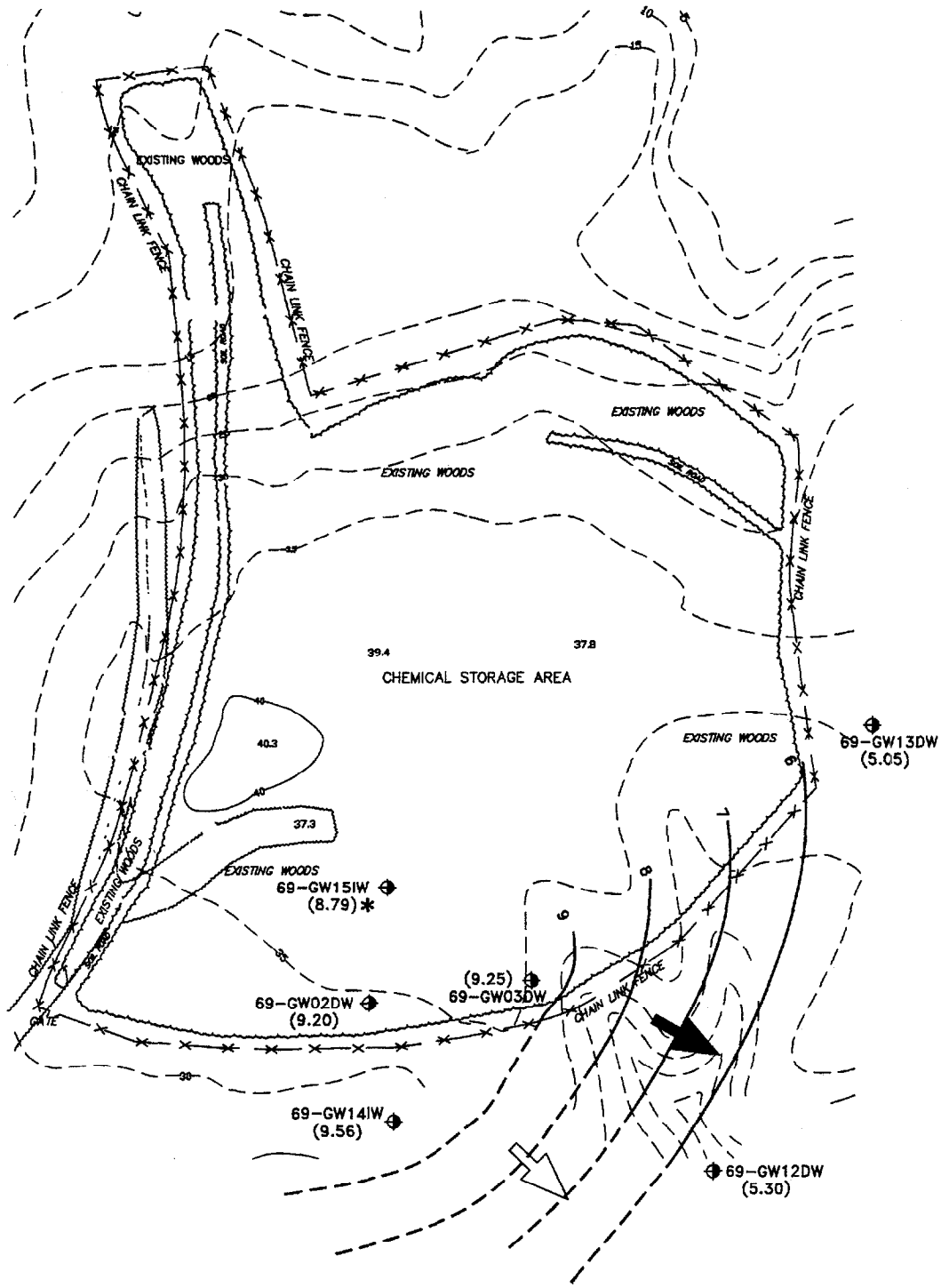
LEGEND

- 69-GW02 ⊕ EXISTING SHALLOW WELLS (ESE)
- 69-GW09 ⊕ EXISTING SHALLOW WELLS (BAKER)
- (28.85) GROUNDWATER ELEVATION (FEET, MSL)
- GROUNDWATER ELEVATION CONTOUR
- GROUNDWATER FLOW DIRECTION

SOURCE: REVISED FROM LANTDIV, OCT. 1991

FIGURE 1-3
SHALLOW GROUNDWATER ELEVATION CONTOURS – FEBRUARY 20, 1995
SITE 69 – RIFLE RANGE CHEMICAL DUMP
CTO-0212
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

212004TS



200 0 100 200 400

1 inch = 200 ft.

Baker

Baker Environmental, Inc.

LEGEND

69-GW02DW — EXISTING DEEP WELLS (BAKER)

(28.36) — GROUNDWATER ELEVATION (FEET., MSL)

GROUNDWATER ELEVATION CONTOUR

GROUNDWATER ELEVATION CONTOUR (INFERRED)

GROUNDWATER FLOW DIRECTION

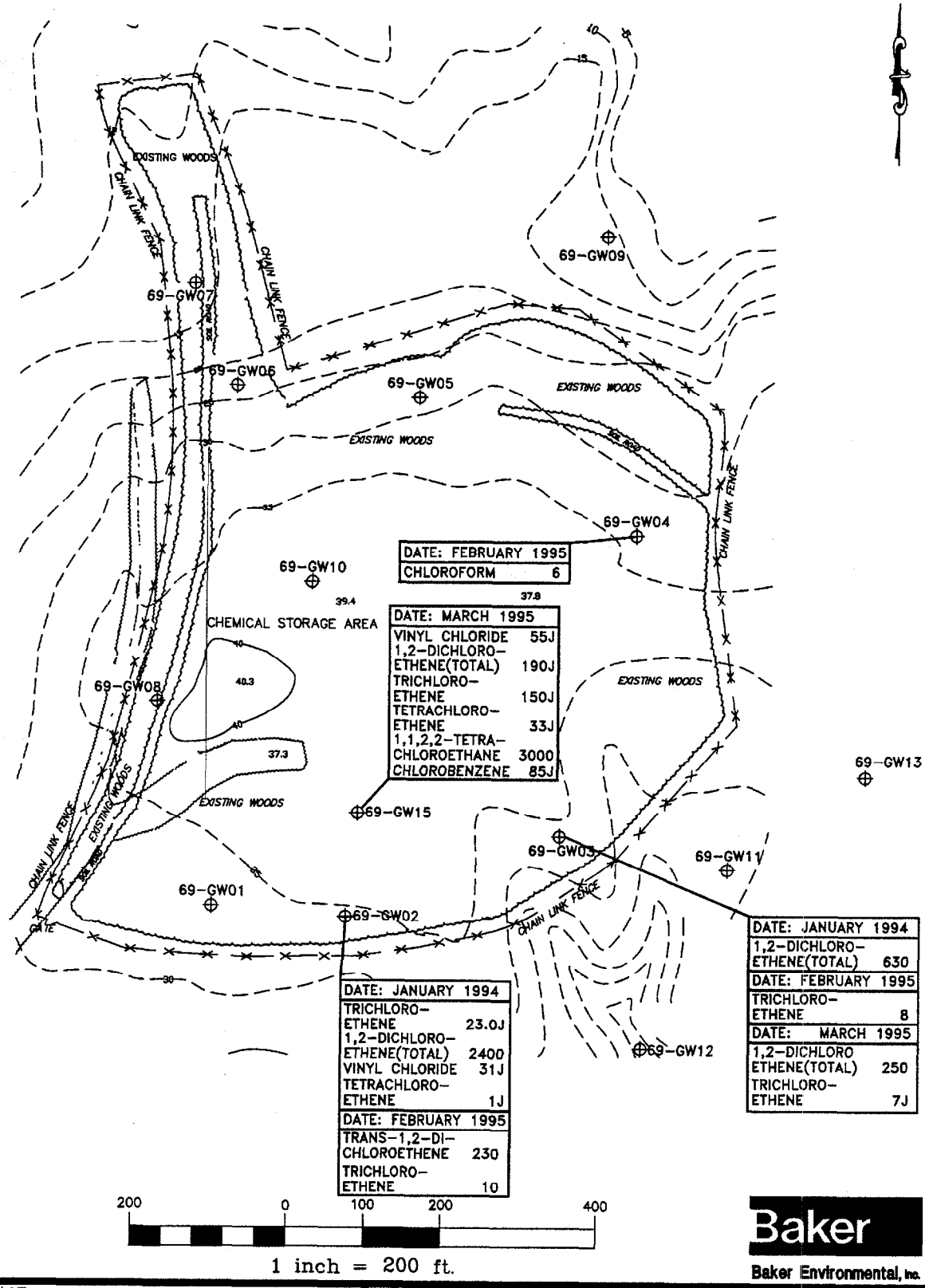
GROUNDWATER FLOW DIRECTION (INFERRED)

* GROUNDWATER LEVEL MEASUREMENT IS QUESTIONABLE

SOURCE: REVISED FROM LANTDIV, OCT. 1991

FIGURE 1-4
INTERMEDIATE GROUNDWATER ELEVATION CONTOURS - MARCH 26, 1995
SITE 69 - RIFLE RANGE CHEMICAL DUMP
CTO-0212
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

212005TS



Baker

Baker Environmental, Inc.

LEGEND

69-GW09 ⊕ EXISTING SHALLOW WELLS

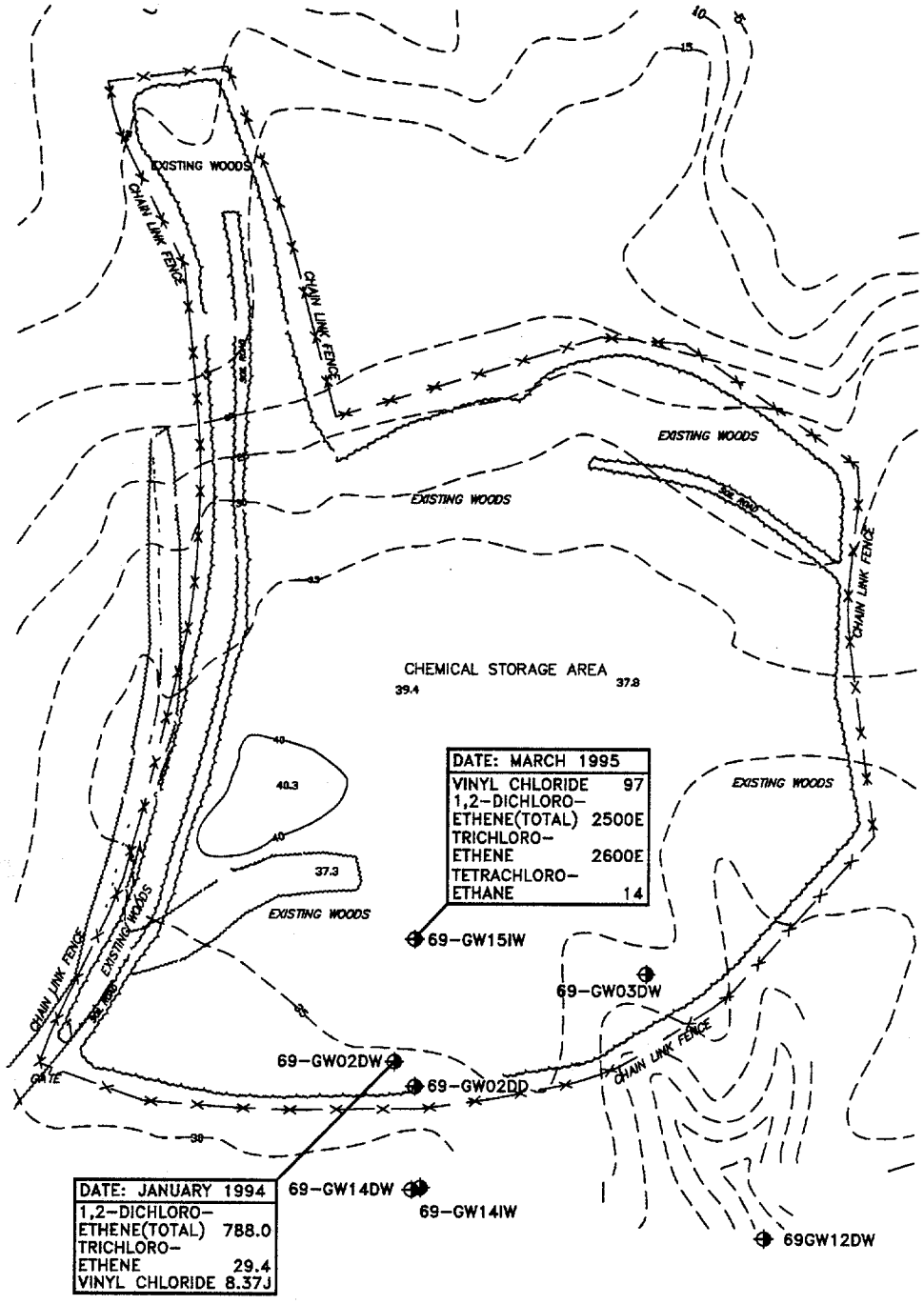
TOPOGRAPHIC ELEVATION LINES (FEET, MSL)

ALL CONCENTRATIONS REPORTED IN MICROGRAMS PER LITER (ug/L).

SOURCE: REVISED FROM LANTDIV, OCT. 1991

FIGURE 1-5
POSITIVE DETECTIONS OF VOLATILES ABOVE FEDERAL MCLs AND/OR NCWQS IN SHALLOW WELLS
SITE 69 - RIFLE RANGE CHEMICAL DUMP
CTO-0212
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

212006TS



200 0 100 200 400

1 inch = 200 ft.

Baker

Baker Environmental, Inc.

LEGEND

69-GW02DW EXISTING DEEP WELLS

TOPOGRAPHIC ELEVATION LINES (FEET, MSL)

ALL CONCENTRATIONS REPORTED IN MICROGRAMS PER LITER (ug/L).

SOURCE: REVISED FROM LANTDIV, OCT. 1991

FIGURE 1-6
POSITIVE DETECTIONS OF VOLATILES ABOVE FEDERAL MCLs AND/OR NCWQS IN DEEP WELLS
SITE 69 - RIFLE RANGE CHEMICAL DUMP
CTO-0212
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

2.0 TECHNOLOGY DESCRIPTIONS

The UVB (Vacuum Vaporizer Well), and the KGB (Coaxial Groundwater Ventilation) technologies were designed and developed by IEG GmbH of Germany as a methodology for in situ treatment of groundwater, and were first introduced in the U. S. in 1992. SBP has the exclusive rights to distribute these technologies to Baker/MCB.

2.1 The UVB Technology

A description of the UVB technology, as well as information on some of the UVB systems installed to date, are provided in the following sections.

2.1.1 Description

The UVB is an in situ groundwater and soil remediation system which remediates volatiles and petroleum hydrocarbons using a combination of physical, chemical, and biological processes. The UVB system consists of a specially adapted groundwater well that creates a circulation cell to transport dissolved mobile-phase hydrocarbons to a central well casing for treatment. The circulation cell is established by the air-lift effect in an air-lift UVB design or by a submersible pump in a support pump UVB design. An aboveground blower is used to create a reduced pressure (vacuum) in the treatment well. This results in an air-lift effect, which lifts the water in the well. The water leaves the well through an upper screen, and to make up for the loss, water enters the well through the lower screen, thus creating a vertical circulation cell.

For a UVB designed with a support pump, two types of flow can be induced: a standard flow where water enters the well through a lower screen and leaves through the upper screen; and a reverse flow where water enters the well through the upper screen and leaves through the lower screen. The standard flow configuration allows mobilization of dense non-aqueous phase liquid (DNAPL) type contaminants, whereas, the reverse flow configuration allows mobilization of light non-aqueous phase liquid (LNAPL) type contaminants. Figure 2-1 shows schematic diagrams of the two configurations. The type of flow configuration used for the treatability study will be based on the vertical distribution of VOC contamination in the Castle Hayne Aquifer. As previously noted, the vertical extent of contamination is currently undefined in the vicinity of monitoring wells 69-GW15 and 69-GW15IW. If significant groundwater contamination does not extend below a depth of 80 ft, then a standard circulation, 8-inch UVB well will be used. However, if groundwater contamination extends below 80 ft and the distribution of contamination is such that significantly higher levels of VOCs are present in the upper Castle Hayne Aquifer (e.g., 50-60 ft) then in the lower portion of the aquifer (e.g., 80-90), then a 10-9 inch diameter reverse circulation UVB well will be used. In this case, the reverse circulation UVB well is recommended to ensure that the highest levels of contamination are captured by the treatment well.

The treatment methodology consists of air stripping for VOCs and bioremediation for light and middle range fraction hydrocarbons. Stripping of VOCs is achieved by the blower, which pulls ambient air through a stripper plate submerged in the treatment well. At the same time, water leaving the treatment well is supplemented with dissolved oxygen to enhance in situ biodegradation of contaminants by native organisms. Stripped VOCs in the off-gas are typically processed in an aboveground granular activated carbon (GAC) unit. Gas phase bioreactors/thermal oxidizers may be used if appropriate instead of GAC. Additional information on the operation of the UVB system is provided in Section 4.3.1.

Two configurations of the UVB system are available: the UVB-200 (8-inch diameter well); and the UVB-400 system (16-inch diameter well). The UVB-400 system is designed for conditions requiring a high groundwater flow rate through the system (e.g., when hydraulic conductivity exceeds 1 x 10^{-2} cm/sec.) or when a high air flow rate is needed due to high contaminant concentrations (e.g., when total VOCs exceed 10 ppm). The UVB-200 system is used when the site conditions require lower groundwater and air flows. A UVB-200 air lift system will be used for this treatability study at Site 69.

2.1.2 UVB Installations and Case Studies

UVB systems have been employed successfully in the United States and Europe for the remediation of soil and groundwater contaminated with various volatile organic compounds, including BTEX and TCE. Over 100 systems have been installed in Europe. Currently, there are 25 UVB systems in operation at 18 sites in the United States. Systems installed in the United Sates are all being evaluated for their performance and percent reduction in contaminants. None of the 18 United States sites has as yet received closure because they went into operation between 1992-1994. Successful demonstration of the UVB technology has resulted in the closure of six sites in Germany (two within two years of start up).

Following are the case studies in brief of the two most recent UVB installations.

Port Hueneme Site

In May 1994, SBP was authorized to install an in situ bioremediation system for groundwater remediation and chemical containment at the Naval Construction Battalion Center (NCBC) Port Hueneme located in Ventura County, California. Approximately 10,800 gallons of leaded gasoline containing the additives methyl tertiary butyl ether (MTBE) and 1,2-Dichloroethane were spilled in the subsurface between September 1984 and March 1985 at the Navy Exchange Gasoline Station. SBP designed and installed four UVB systems. One was installed at the source, and three were installed downgradient. The three downgradient UVBs were installed in a series at the edge of the migrating BTEX plume with overlapping zones of influence. The objective is to initiate a biocurtain to effectively biodegrade regulated constituents as they passively traverse the active zones. The goal is to reduce benzene concentrations to less than 5 ppb. The cost savings from this system over the pump-and-treat alternative is estimated at $ 2.5 million. The unit has already allowed the operators to avoid a fine for non-compliance of plume mitigation and chemical containment, and, if effective, will provide for chemical containment.

Sweden-3 Chapman Site

In July 1994, as part of a multi-vendor treatability study demonstration of bioremediation technologies, SBP received an approval from the New York State Department of Environmental Conservation (NYSDEC) in collaboration with the EPA Site Program, to install a UVB with an in situ bioreactor at the Sweden-3 Chapman Site, Sweden, New York. SBP designed and installed this system to demonstrate treatment of chlorinated volatile organic compounds (TCE, DCE, TCA, vinyl chloride, etc.) and non-chlorinated volatile organic compounds (toluene, xylenes, MEK, MIK, acetone, etc.) in soil and groundwater at this former drum disposal site. The objective was to demonstrate that concentrations of target compounds can be significantly reduced in an area measuring 50 ft x 50 ft around the UVB system.

After six months of operation, results indicate that there has been a 45% reduction in total VOCs in 15 groundwater monitoring wells surrounding the UVB system. In addition, soil microbiological analysis has shown significant increases in TCE degraders, while soil nutrient analysis has shown significant decreases in nitrate, nitrite, and ammonia.

The original six month project has been approved for an extension of six more months following encouraging results.

2.2 The KGB Technology

2.2.1 Description

The KGB system is used to create a circulation cell within perched groundwater and thin aquifers (<15' deep) to remove volatile organics and enhance microbiological degradation. A special advantage of the KGB system is its ability to effectively remediate the often highly contaminated capillary fringe. Figure 2-2 shows a schematic diagram of the KGB system. A KGB system is operated by pumping compressed air into a pressurized air distributor located between the capillary fringe and the aquifer base. The air bubbles rise within the borehole filled with gravel pack and cause the water to flow upward via an air lift effect. Consequently, a continuous circulation of groundwater is established in the area surrounding the KGB well which delivers contaminated water for air stripping. Volatile hydrocarbons dissolved in groundwater are transferred from the aqueous phase to the gaseous phase in an amount relative to their gas-liquid distribution coefficients. These gases, and the vapors from the vadose zone, are drawn by the blower resulting in the removal of volatile organics. The off-gases are processed in aboveground GAC units. Gas phase bioreactors/thermal oxidizers may be used instead of GAC, if appropriate.

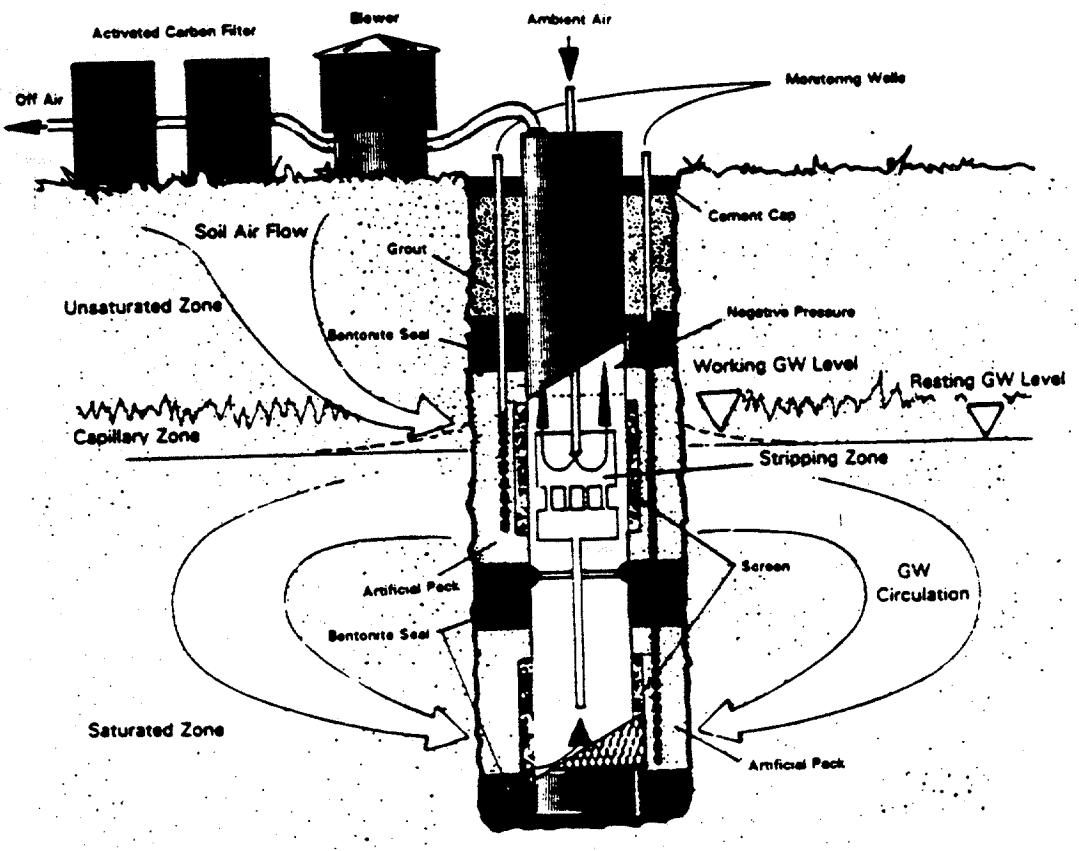
2.2.2 KGB Installations and Case Studies

KGB systems have been employed successfully in the United States and Europe for the remediation of soil and groundwater contaminated with a myriad of volatile organic compounds, including BTEX and TCE. Currently, there are three KGB systems in operation in the United States. These systems are currently being evaluated for their performance and percent reduction in contaminants.

The most recent installation was in June 1994 at the Tyndall Air Force Base in Florida. This system is a modified version of the KGB for bioventing application. Petroleum hydrocarbon contaminated groundwater is being air stripped using the KGB. However, the off-gases are not withdrawn for aboveground off-gas treatment. Instead, the gases are injected back into the vadose zone to be treated by means of bioventing. Preliminary results indicate that significant reduction in BTEX compounds has been achieved during the first six months of operation.

SECTION 2.0 FIGURES

UVB - Standard Circulation ©



UVB - Reverse Circulation ©

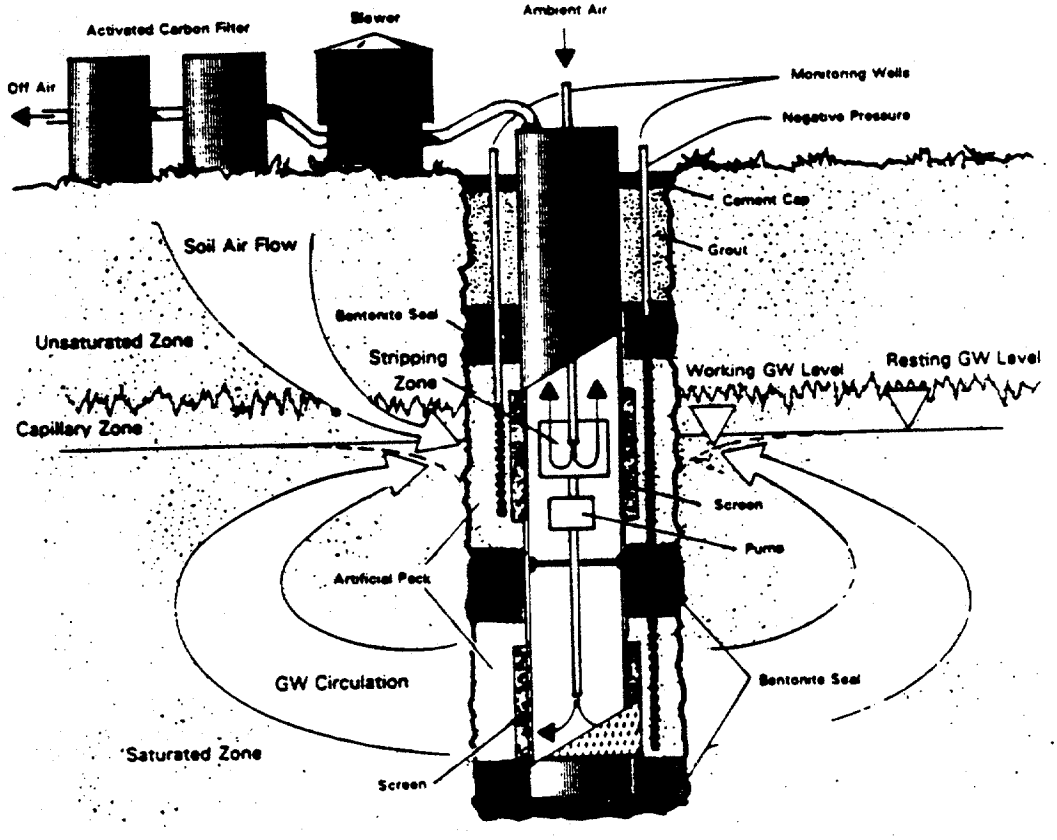


FIGURE 2-1
SCHEMATIC DIAGRAM OF THE UVB SYSTEM
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

Technologies Corp.
8330 Crossroads Drive Charlotte NC 28217

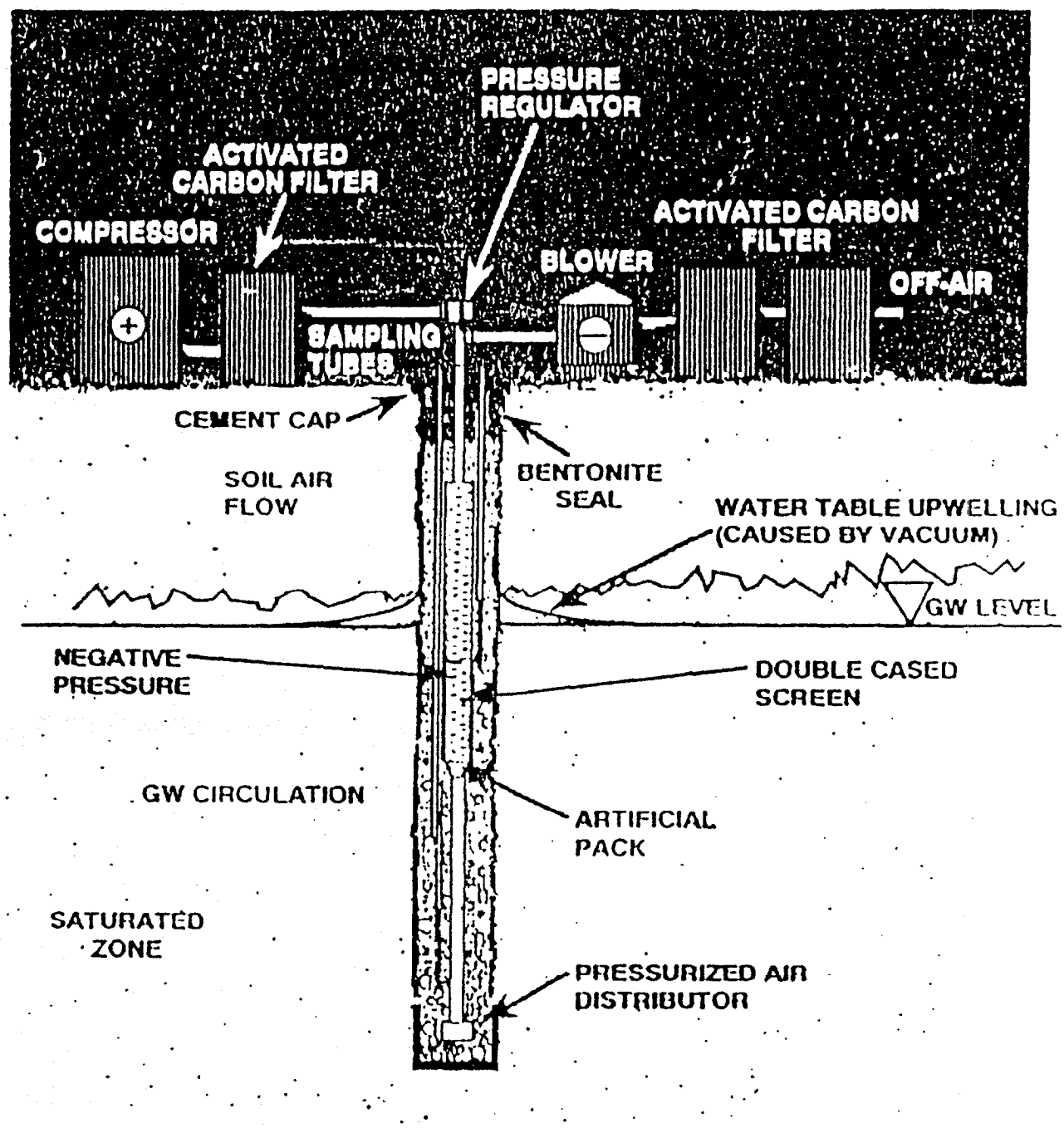


FIGURE 2-2
SCHEMATIC DIAGRAM OF THE KGB SYSTEM
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

3.0 TREATABILITY STUDY OBJECTIVES

As previously noted, the major objectives of this treatability study are to:

- Determine if the UVB/KGB technologies are implementable, effective and economical for remediation and/or containment of contaminants in the shallow and upper Castle Hayne Aquifers at Site 69, Marine Corps Base, Camp Lejeune, NC.

- Provide engineering parameters related to the design and implementation of full-scale UVB and KGB remediation systems at Site 69.

More specifically, during this treatability study the following questions will be answered:

1. Can the UVB and KGB technologies be implemented on a full scale under the existing hydrogeologic conditions at Site 69? This question will be answered by determining, via tracer analysis, if a circulation zone can be established. Without a circulation cell, active remediation is not possible.

2. How effective are the UVB and KGB technologies? The degree of effectiveness will be determined from analysis of the stripped off-gases, analysis of the granular activated carbon (GAC) used to treat the off-gases, as well as periodic analysis of groundwater in monitoring wells located within and around the estimated zone of influence (ZOI) for each system. The GAC off-gas treatment system is designed to adsorb the VOCs stripped by the UVB/KGB systems from groundwater. Consequently, the concentration of VOCs in groundwater should decrease, indicating that the UVB/KGB technology is effective in remediating the groundwater at Site 69. The contaminant removal rate will depend on the effectiveness of the UVB/KGB circulation cells (under existing hydrogeologic conditions) to mobilize the contaminants and transport them to the UVB/KGB wells for air stripping. This will be determined from the amount of organics adsorbed by the GAC units over the treatability study duration.

3. Is the UVB/KGB remediation technology cost-effective? The economics will be determined based on the ZOIs created by the UVB/KGB systems. The ZOIs will be determined via tracer analysis. The ZOIs will determine the number and types of UVB/KGB systems required to treat the impacted area. The capital costs for these units along with the associated annual operating and maintenance costs over an estimated period of operation will be determined.

The following parameters will be determined to assess the technical and economical feasibility of the UVB and KGB technologies during the treatability study:

- Approximate zone of influence of the UVB-200 well (from tracer study)

- Approximate zone of influence of the KGB well (from tracer study)

- Cumulative water processed by the UVB-200 well (from direct measurement)

- Cumulative water processed by the KGB well (to be estimated)

- Cumulative air processed by the UVB-200 system (from average of weekly monitoring)
- Cumulative air processed by the KGB system (from average of weekly monitoring)
- Carbon breakthrough and carbon consumption for the UVB-200 system (from GAC analysis)
- Carbon breakthrough and carbon consumption for the KGB system (from GAC analysis)
- Contaminants removed by the UVB-200 system (from GAC, groundwater, and off-gas analysis)
- Contaminants removed by the KGB system (from GAC, groundwater, and off-gas analysis)
- Electric power consumption (pump, UVB blower, KGB blower, compressor)
- Frequency and extent of maintenance requirements for each system
- Cumulative water removed by the knock-out vessels

4.0 TESTING PROCEDURES

4.1 Mobilization

Mobilization will include site preparation, site clearing, installation of utilities, installation of temporary facilities, and mobilization of drilling crew and rig.

4.1.1 Site Preparation/Site Clearing

At this time, no site preparation/site clearing activities are envisioned for access roads to the site. The existing roads are generally accessible for the drilling rigs and 4-wheel drive vehicles. Low-lying portions of the access road, which become flooded during storm events, will be improved by the Remedial Action Contract (RAC) contractor prior to treatability study mobilization activities. Limited site clearing, which may include cutting small trees and removing shrubs, may be required to install the UVB/KGB systems and the associated monitoring wells. This activity will be performed by the drilling subcontractor.

4.1.2 Installation of Utilities

The UVB/KGB systems will be operated using permanent electricity hook-ups to be made available at the site. No electric power is currently available at the site; however, prior to start of the treatability study, a permanent power line will be installed along the site access road by the RAC contractor. Equipment specification sheets indicating the voltage, amperage, and phase requirements for the treatment system components are provided in Appendix F.

Water will be made available at the site via a temporary 5,000-gallon high density polyethylene (HDPE) water tank. A local company will be used to provide water during the treatability study. This water will be analyzed for VOCs by EPA Method 8260 in accordance with the ECBSOPQAM.

4.1.3 Temporary Facilities

Since the site is located in a remote area, no facilities or services are available on site. The following temporary facilities will be used during the treatability study:

- No trash pick-up services are available near the site. Trash will be collected in garbage bags and disposed of at a designated location on the Base. Mobilization of a dumpster will not be necessary.
- A temporary sanitary facility will be mobilized for use during the well installation and startup period (approximately 3-4 weeks). The facility will be installed outside of the fenced area so that it can be serviced periodically.
- No office or storage trailers will be used during the study.
- SBP will have a mobile phone on site during the well installation and startup period.
- A local subcontractor will be used to receive and store field monitoring equipment, UVB/KGB equipment, sampling equipment, and supplies.

4.2 Drilling and Well Construction

This section describes the procedures for the construction and installation of groundwater monitoring wells (2-inch PVC and 2-inch drive points), the UVB-200 well, and the KGB well. All drilling activities will be performed under the direct supervision of a licensed well driller. Oversight will be provided by SBP. In addition, prior to drilling within the fenced area, all boreholes will be cleared by the Army Technical Escort Unit (TEU) and the unexploded ordnance (UXO) subcontractor. The TEU will screen each boring for chemical surety agents, and the UXO subcontractor will screen each area for buried drums and ordnance using geophysical methods. At a minimum, drilling activities will be performed using Level B respiratory protection (i.e., air line or self-contained breathing apparatus) until the water table is encountered. Once drilling is advanced past the water table and the TEU has cleared the hole, the level of respiratory protection will be downgraded as appropriate in accordance with the HASP.

4.2.1 PVC (2-inch) Monitoring Wells for the UVB-200

The layouts of the proposed UVB well and the 2-inch PVC UVB groundwater monitoring wells are shown in Figures 4-1 and 4-2, respectively. As shown in Figure 4-2, 12 monitoring wells are proposed in two 90° arms; one arm in an approximate downgradient (southern) direction, and one arm in a cross-gradient (eastern) direction. Two existing wells, 69-GW15IW and 69-GW02DW, will be utilized in the southern arm. Each arm will contain six wells, three shallow (approximately 35 ft bgs), and three deep (approximately 65 ft bgs). Three such clusters (each consisting of a shallow and a deep well) will be located at radial distances of approximately 43 ft, 73 ft, and 128 ft from the UVB well in both arms, except for wells S3,1 and S3,2 (Figure 4-2). Existing monitoring well 69GW02DW will be used for wells S3,1 and S3,2, which is located approximately 130 ft from the UVB. These distances represent the 25% ZOI, 43% ZOI, and 75% ZOI values, respectively (see Section 4.3.3 for explanation of ZOI). In addition to these two arms, a shallow and deep well cluster will be located 43 ft west of the UVB well, and another well cluster 43 ft north (upgradient) of the UVB, as shown in Figure 4-2. In addition, two deep and one shallow monitoring well will be installed in the annulus of the UVB well (two for monitoring and one for maintenance).

All new monitoring wells will be installed immediately prior to performance of the treatability study, except for two wells, monitoring wells 69-GW15UW (S1,1) and 69-GW15DW, which will be installed initially as part of a separate field effort. All treatability study well locations will be located and cleared during this initial field effort so that remobilization of the TEU and UXO subcontractor is not required for the treatability study.

Since the size and type of UVB well must be determined prior to mobilization and installation of the UVB system, an additional field effort is needed to evaluate the vertical extent of contamination near wells 69-GW15 and 69-GW15IW at Site 69. Therefore, prior to performance of the treatability study, a 120-ft deep, Type III well (69-GW15DW) will be installed to determine the vertical extent of groundwater contamination, as described below.

A pilot hole will be drilled using 12-inch outside diameter (O.D.) hollow stem augers. Split spoon samples will be collected continuously to identify the clay layer which separates the surficial aquifer from the Castle Hayne Aquifer. It is estimated that the clay will be encountered at a depth of approximately 12 ft. Upon encountering the clay, a 10-inch inside diameter (I.D.) steel casing will be set and grouted in place. Drilling will continue using mud rotary (9 7/8-inch diameter bit) with split spoon samples collected at 5-ft intervals. Hydropunch samples will be collected at 10-ft

intervals starting at a depth of 50 ft. Due to the groundwater contamination detected in intermediate well 69-GW15IW, an inner casing will be set at a depth of approximately 80 ft to seal off the upper portion of the borehole before proceeding to the final depth so that any potential contamination will not be carried to deeper depths. This casing will be constructed of 8-inch I.D. steel and will be grouted into place. The grout will be allowed to set overnight before proceeding with drilling, sampling, and the well installation. Following the setting of the inner casing, mud rotary drilling will continue with a 7 7/8-inch bit, and split spoon samples collected at 5 ft intervals. Hydropunch samples will continue to be collected at 10 ft intervals to the final depth of the borehole, which is anticipated to be 120 ft. Following completion of the drilling and sampling, a 15 foot, 2-inch I.D. PVC screen (0.010-inch slots) will be installed with 2-inch I.D. PVC threaded, flush joint riser.

Well 69-GWUW (S1,1) will also be installed as part of the initial field effort. Since there are currently no on-site wells screened in the 20-ft. to 40.ft interval, the depth of the static water table (assumed to be 25-ft. to 35-ft.) requires verification. It is desirable to verify this depth during the initial field effort so that the drilling scope of work can be finalized prior to mobilization for the treatability study. Installation of well 69-GW15UW, designed to straddle the static water table, will accomplish this goal. Well 69-GW15UW will also be a Type III well. Figure 4-3 shows construction details of a typical Type III monitoring well proposed for the shallow and deep UVB monitoring wells.

4.2.2 KGB Monitoring Wells

Figures 4-4 and 4-5 show a layout of the proposed KGB well and the KGB monitoring wells. A total of eight monitoring wells is proposed in two 90° arms (one downgradient or south and one lateral or east). Each arm will contain four wells, two shallow (approximately 9 ft bgs), and two deep (approximately 12 ft bgs). Two pairs (each consisting of a deep and a shallow well) will be located at radial distances of 11 ft and 16 ft from the KGB well in both arms. These represent distances of 50% ZOI, and 75% ZOI, respectively (see Section 4.3.7 for explanation of ZOI). All KGB monitoring wells, except one shallow and one deep well, will consist of 2-inch diameter galvanized steel drive points with 2-ft screens. Figure 4-6 shows construction details of a typical Type II monitoring well proposed for one shallow and one deep KGB monitoring well.

4.2.3 Procedures

4.2.3.1 Drilling

A combination of hollow-stem auger and mud rotary drilling methods will be used for drilling of all UVB monitoring wells as described in Section 4.2.1 for monitoring well 69-GW150W. All drilling will be performed in accordance with the USEPA Region IV ECBSOPQAM. Details on drilling methods and borehole logging are described in the SOPs (Appendix D).

4.2.3.2 Surface Casing

Due to the presence of perched water (5-12 ft bgs), all drilling work beyond 12 ft bgs will require installation of a surface casing. A 6-inch surface casing will be used on all shallow and deep 2-inch PVC UVB monitoring wells. The casing will be set to a depth of 12 ft bgs. The outside and inside of the casing will be grouted to within 2 ft of surface grade and allowed to dry. Once the grout has set, drilling will continue through the grouted casing and into the underlying aquifer. Details on surface casing installation are outlined in the SOPs.

Surface casings will not be required during installation of KGB monitoring wells.

4.2.3.3 PVC Wells and Screen Slot Size

The UVB monitoring wells will be 2-inch diameter SCH 40 PVC with a 6-ft slot screen at the bottom. The KGB monitoring wells will be 2-inch diameter SCH 40 PVC with a 1 ft slot screen at the bottom. The screen slot size will be designed to retain approximately 90% of the filter pack material. Where necessary a sediment sump (trap) will be constructed of blank PVC at the bottom of each screened interval.

4.2.3.4 Filter Pack and Bentonite Seal

The grain size of the filter pack will be specified to be between four and six times the grain size of the formation. The filter pack material will be graded silica sand (Colorado Silica Sand or equivalent). The sandpack will extend from the bottom of the screened interval to about 2 ft above the top of the screen section. After the filter pack is in place, bentonite seal will be placed in the borehole using one of the methods described in the SOPs. Seals will be 1 to 2 ft in thickness. The borehole annulus will be grouted with a cement-bentonite grout mix which will extend to within approximately 2 ft of the ground surface. Details on installation of filter pack and bentonite seals are outlined in the SOPs.

4.2.3.5 Cement-Bentonite Grout

Grout will be placed directly above the bentonite seal and will extend to within 2 ft of the ground surface. This will inhibit water flow through the annular space between zones of the aquifer system and from the ground surface. The grout will then be allowed to settle. If significant settlement of grout occurs, additional grout will be added to the prescribed depth of approximately 2 ft below ground surface prior to installation of the protective casing and the concrete pad. Procedures on installation of cement-bentonite grout are detailed in the SOPs.

4.2.3.6 Protective Steel Casing

Casing stickup above the ground surface will be approximately 1.8 ft. A spacer will be temporarily installed so that the protective casing is 0.2 ft higher than the top of the well casing. Protective steel casing with a locking cap will be placed over the PVC stickup with the top of the casing being approximately 2 ft above the ground surface. Protective casing will be secured by means of a padlock which will be installed at the time of protective casing installation. The protective casing will be painted prior to installation. Well designations will be painted or permanently attached on the protective casing for all wells.

A concrete mix consisting of approximately one part sand to two parts cement will be used for the concrete pad. The concrete pad will be poured into temporary forms and will be troweled so as to provide positive drainage away from the steel casing. Four, 4-inch steel protection posts (bollards) (five feet long, set 2.0 to 2.5 feet into the ground and painted day-glo orange or other high-visibility paint approved by LANTDIV/Baker) will be embedded into the concrete pad. The posts will be constructed of 3-inch ID schedule 40 steel pipe.

4.2.4 UVB-200 Well

The drilling method proposed for the UVB-200 well at Site 69 is mud rotary type. Rotary drilling methods are used in cases where deep penetrative work is to be conducted in unconsolidated sediments or shallow penetrative work is to be conducted in soft rock, tills, and other deposits containing boulders. Rotary drilling procedures are described in the SOPs. A boring log, based upon continuous or interval sampling and observed cuttings, will be prepared in accordance with the standard lithologic logging procedures described in the SOPs. Figure 4-7 shows a construction diagram for the UVB-200 well.

The UVB-200 PVC casing will rise 2 ft above the ground surface where the vacuum line connection will be made to the blower. The UVB casing will be fitted with two screen sections (a lower screen [4 ft.] and an upper screen [8 ft.]). These screens will be provided by IEG. The depth of the UVB-200 well will be determined following installation of well 69-GW15OW, as described in Section 4.2.1.

As discussed earlier, a permanent surface casing will be installed to prevent migration of groundwater from the upper aquifer to the lower aquifer through the borehole. The UVB-200 well will be installed through a permanent 18-inch surface casing, grouted in place to 11 ft bgs. For capture zone calculations (Section 4.3.3), a well depth of 62 ft deep bgs was assumed. The installation of the UVB-200 system, including three 2-inch PVC wells (two monitoring, one maintenance) in the UVB annulus will require an open borehole or temporary casing of at least 16-inch inner diameter.

After the UVB casing stem and annulus sampling ports are set in place, the remaining annular space can be filled with bentonite (sealed pellets), gravel and portland/bentonite grout in the amounts required by the borehole size, and as described in the SOPs. A 6 ft x 6 ft concrete pad with steel protection poles will be constructed around the UVB well, as described for the monitoring wells.

Figure 4-8 shows details of the stripping plate, the packer, the lower screen, and the upper screen of the proposed UVB-200 for Site 69.

4.2.5 KGB Well

Figure 4-9 shows a construction diagram, as well as details of the air distributor and the double cased screen for the KGB well. The KGB well will be 6-inch in diameter and will be installed to 11 ft bgs. The KGB well will be hollow stem augured using an 12-inch I.D. auger according to the standard drilling procedures in the SOPs. No surface casing will be required during the installation of KGB well.

4.2.6 Pilot Borehole

The purpose of the pilot borehole is to verify that geologic conditions are favorable at the specific locations where installation of the UVB well is proposed. The pilot borehole will provide information regarding the presence or absence of subsurface confining layers which could adversely impact the capability of the UVB to establish a vertical circulation cell between its upper and lower screens. This pilot hole will eliminate potential downtime and additional costs during the UVB well drilling. In addition, last minute changes in the UVB/KGB well construction and design (e.g., well screen lengths, well screen spacing) can be made from the geologic data collected during this event.

The proposed depths and spacings of all monitoring wells, the UVB well, and the KGB well may change depending on the data obtained from the borehole drilling/hydropunching during installation of well 69-GW15DW and the pilot borehole.

The pilot borehole will be 4 inches in diameter and will be drilled using a hollow stem auger. A 6-inch surface casing will be installed to 12 ft bgs as previously described. Continuous split spoon sampling will be conducted after the surface casing to 50 ft bgs. Split spoon samples will be archived as described in the Sampling and Analysis Plan (SAP) in Section 6.0.

4.2.7 Well Development

The methods used for the purpose of monitoring well development are described in the SOPs. All development methods will be employed in a manner to enhance flow reversals in the filter pack material. The water removed in the course of well development will be handled in accordance with the procedures developed for handling and disposal of investigation derived wastes for the project (Section 8.2). The volume of water removed, method and time, and other development measurements will be recorded in the field logbook. In general, the method which will provide the highest flow velocity into and out from the filter pack will be used. This activity will be conducted by the drilling contractor or SBP personnel a minimum of 24 hours after well installation is completed.

4.2.8 Well Identification

A metal identification tag will be mounted on each well indicating date installed, Baker Environmental, drilling firm, depth of well, screen interval, and well identification number.

4.2.9 Drilling Equipment (Assembly, Decontamination)

All equipment will be assembled, and tested prior to drilling. All downhole drilling equipment will be decontaminated between drilling locations. Equipment will be placed on plastic sheeting to prevent contact with the ground surface. If a truck tailgate is used as an equipment bench, it will be covered with plastic sheeting. Decontamination of all drilling equipment will be performed using high pressure steam. Decontamination water will be collected, sampled, and disposed in accordance with Section 8.3.

4.3 System Design and Operation

4.3.1 General Operation of the UVB-200

The UVB well is an in situ groundwater and soil remediation system, which remediates a range of organic contaminants using a combination of both physical and biological processes. The UVB system creates a circulation cell that transports the VOCs in groundwater to a central well casing for treatment. The treatment methodology is primarily air stripping, and secondarily bioremediation for light and middle range fraction hydrocarbons.

During operation, the water level rises inside the air tight UVB well due to a reduced atmospheric pressure generated by a blower. Atmospheric air enters the well through a fresh air pipe connected to the stripping reactor, which floats on the raised groundwater level. The incoming fresh air creates a pressure equilibrium and forms bubbles through the groundwater as it is jetted through the pin hole

plate of the stripping reactor in the well casing. An "airlift" effect is produced as the bubbles rise and expand. The "airlift" effect will generate a standard upward flow pattern inside the remediation well and allow for a variable amount of water to pass into the stripping reactor.

The groundwater elevation in the well casing is also amplified by the rising of air bubbles ("airlift" effect). The reduced pressure in the well casing accelerates the rise of bubbles by allowing for an increased rate of expansion. When the bubbles reach the air/water interface inside the well casing they burst and allow the VOC's to be transported through the well shaft and up to the off-gas treatment unit. After the bubbles burst, the groundwater then falls along the walls of the well, and produces a significant hydraulic pressure, forcing the water horizontally into the aquifer through the upper screen section straddling the top of the aquifer.

Groundwater flows into the lower part of the well to compensate for the water removal from the upper section. Thus, a vertical circulation pattern develops with water entering the screen in the lower part of the well near the bottom of the aquifer or contamination zone, and leaving through the upper screen segment, or the top of the aquifer. The majority of the treated groundwater leaving the upper screen section of the well circulates through the entire sphere of influence and returns to the lower screen section a number of times before exiting the circulation cell.

4.3.2 Operational Characteristics of the UVB-200

The stripping efficiency of the UVB is based on the air to water ratio. The UVB 200 system usually draws in approximately 100 m^3/h (58.9 cubic feet per minute (CFM)) of air, and in this case approximately 4 m^3/h (17.6 gallons per minute (gpm)) of water are being pumped into the stripping reactor producing a water to air ratio of 1:25, and an approximate stripping efficiency ranging from 90 to 99%.

Based on an aquifer flow rate (Q_o) of 0.26 m^3/h through the capture zone area (see Section 4.3.3), and an internal combined flow rate (Q) of 4.0 m^3/h, the UVB 200 system will be able to recirculate 93% of the influent more than once though the circulation cell.

Assuming complete mixing, 7% of the effluent that moves downstream will have passed once through the stripping zone, while the remaining 93% of the effluent will have passed through the stripping zone at least twice.

4.3.3 Capture Zone and Circulation Cell of the UVB-200

The capture zone and circulation cell for the UVB 200 system to be installed at Site 69 have been estimated using the aquifer parameters developed in the Draft Final RI Report (Baker, June 1995) and the equations and graphical solutions developed by Dr. Bruno Herrling of the Groundwater Research Group, Hydromechanic Institute, University of Karlsruhe, Germany. These equations and graphical solutions are provided in Appendix E.

The estimations were based on the following assumptions and simplifications:

- The aquifer thickness is constant.
- Only confined aquifer conditions are considered in the estimations.

- The aquifer structure is assumed radially homogeneous to hydraulic conductivities. Horizontal layers, each with different conductivities, can be used. The hydraulic conductivities may be anisotropic, but each horizontal layer may have only one vertical and one horizontal conductivity.
- The local below-atmospheric pressure field near the well is neglected.
- Density effects are neglected.
- The computations assume steady-state conditions.

Based on these assumptions, the following aquifer and UVB parameters have been estimated:

- Darcian velocity = 6.5×10^{-8} m/sec
- n (Porosity) = 0.3
- K_h (Horizontal Hydraulic Conductivity) = 1.0×10^{-4} cm/sec
- K_v (Vertical Hydraulic Conductivity) = 1.0×10^{-5} cm/sec
- Horizontal Hydraulic Gradient = 0.065
- Thickness of Treatment Zone = 10.27 m (33.7 ft)
- Height of Upper Screen = 1.83 m (6.0 ft)
- Height of Lower Screen in Saturated Zone = 1.22 m (4.0 ft)
- Q, Flow from Upper Zone to Lower UVB Zone = 4 m^3/h (estimated) for the UVB-200 well

Based on the above parameters, the upstream and downstream stagnation points, and the distances B_b and B_t, have been estimated, as shown in Figures 4-10 and 4-11. For standard flow UVB systems, distance B_b is defined as the bottom width of the capture zone, and distance B_t is defined as the top width of the capture zone. These distances have been calculated for an upstream distance from the UVB well of 5H, where H is the height of saturated zone affected by the UVB. The distance 5H is the minimum distance required from the UVB/KGB in order to eliminate any distortion effects caused by the circulation cell at the points where B_b and B_t are calculated.

For the UVB-200 treatment system, the estimated downstream and upstream stagnation point (S) for the circulation cell is 52 m (171 ft) from the center of the system. The stagnation point, S, represents the minor axis of the ZOI. The width of each circulation cell is $\{(B_b + B_t)/2\} = 111$ m. The theoretical capture zone width for the top of the zone (B_t) is 81 m, and for the bottom of the zone (B_b) is 141 m. The major axis of the ZOI is calculated as $\{(B_b+B_t)/4\} = 55.6$ m.

To calculate the circulation cell capture zone and downgradient release zone dimensions, aquifer data are entered into a computer spreadsheet, and the variables $Q / H^{2*} V$ and a/H are calculated. These variables are then used in conjunction with Dr. Herrling's graphical solutions (Figures 4-12

through 4-17) to determine the various ratios. Table 4-1 lists the parameters evaluated for the determination of the capture and circulation zones for the UVB-200. These values are inserted in the spreadsheet to calculate the dimensions of the theoretical circulation cell capture zone and release zone. The circulation zone of influence (ZOI) is typically estimated as 90 to 98% of the major axis. For this study, the ZOI was estimated as approximately 94 percent of the major axis, which is 52 m (171 ft). Circulation times were estimated for Site 69 using porosities (n) of 0.3, 0.35, and 0.4 as shown in Figure 4-18. Using a porosity value of 0.3, UVB monitoring well locations were selected for the 25% ZOI (40-day circulation time), 43% ZOI (160-day circulation time), and 75% ZOI (circulation time >700 days).

4.3.4 Maintenance Intervals and Parameters for the UVB-200

The maintenance intervals will begin immediately after start-up and continue every two months thereafter until completion of the six-month study. The parameters to be checked during these periods are as follows:

A. Measure and record height of the fresh air inlet pipe above top of UVB-HDPE well head flange.

B. Check direction of rotation for blower fan. Should match the arrow on the fan housing.

C. Check for wear and tear of blower fan belt. Replace or tighten as necessary (refer to blower specifications Section 5 for specifics).

D. Check water content in moisture knock out (remove all water after stripping, if necessary). To strip water in moisture knock-out, open hose bib to allow for a minimum of 1 hour ambient air to be drawn into knock out.

E. Check cables holding packer(s) check for fraying and replace as necessary.

F. Check cables for tightness and twisting, if necessary deflate and reset packer to make cables tight or untwist (inflatable packer only)

G. Check packer air pressure. Add air as necessary, maintain 3.5 bars (inflatable packer only)

H. Check air hose(s) for wear, and replace as necessary (inflatable packer only)

I. Observe vacuum gauge readings, adjust sieve plate up or down, or open/close blower butterfly valve accordingly (2/5 blower only) to maintain desired vacuum (range 65 to 45 millibars as per manufacturer's recommendation for proper operation)

J. Check buoyancy of the UVB if applicable. UVB floating system should be able to move freely up or down. If system is not floating, the cables and air lines may be tangled.

K. Check bearings on blower motor. Replace as necessary.

L. "Bird" cage should be secured to top of fresh air intake pipe.

M. Record hours of operation by checking cumulative hour meter on the blower or at the electrical panel.

N. While the blower is ON, verify that air is being pulled in through the air intake pipe, and through groundwater. This is done by measuring air flow through the fresh air intake pipe. If neither air flow, vibration or bubbling is heard, re-check items B through J. If problems persist, contact IEG (see Section 12 for phone numbers). If air is bubbling through water, vibration of the air intake pipe will be observed, and a vigorous bubbling action will be heard by placing the ear against the air intake pipe.

O. Verify proper functioning of the support pump (if applicable) by switching the pump ON/OFF. This procedure should cause the air intake pipe to move downward when the pump is turned "on", and upward then turned "off".

P. For fixed UVB's, place the ear to the intake pipe and this will allow one to hear when the pump is turned on and off.

Q. Remove iron and scaling build-up on upper screen section and UVB component parts. This may cause a significant reduction in the performance of the system. Moderate iron and scaling build-up is removed via high pressure water/steam washing. Extensive iron and scaling build-up is removed by dilute acid treatment.

The UVB system will be removed from the well for inspection twice during the study. The following checks will be performed during the inspections:

Check for iron and scaling build-up, any build-up or clogging of the screen holes should be removed.

R. When all the parts of the UVB system are removed, the packer lines and cables should be checked for twisting and tightness, and corrections made if necessary (floating UVB system only).

S. When a fixed or floating UVB system is removed, the well should be sounded and checked for sediment build-up, and any sediment covering more than 15% of the lower screen should be removed.

T. In cold weather, check for frost hindering the floating of the UVB or air flow through the inlet for a floating or fixed UVB. If frost persists, fix the UVB at a point matching the start-up influent velocity until temperature rises to enable free floating of the system.

4.3.5 General Operation of the KGB

The KGB system consists of a combination of soil air venting, and in situ groundwater stripping (push and pull technique) technologies. Clean compressed air is pumped into a pressurized air distributor located between the capillary fringe and the aquifer depending on the vertical contaminant distribution.

The design of the pressurized air distributor regulates the air flow so that the air can only flow upward. The air bubbles rise within the well, causing water inside the well casing to flow upward (air-lift effect). Consequently, a continuous circulation of groundwater is generated in the area surrounding the remediation well, delivering new contaminants to the stripping zone. In contrast to other sparging methods, the clean water leaving the upper screen section of the well has no air bubbles, therefore no air-water phases can impede the flow. In addition, a mass balance can be obtained between influent and effluent air. The KGB system needs lower pressure, less air volume, and thus, consumes less energy than conventional air sparging methods. Volatile hydrocarbons dissolved in the groundwater are transferred from the liquid to the gas phase in an amount relative to their gas-liquid distribution coefficient, and are extracted from the groundwater surface via the double-cased screen (see Figure 4-9). Soil air from the unsaturated zone is also extracted and remediated.

The stripping efficiency of the KGB is based on the air to water ratio. The KGB usually pushes in approximately 3.4 m^3/h (2 CFM) of air, and in this case approximately 0.5 m^3/h (2.2 gpm) of water is being pumped into the KGB well producing an air to water ratio of 6.8.

Based on an aquifer flow rate (Q_o) of 0.0185 m^3/h through the upstream capture zone (Section 4.3.7), and an internal combined flow rate (Q) of 0.5 m^3/h, the KGB system will be able to recirculate 96% of the influent more than once though the circulation cell.

Assuming complete mixing, 4% of the effluent that moves downstream will have passed once through the stripping zone, while the remaining 96% of the effluent will have passed through the KGB well at least twice.

4.3.6 Capture Zone and Circulation Cell of the KGB

The capture zone and circulation cell for the KGB system to be installed at Site 69 have been estimated using equations and graphical solutions developed by Dr. Bruno Herrling (Appendix E). The estimations were based on the assumptions and simplifications listed in Section 4.3.3. Based on these assumptions, the following aquifer and KGB parameters were estimated:

- Darcian velocity = 6.5×10^{-8} m/sec
- n (Porosity) = 0.3
- K_h (Horizontal Hydraulic Conductivity) = 1.0×10^{-4} cm/sec
- K_v (Vertical Hydraulic Conductivity) = 1.0×10^{-5} cm/sec
- Thickness of Treatment Zone = 2.74 m
- Height of Upper Screen = 1 m
- Height of Lower Annulus Zone = 1 m
- Q, Flow from Upper Zone to Lower Zone = 0.5 m^3/h (estimated)

For the KGB treatment system, the estimated downstream and upstream stagnation point (S) for the circulation cell is 11.37 m from the center of the system. The width of each circulation cell is $\{(B_b + B_t)/2\}$ = 25.07 m, as shown in Figures 4-19 and 4-20. The capture zone width for the top of each zone (B_t) is 16.99 m, and for the bottom of each zone (B_b) is 33.15 m.

To calculate the circulation cell capture zone and downgradient release zone dimensions, aquifer data are entered into a computer spreadsheet, and the variables Q / H^2* V and a/H are calculated. Table 4-2 lists the parameters evaluated for determination of the capture and circulation zones for

the KGB. These variables are then used in conjunction with Dr. Herrling's graphical solutions (Figures 4-12 through Figures 4-17) to determine the various ratios. These values are inserted in the spreadsheet to calculate the dimensions of the circulation cell capture zone and release zone. For this study, a ZOI of 12.25 m (40 ft.) was estimated, which represents approximately 98 percent of the major axis $\{(B_b+B_t)/4\}$. Circulation times were estimated for porosities of 0.3, 0.35, and 0.4 as shown in Figure 4-21. Using a porosity value of 0.3, KGB monitoring well locations were selected for the 50% ZOI (20-day circulation time) and the 75% ZOI (70-day circulation time).

4.3.7 Maintenance Intervals and Parameters for the KGB

The maintenance intervals will begin immediately after start-up and continue every two months thereafter until completion of the study. The parameters to be checked during these periods are as follows:

A. Check direction of rotation of blower fan. It should match the arrow on the fan using.

B. Check for wear and tear of blower fan belt. Replace or tighten as necessary (refer to blower specifications Section 5 for specifics).

C. Check water content in moisture knock out (remove all water after stripping, if necessary). To strip water in moisture knock-out, open hose bib to allow for a minimum of 1 hour ambient air to be drawn into knock out.

D. Check bearings on blower motor. Replace as necessary.

E. Record hours of operation from blower clock.

F. Maintain 2 to 3 CFM compressed air flow, as water table fluctuates flow rate will have to be adjusted to maintain the desired flow rate.

G. Check air filter on compressor clean or replace if necessary.

H. Check compressor inlet port. It should be kept free of obstructions.

I. Vanes on compressor should be checked for wear by removing six bolts and an end plate to expose rotor and vanes for inspection.

J. Maintain air tight seals at well head and all blower and compressor connections.

4.4 Dye Tracer Test

4.4.1 Objectives

The dye/tracer study will use fluorescent dyes (fluorescein, eosine, and rhodamine WT) as tracers to realize the following objectives for both UVB and KGB systems:

- Ascertain that a groundwater circulation cell has been established under the given hydrogeologic conditions.

- Determine the dimensions of groundwater circulation cell.
- Determine the time required after startup to establish a well-developed circulation cell.

The tracer dyes are referred to as either convergent or divergent. The divergent dye moves away from the UVB to the outer perimeter of the circulation zone. This dye is injected to the subsurface at the innermost shallow wells for a standard flow UVB. A convergent dye moves toward the UVB from its point of injection at the outermost deep wells within the estimated circulation zone. A dye tracer test has been performed at the Letterkenny Army Depot Superfund Site in Pennsylvania under the supervision of the U.S. Army Environmental Center at Aberdeen Proving Ground, Maryland. Results of the test indicate that the chlorinated VOCs should not interfere with the dyes proposed for this study.

4.4.2 Monitoring Wells Included in Dye/Tracer Study

Dye/tracer tests will be simultaneously performed in both systems (UVB and KGB). Eighteen (18) UVB monitoring wells will be included to monitor the performance of the UVB during the dye tracer test. These include the two UVB annulus wells, and the 14 monitoring wells around the estimated zone of influence of the UVB. The spatial distribution of these twelve monitoring wells is described in Section 4.2. Eight (8) KGB monitoring wells will be included for dye tracer analysis of the KGB system. The spatial distribution of these wells is also described in Section 4.2.

4.4.3 Procedures

Immediately after start up of the UVB/KGB systems, two rounds of background samples will be collected to determine if there are any constituents in groundwater that may cause analytical or other problems in successfully performing the dye tracer test. A high background concentration of the dyes to be used in the study would represent a problem; however, such conditions are not expected. Eosine may be used in cases when there is interference in the emission wavelength of fluorescein. Immediately after the second background sample is collected, dyes will be injected. Fluorescein is a divergent dye which will migrate to the edge of the circulation cell. Fluorescein dye will be injected in the innermost shallow wells (0% ZOI well for UVB, 50% ZOI well for KGB). The time of arrival and dye concentration will be monitored in shallow wells (43% and 75% ZOI wells for UVB, 75% ZOI well for KGB). Rhodamine WT is a convergent dye which will migrate towards the UVB/KGB. Rhodamine WT will be injected in the deep 75% ZOI, 43% ZOI UVB and KGB wells. The time of arrival, and concentration will be monitored in the deep wells (25% ZOI and the UVB annulus wells for UVB, 50% ZOI well for KGB).

Following dye injection, charcoal and groundwater samples will be collected periodically as outlined in the SAP (Section 6.0) to determine the time of arrival and the concentration of dye in the monitoring wells. The procedures for the dye tracer program are based on the following guidance document being prepared for the USEPA Office of Research and Development, Washington, D.C.: A Practical Manual of Groundwater Tracing with Fluorescent Dyes and Particles (T. Aley and M. Field, In Press).

The proposed dye amounts to be used are:

- Fluorescein color index 45350 - 2 lb. per station as a 75% equivalent
- Eosine color index 453870 - 3 lb. per station as a 75% equivalent
- Rhodamine WT (no color index) - 5 lb. per station as a 20% solution

4.5 Equipment Decontamination Procedures

All drilling and sampling equipment will be decontaminated before use, between each sampling station, and at the completion of the sampling program in accordance with the EPA Region IV ECBSOPQAM. Decontamination standard operating procedures are provided in Appendix D.

4.6 Progress Reporting

Upon initiation of on-site work (mobilization) and through completion of on-site work (demobilization), SBP will generate a short Weekly Progress Report (i.e., 1-2 pages). One copy of this report will be telecopied to Baker before 5:00 pm EST on Friday of each week. An additional copy will be mailed to Baker via regular mail. The Progress Report will include the following information:

- Summary of the work completed that week including personnel on site
- Schedule status
- Discussion of any problems encountered and how they were or will be resolved
- Anticipated changes in scope of work
- Preliminary test results
- Outstanding issues to be resolved

SECTION 4.0 TABLES

Camp Lejeune UVB 200				7/7/95
Gradient i=		0.016		
kh=		1.00E-06 m/s		
kv=		1.00E-07 m/s		
v= kh*i=		1.60E-08 m/s		1.38E-03 m/d
thickness: saturated zone		10.27 m		
Well data				
aT=		1.83 m		
aB=		1.22 m		
Q=		4 m3/h		0.00111 m3/s
a/H=	ca.	0.1		
Q/H^2*kh=		11		
Q/H^2*v=		658		
Q for Qo		3.04		
HERRLING'S Diagrams				
S/H=	ca.	5.1	52	S (m)
D/H=	ca.	10.9	112	D (m)
BT/H=	ca.	7.9	81	BT (m)
BB/H=	ca.	13.75	141	BB (m)
Q0/Q=	ca.	0.026	0.08	Q0 (m3)
A/H^2=	ca.	12	1266	A (m2)
***** R applies only for NO GROUNDWATER FLOW******				
R/H=	ca.		0	R (m)
				55.586375
				5.4125

TABLE 4-1
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

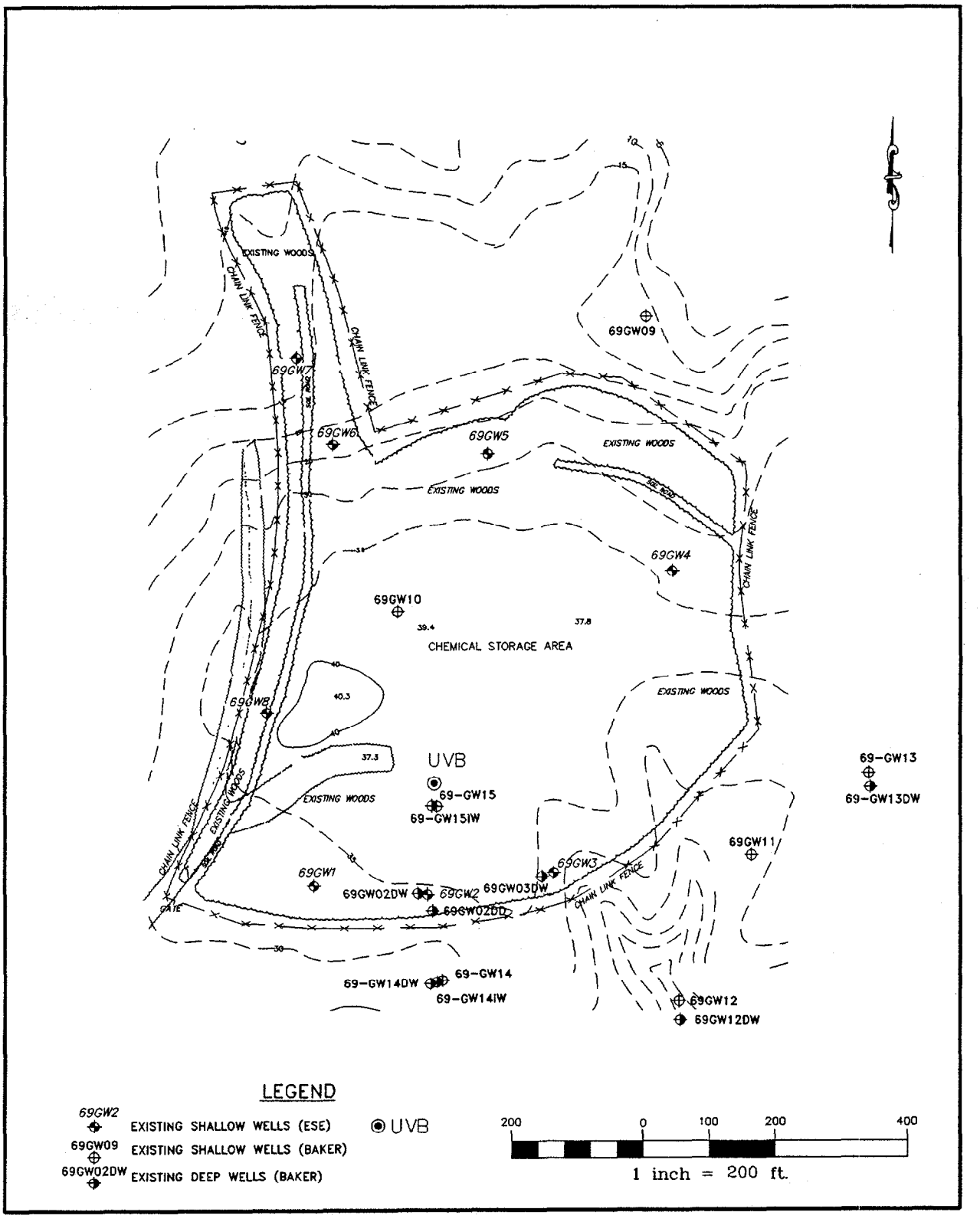
Camp Lejeune KGB

Gradient i =		0.065		
kh =		1.00E-06 m/s		
kv =		1.00E-07 m/s		
v = kh*i =		6.50E-08 m/s		5.62E-03 m/d
thickness: saturated zone		2.74 m		
Well data				
---				
aT =		1 m		
aB =		1 m		
Q =		0.5 m3/h		0.000 m3/s
a/H =	ca.	0.4		
Q/H²*kh =		18		
Q/H²*v =		285		
HERRLING'S Diagrams				

S/H =	ca.	4.15	11.371	S (m)
D/H =	ca.	9.15	25.071	D (m)
BT/H =	ca.	6.2	16.988	BT (m)
BB/H =	ca.	12.1	33.154	BB (m)
Q0/Q =	ca.	0.037	0.0185	Q0 (m3)
A/H² =	ca.	10.45	78	A (m2)
**** R applies only for NO GROUNDWATER FLOW******				
R/H =	ca.		0	R (m)

TABLE 4-2
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

SECTION 4.0 FIGURES

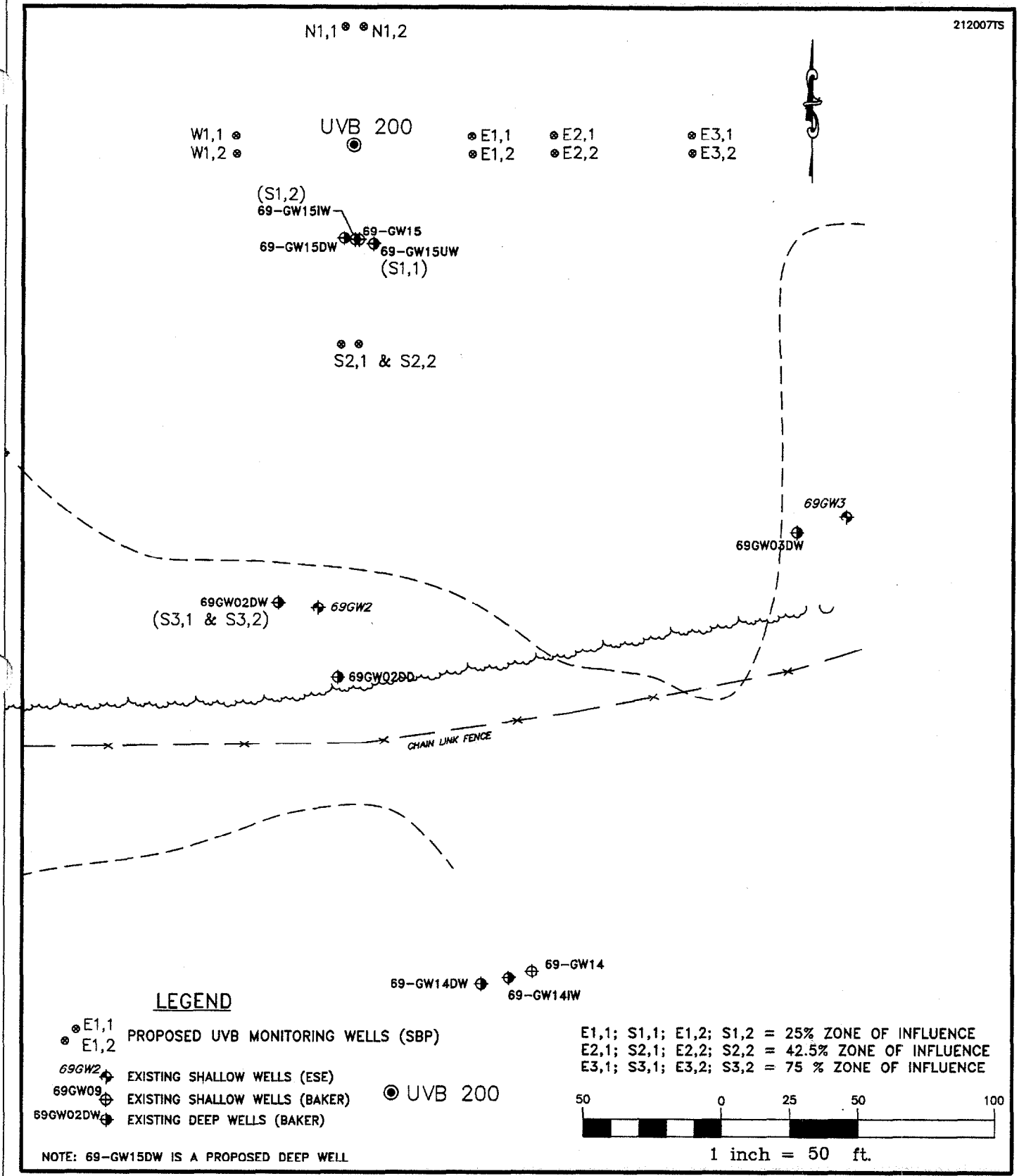


SBP Technologies, Inc.

Environmental Engineers
& Bioremediation Specialists
A Subsidary of The EICON Group, Inc.
Connecticut, Florida, Louisiana
New York, Maryland

PROJECT TITLE	SITE 69 – RIFLE RANGE CHEMICAL DUMP		
DWG. TITLE	UVB LOCATION PLAN	SCALE	1"=200'
DRAWN BY	AJM (file C1R)	FIGURE No.	**4-1**
DATE	09-JUL-1995	PROJECT NO.	S5048.10

MARINE CORPS BASE, CAMP LEJEUNE, NORTH CAROLINA



SBP Technologies, Inc.
Environmental Engineers
& Bioremediation Specialists
A Subsidary of The EICON Group, Inc.
Connecticut, Florida, Louisiana
New York, Maryland

PROJECT TITLE	SITE 69 – RIFLE RANGE CHEMICAL DUMP		
DWG. TITLE	UVB MONITORING WELLS	SCALE	1"=50'
DRAWN BY	AJM (file 212007TS)	FIGURE No.	4–2
DATE	09–JUL–1995	PROJECT NO.	S5048.10

MARINE CORPS BASE, CAMP LEJEUNE, NORTH CAROLINA

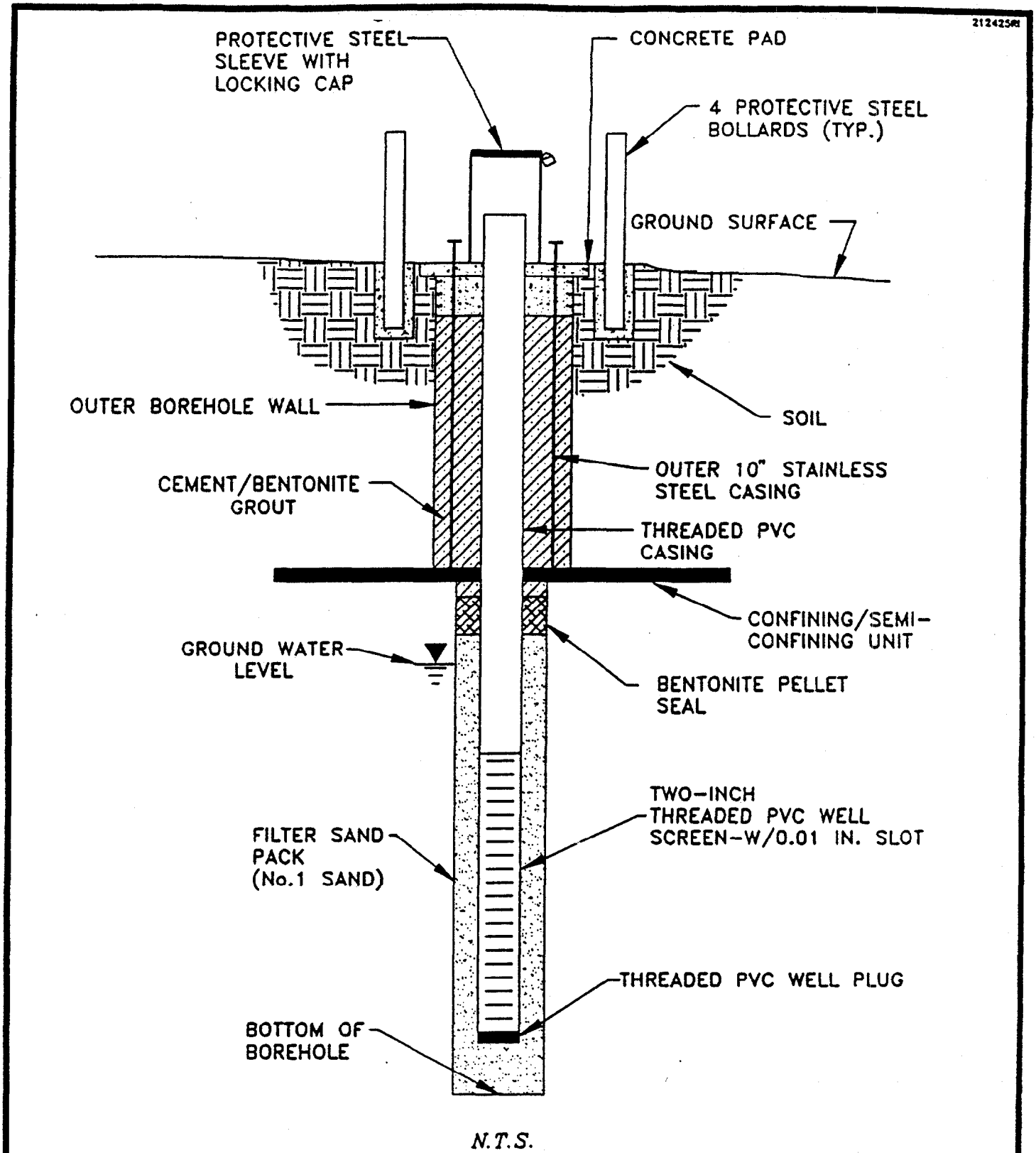
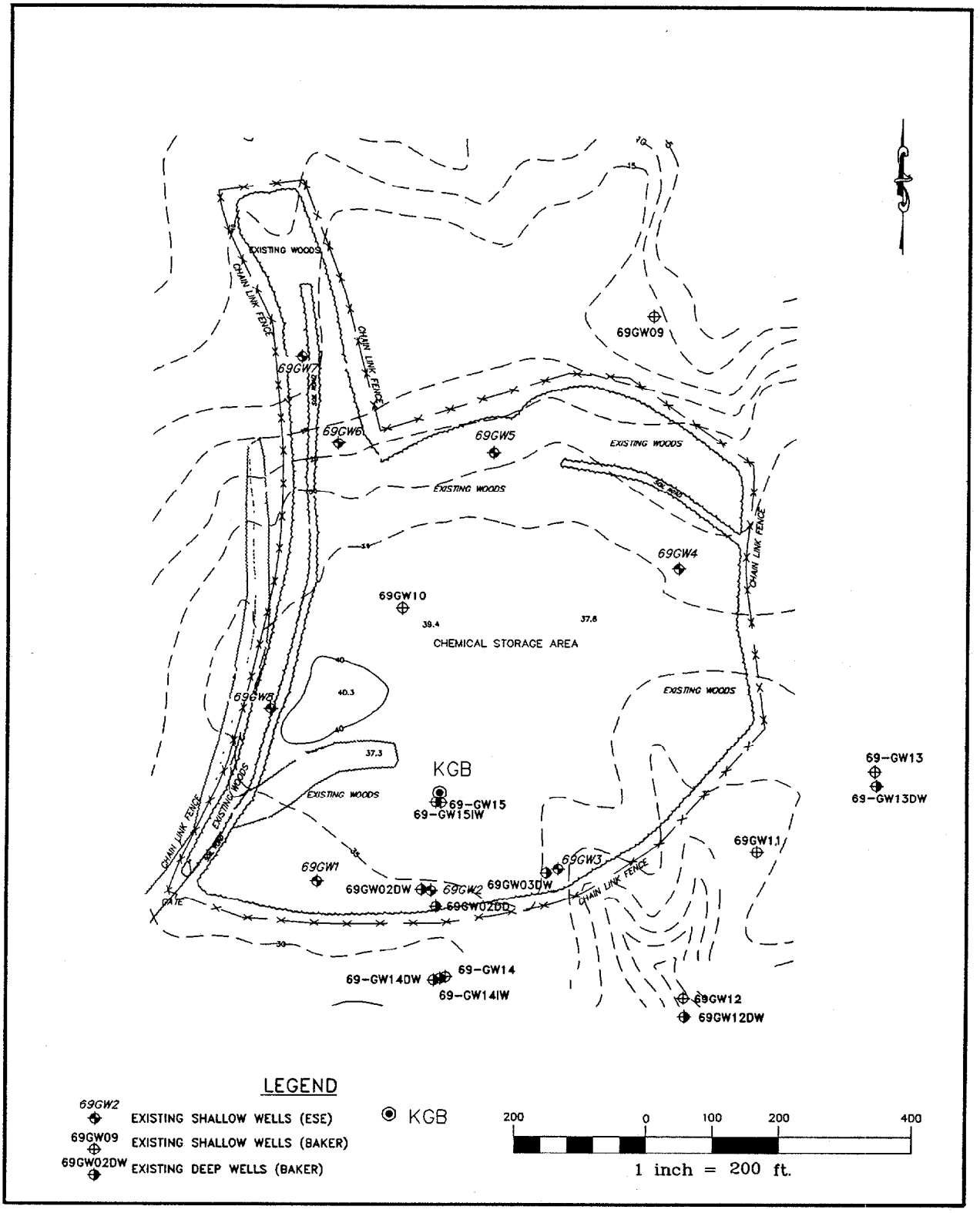


FIGURE 4-3
CONSTRUCTION DIAGRAM FOR A TYPICAL TYPE III (2" PVC) DEEP AND SHALLOW UVB MONITORING WELL
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA



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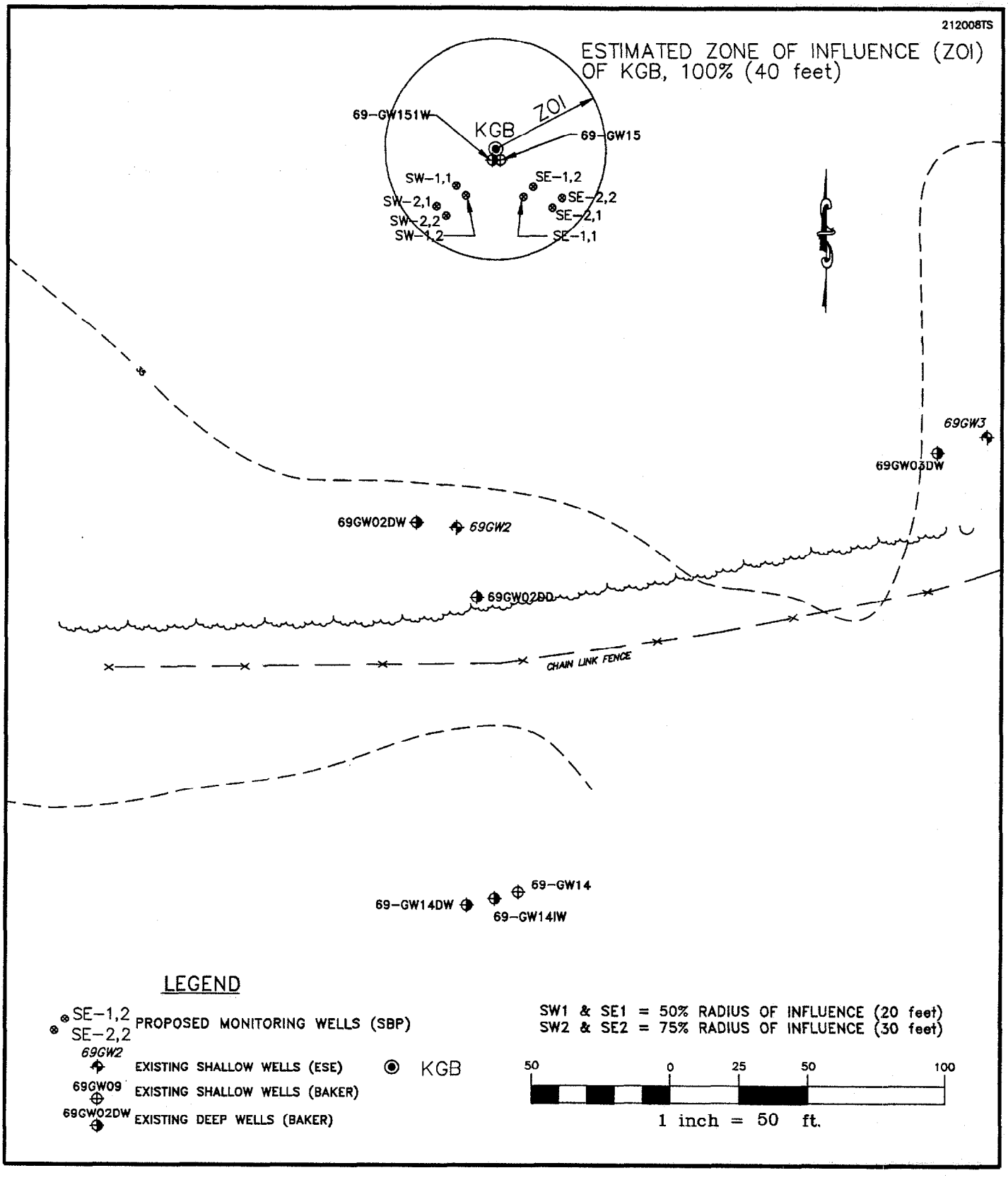
New York, Maryland

PROJECT TITLE	SITE 69 – RIFLE RANGE CHEMICAL DUMP		
DWG. TITLE	KGB LOCATION PLAN	SCALE	1"=200'
DRAWN BY	AJM (file C3R)	FIGURE No.	4-4
DATE	09-JUL-1995	PROJECT NO.	S5048.10

MARINE CORPS BASE, CAMP LEJEUNE, NORTH CAROLINA

212008TS



LEGEND

SE-1,2 / SE-2,2 PROPOSED MONITORING WELLS (SBP)

69GW2 EXISTING SHALLOW WELLS (ESE)

KGB

69GW09 EXISTING SHALLOW WELLS (BAKER)

69GW02DW EXISTING DEEP WELLS (BAKER)

SW1 & SE1 = 50% RADIUS OF INFLUENCE (20 feet)
SW2 & SE2 = 75% RADIUS OF INFLUENCE (30 feet)

50 0 25 50 100

1 inch = 50 ft.

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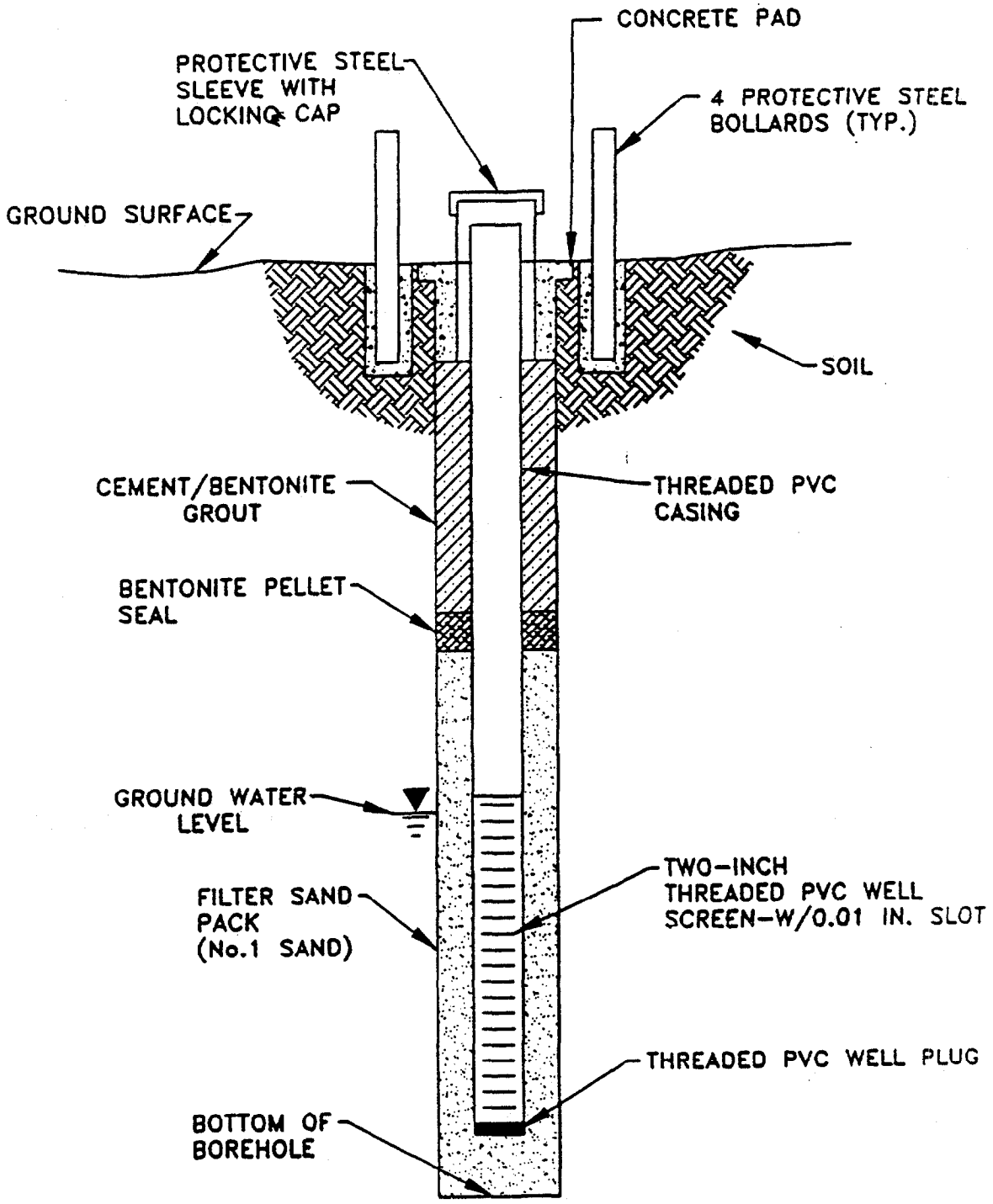
New York, Maryland

PROJECT TITLE	SITE 69 – RIFLE RANGE CHEMICAL DUMP		
DWG. TITLE	KGB MONITORING WELLS	SCALE	1"=50'
DRAWN BY	AJM (file 212008TS)	FIGURE No.	4-5
DATE	09-JUL-1995	PROJECT NO.	S5048.10

MARINE CORPS BASE, CAMP LEJEUNE, NORTH CAROLINA



N.T.S.

FIGURE 4-6
CONSTRUCTION DIAGRAM FOR A TYPICAL TYPE II (2" PVC) DEEP AND SHALLOW KGB MONITORING WELL
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE NORTH CAROLINA

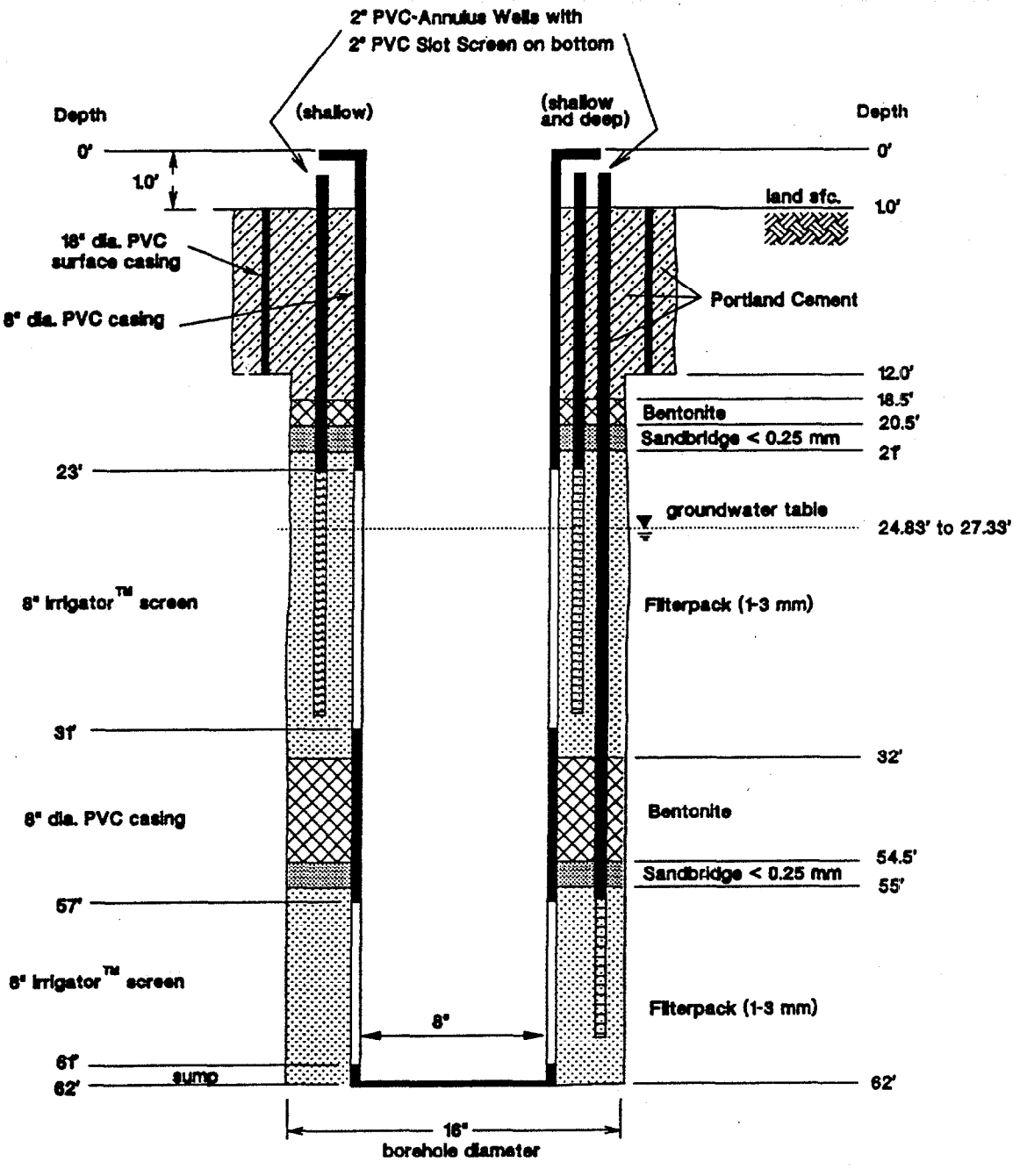


FIGURE 4-7
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

NOT TO SCALE

IEG - Technologies 1833-D Crossbeam Dr. Charlotte, N.C. 28217 Phone: (704) 357 6090 FAX: (704) 357 6111	**Drawn By** BL	**Date** 3/17/95	**Description** Well Schematic, UVB 200
	Saved as 117wu.dw2	**Proj. No.** 0117.15.95	**Prepared for** SBP Camp Lejeune, NC

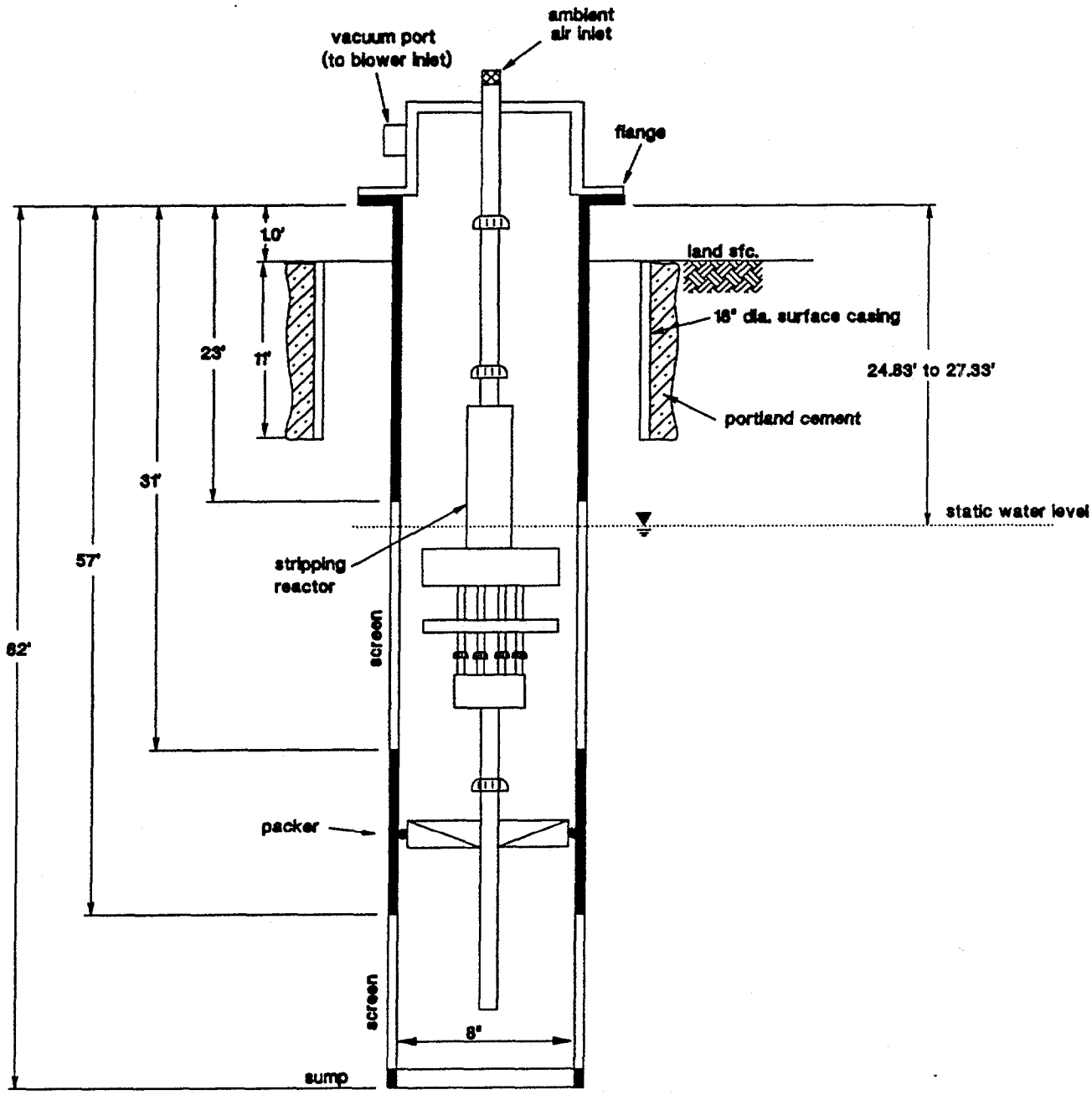


FIGURE 4-8
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

NOT TO SCALE

IEG - Technologies 1833-D Crossbeam Dr. Charlotte, N.C. 28217 Phone: (704) 357 8090 FAX: (704) 357 8111	Drawn By BL	Date 3/17/95	Description Floating UVB-200
	Saved as 117su.dw2	Proj. No. 0117.15.94	Prepared for SBP Camp Lejeune, NC

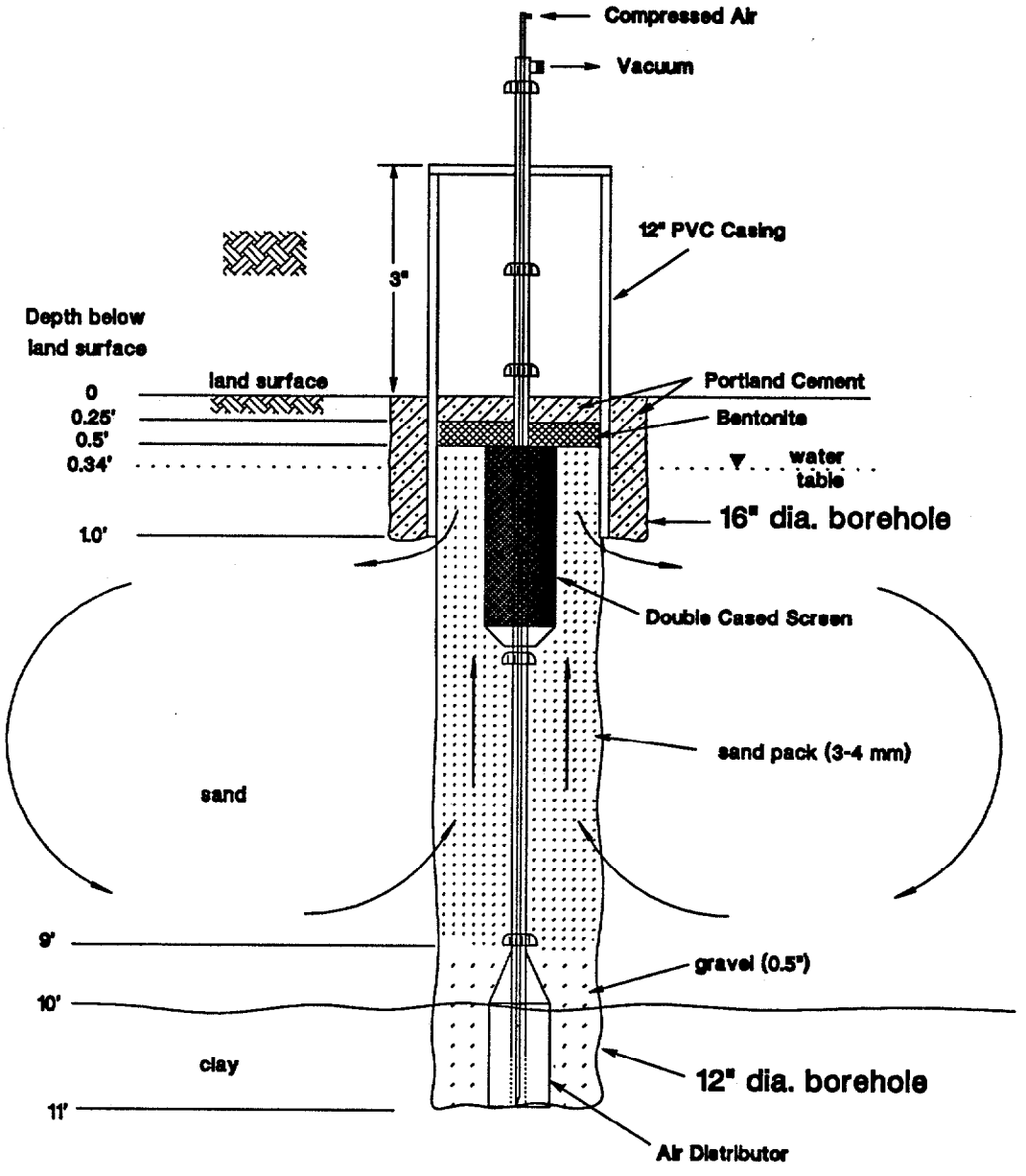


FIGURE 4-9
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

NOT TO SCALE

NOT TO SCALE

IEG - Technologies 1833-D Crossbeam Dr. Charlotte, N.C. 28217 Phone: (704) 357 6090 FAX: (704) 357 6111	Drawn By BL	Date 3/16/95	Description KGB
	Saved as 117SK.DW2	Proj. No. 117.15.94	Prepared for SBP Camp Lejeune, NC

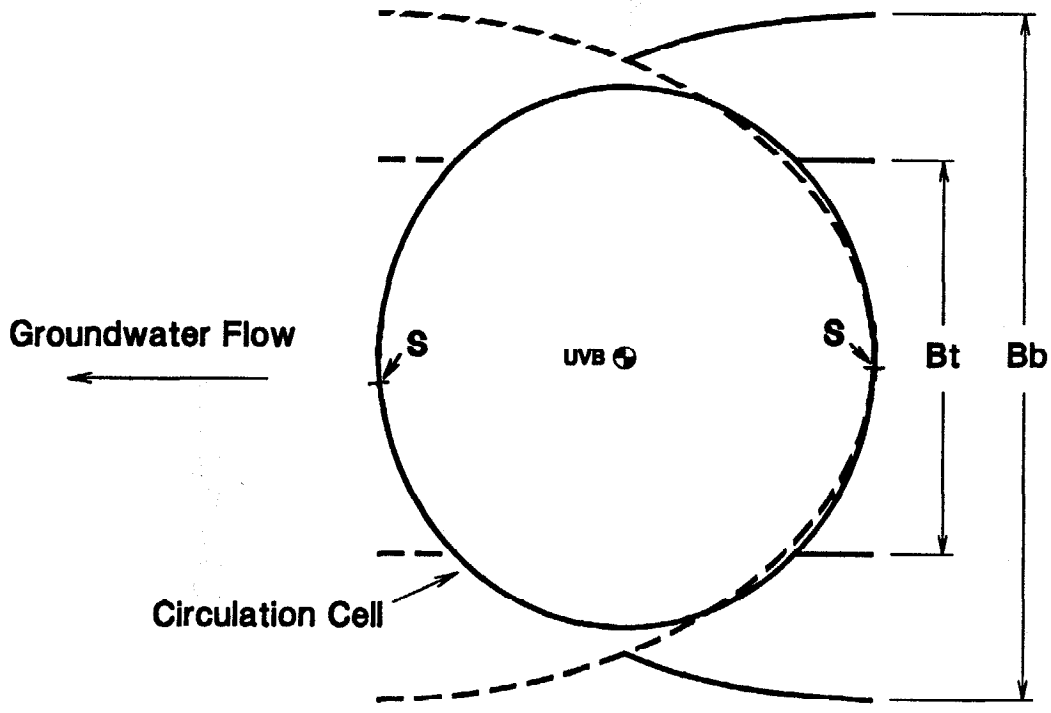
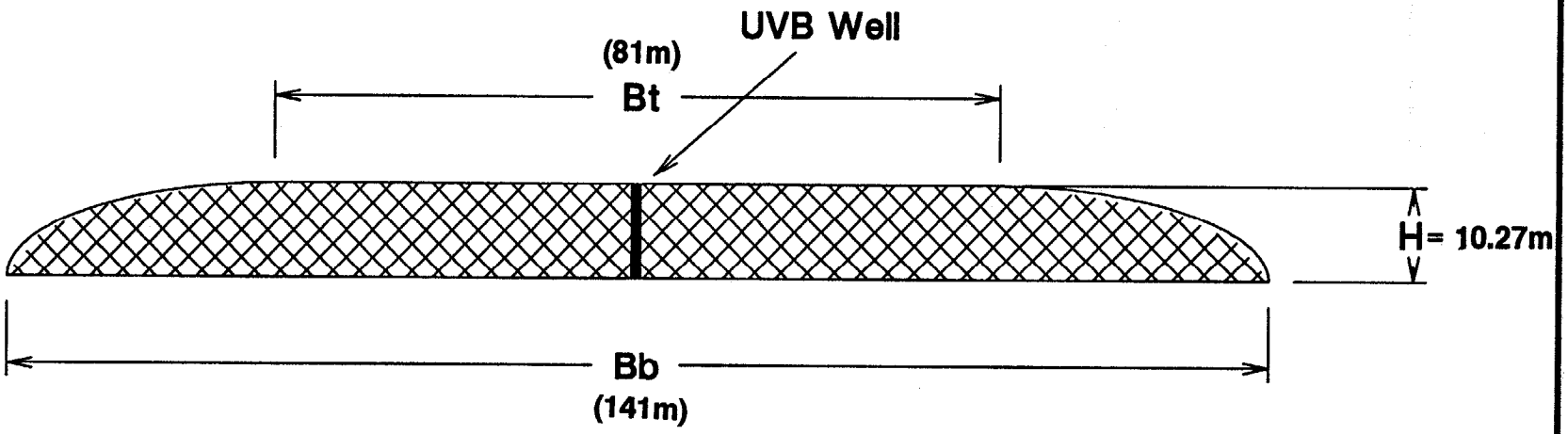


FIGURE 4-10
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

0 40
SCALE IN METERS

Title: Capture Zone, Release Zone, and Circulation Cell for UVB-200			Prepared for: SBP Camp Lejeune, NC
Scale: 1 in = 40 m	Drawing No.: 1170ou.dw2	Project No.: 0117.15.94	Prepared by: IEG TECHNOLOGIES CORP. 1833-D Cross Beam Drive Charlotte, NC 28217
Date: 7/7/95	Description: UVB 200 Circulation Cell		

FIGURE 4-11
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA



B_t = width at top

B_b = width at bottom

H = height of saturated zone to be treated

A = area of capture zone

0 20
Scale in meters

Title: VERTICAL CROSS SECTION PERPENDICULAR TO FLOW OF UVB-200			Prepared for: SBP Camp Lejeune, NC
Scale: 1 in = 20 m	Drawing No.: 117ozu.dw2	Project No.: 117.15.94	Prepared by: IEG TECHNOLOGIES CORP. 1833-D Cross Beam Drive Charlotte, NC 28217
Date: 7/7/98	Description: UVB 200 Capture Zone		

FIGURE 4-12
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

adapted from:

Dr.-Ing. B. Herrling
Forschungsgruppe Grundwasser
Institut fur Hydromechanik
Universitat Karlsruhe

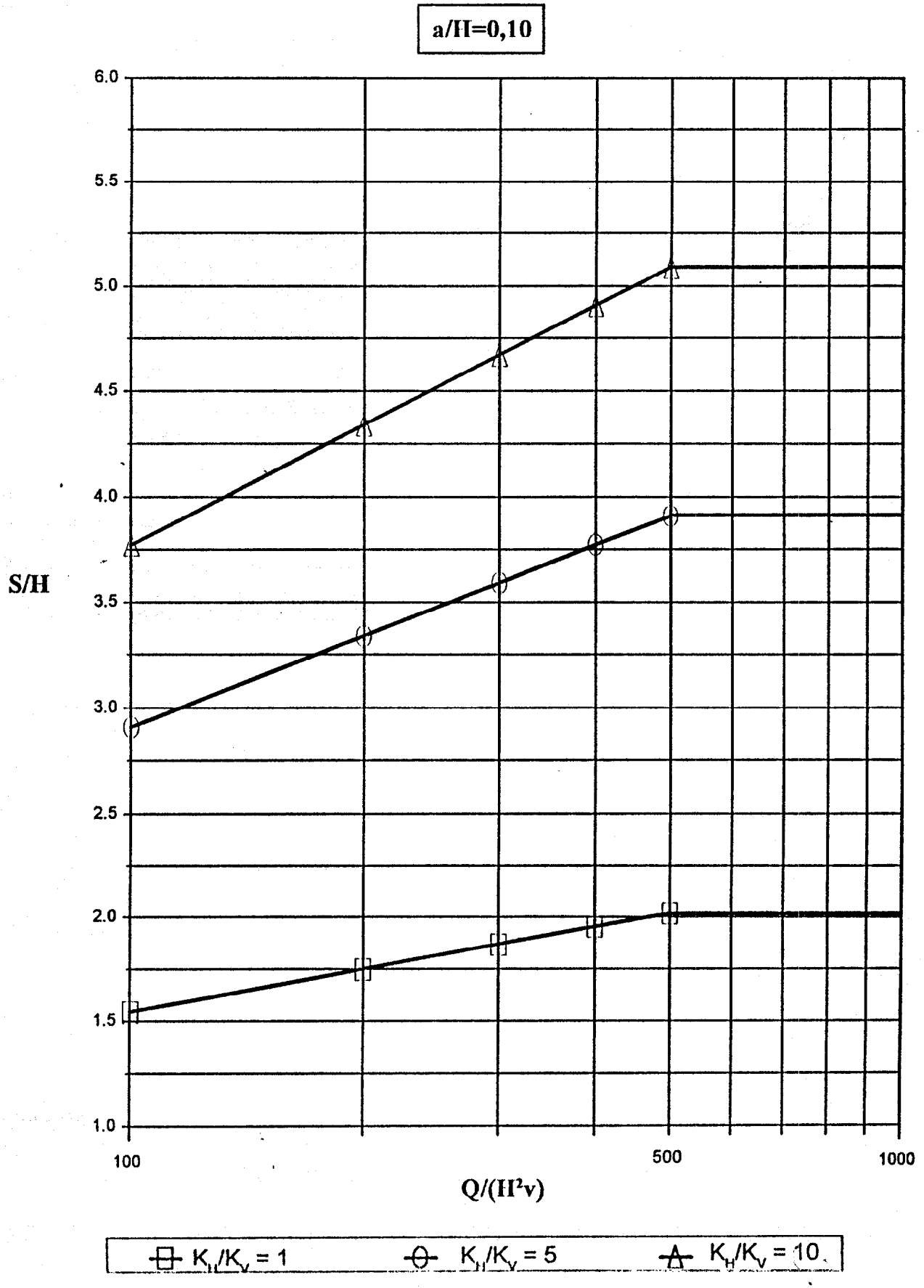


FIGURE 4-13
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

adapted from:

Dr.-Ing. B. Herrling
Forschungsgruppe Grundwasser
Institut fur Hydromechanik
Universitat Karlsruhe

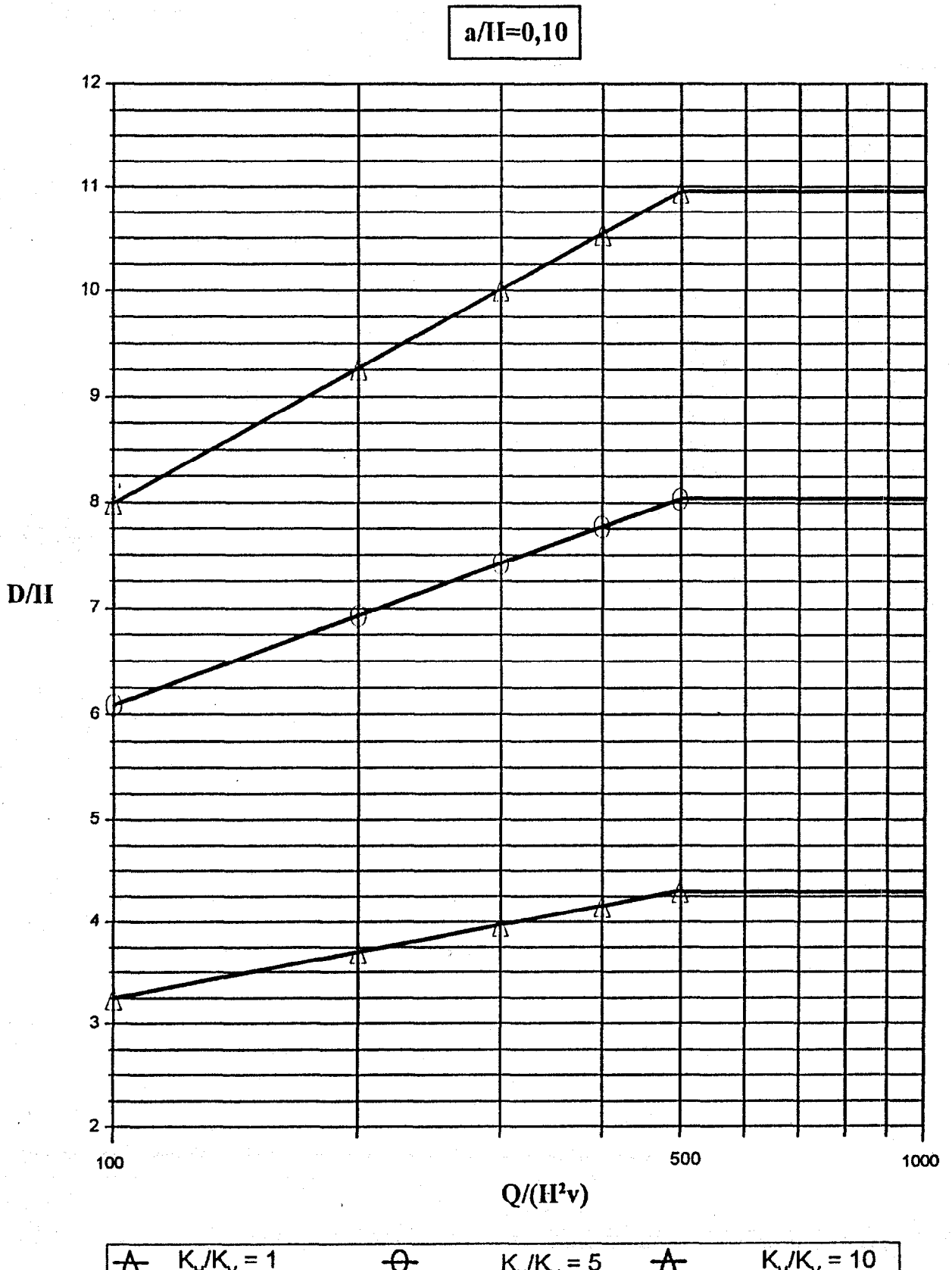


FIGURE 4-14
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

adapted from:
Dr.-Ing. B. Herrling
Forschungsgruppe Grundwasser
Institut fur Hydromechanik
Universitat Karlsruhe

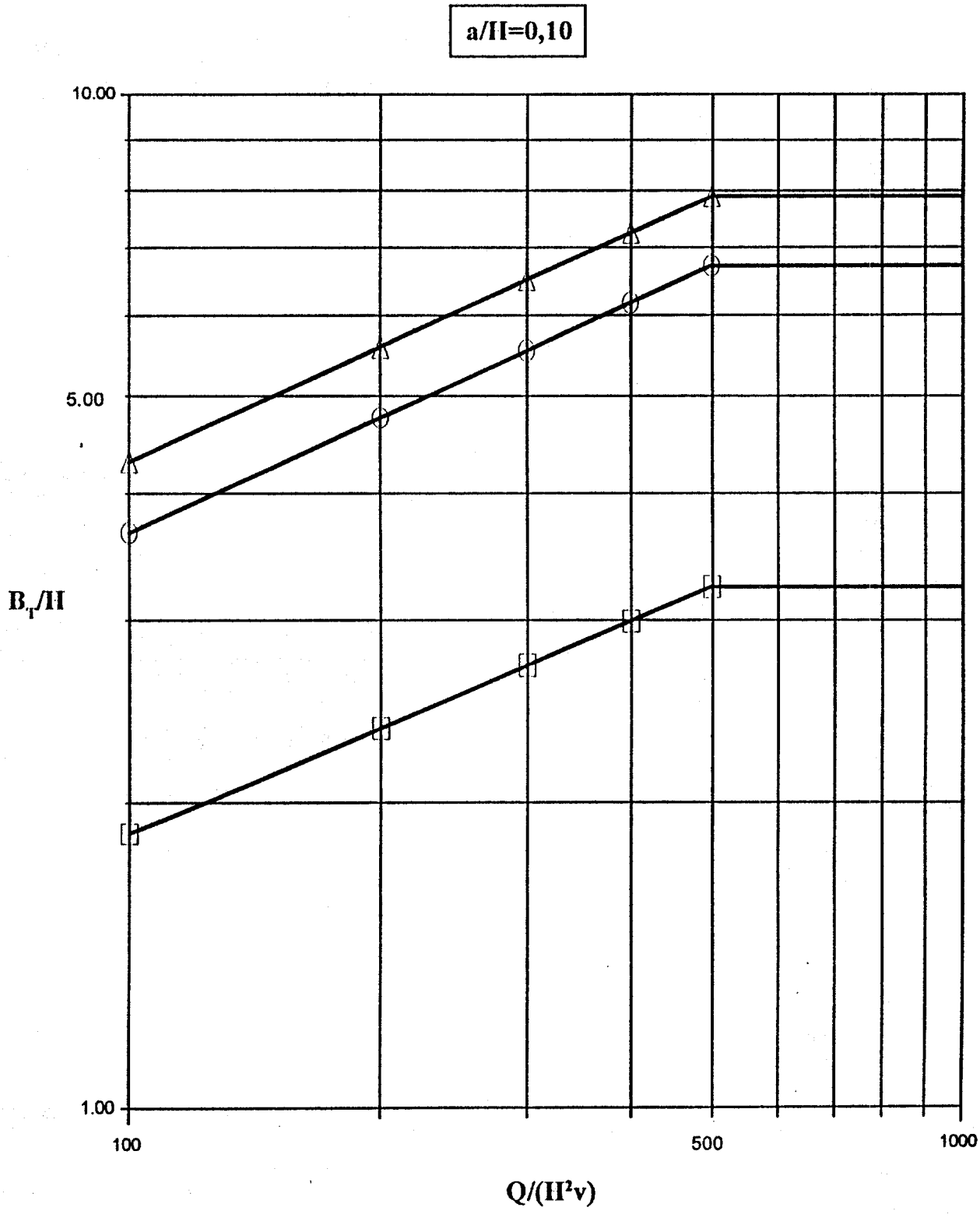


FIGURE 4-15
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

adapted from:

Dr.-Ing. B. Herrling
Forschungsgruppe Grundwasser
Institut fur Hydromechanik
Universitat Karlsruhe

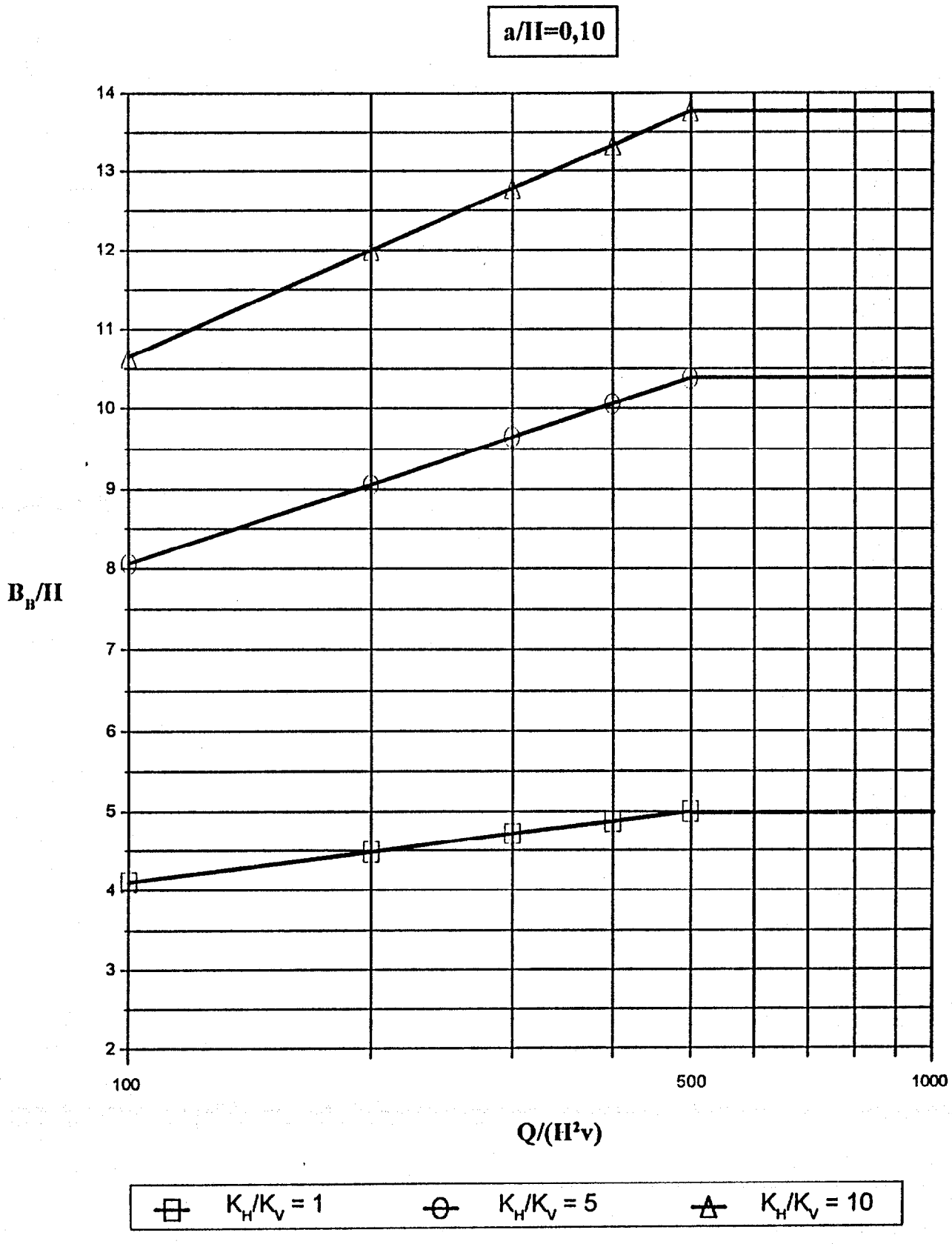


FIGURE 4-16
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

adapted from:
Dr.-Ing. B. Herrling
Forschungsgruppe Grundwasser
Institut fur Hydromechanik
Universitat Karlsruhe

a/H=0,10

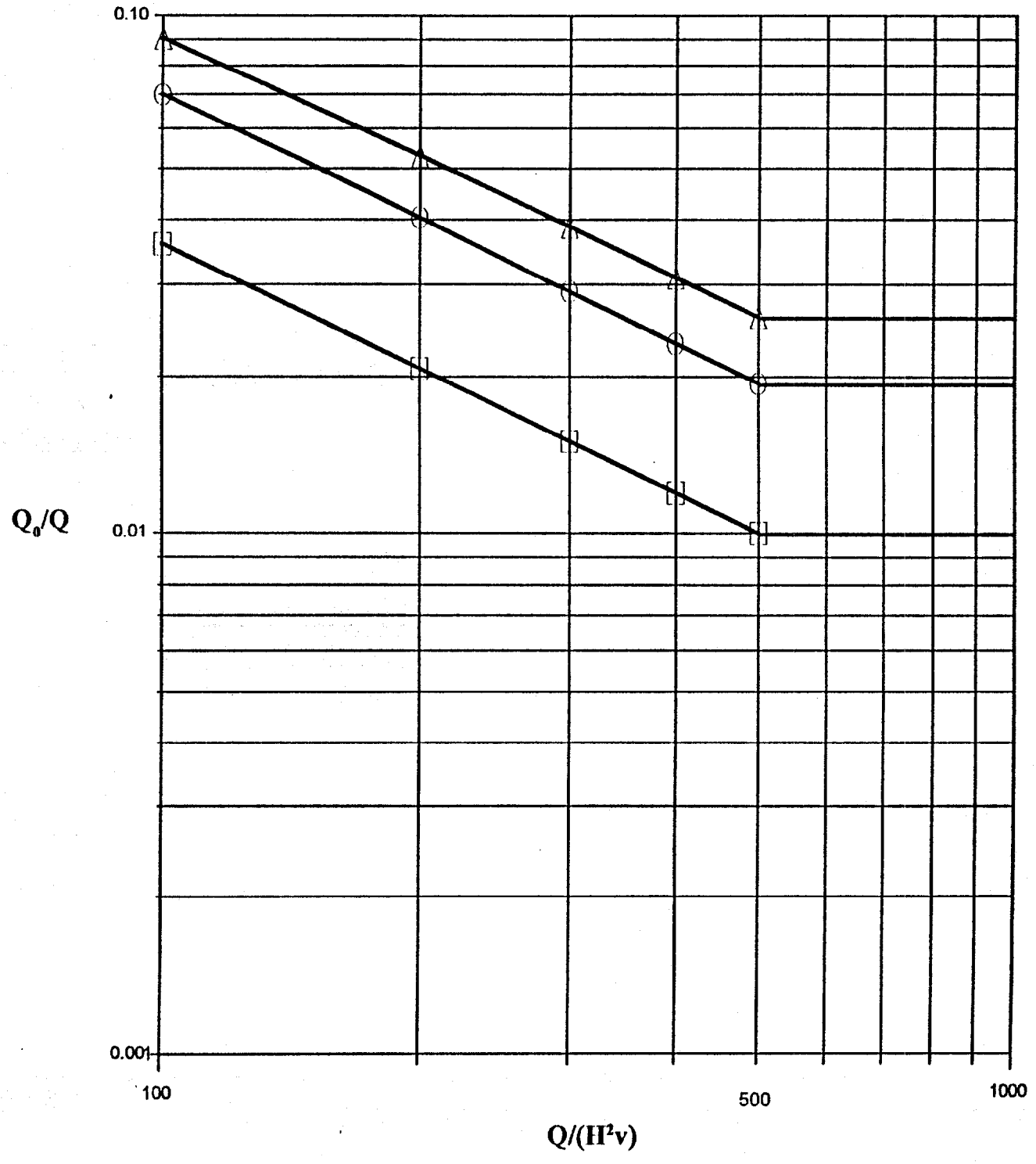


FIGURE 4-17
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

adapted from:
Dr.-Ing. B. Herrling
Forschungsgruppe Grundwasser
Institut fur Hydromechanik
Universitat Karlsruhe

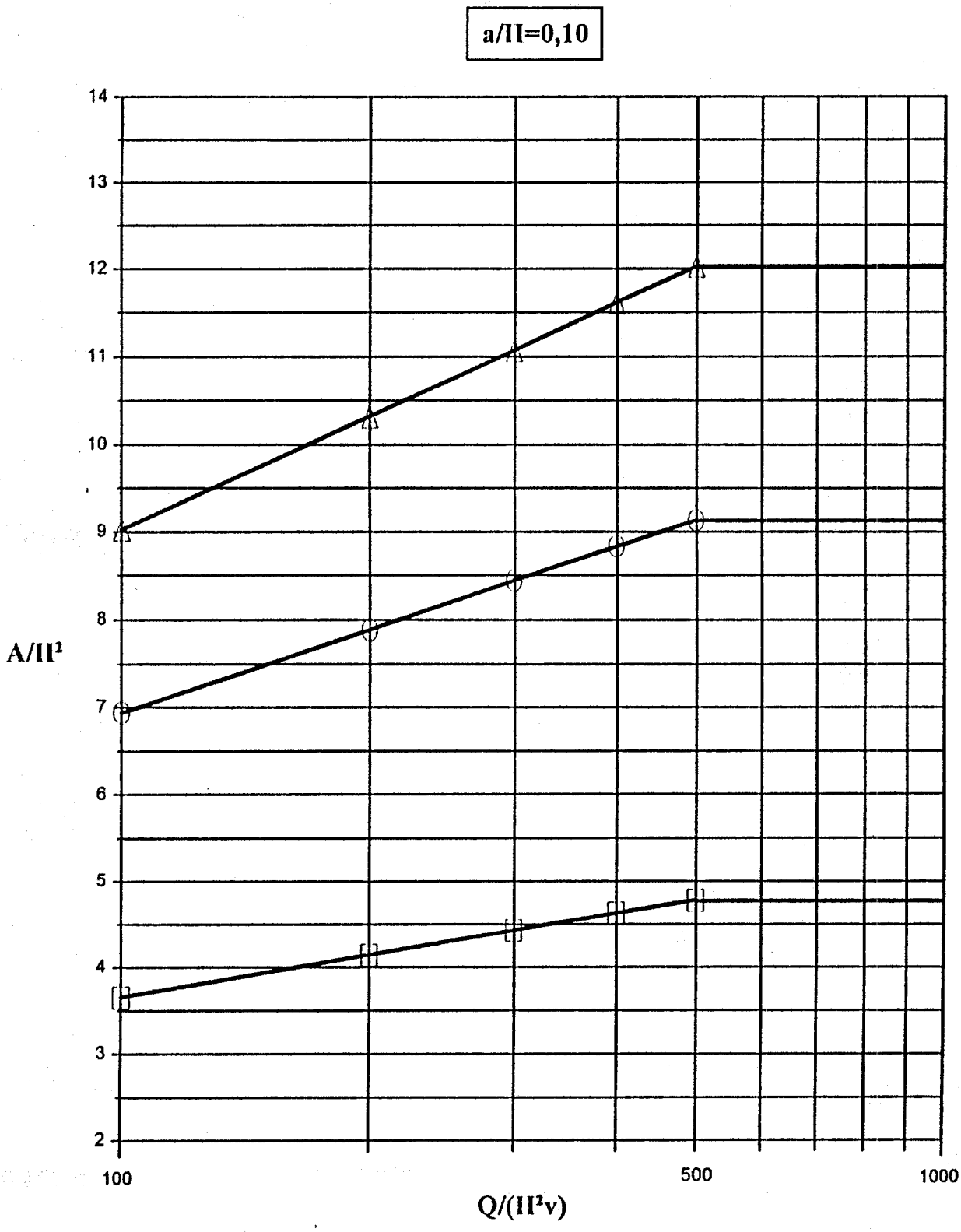


FIGURE 4-18

SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

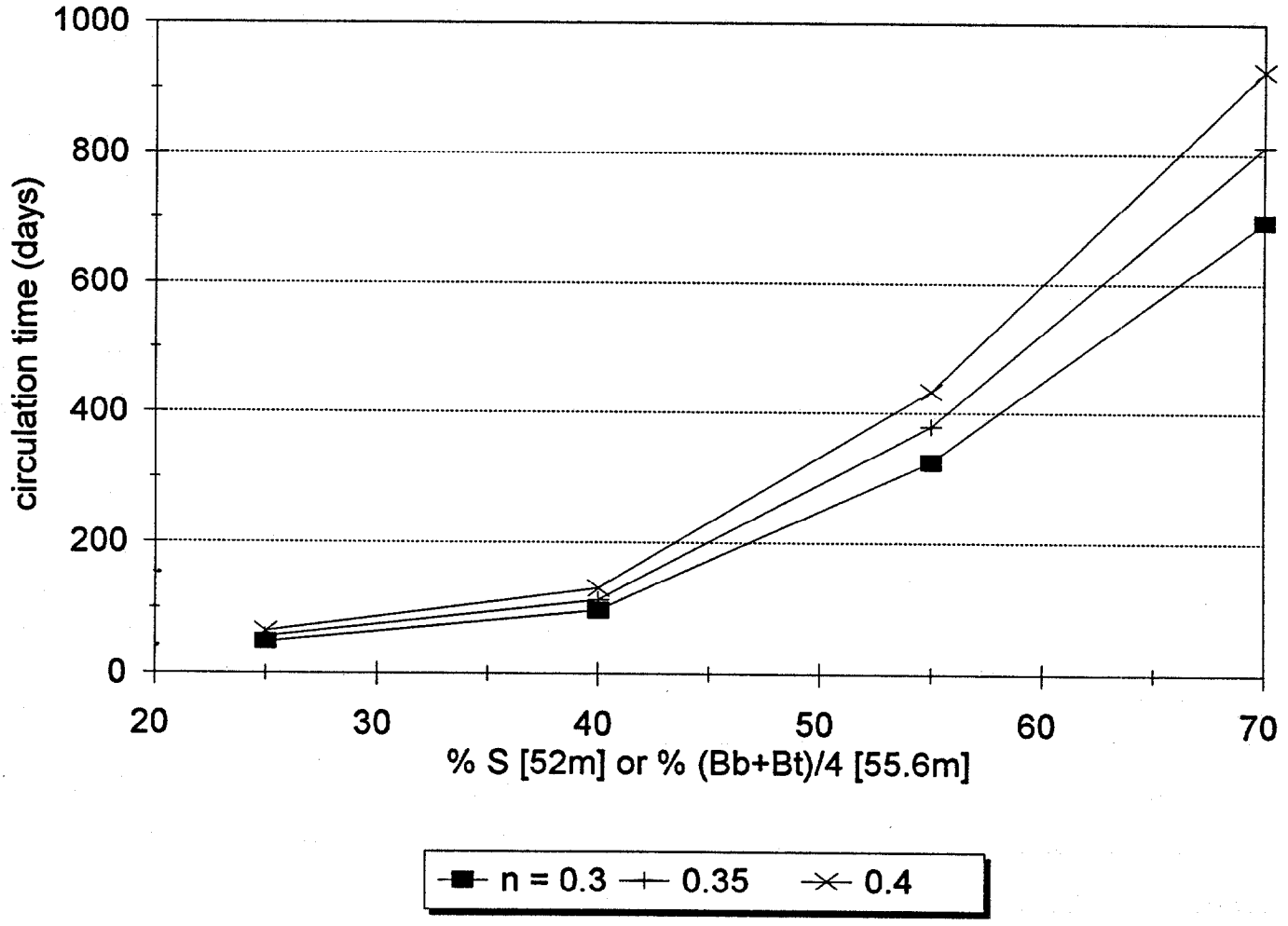
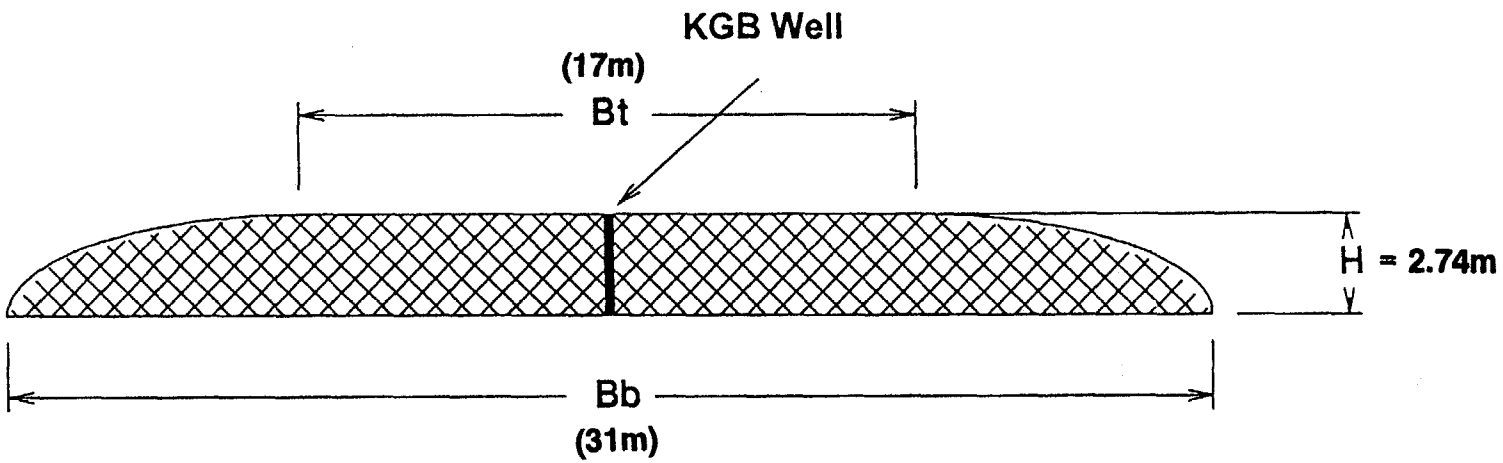


FIGURE 4-19

SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA



B_t = width at top

B_b = width at bottom

H = height of saturated zone to be treated

A = area of capture zone

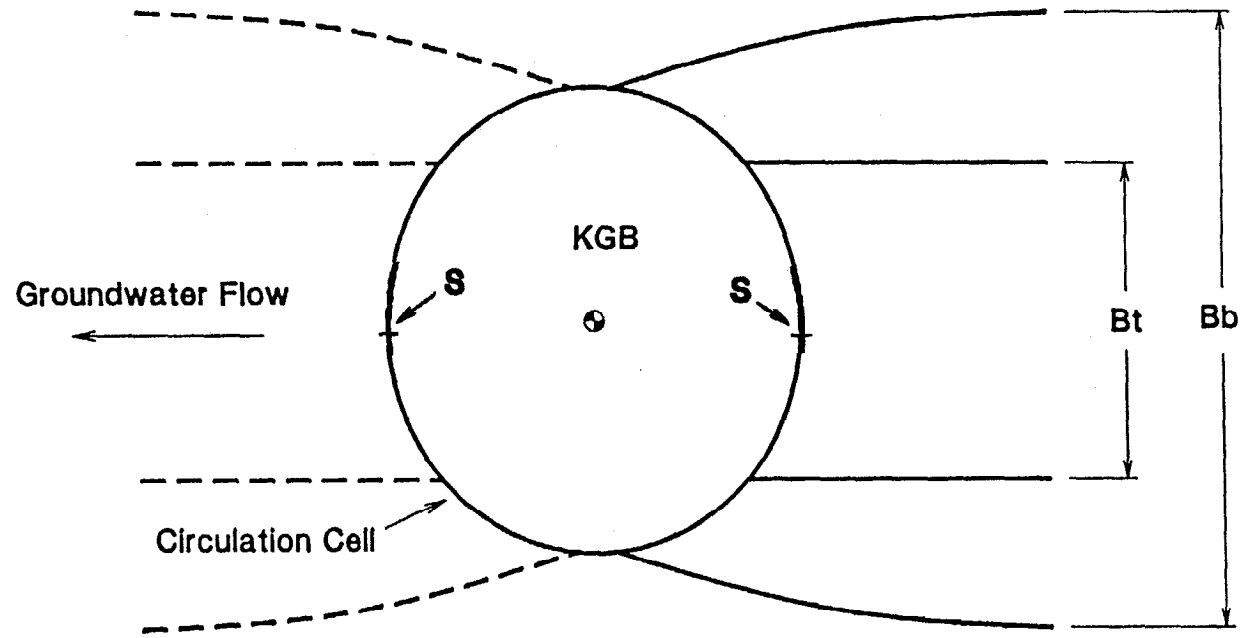
0 8

Scale in meters

Title: VERTICAL CROSS SECTION PERPENDICULAR TO FLOW OF KGB			Prepared for: SBP Camp Lejeune, NC
Scale: 1 in = 5 m	Drawing No.: 117ozk.dw2	Project No.: 117.15.94	Prepared by: IEG TECHNOLOGIES CORP. 1833-D Cross Beam Drive Charlotte, NC 28217
Date: 8/17/96	Description: KGB Capture Zone		

FIGURE 4-20

SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA



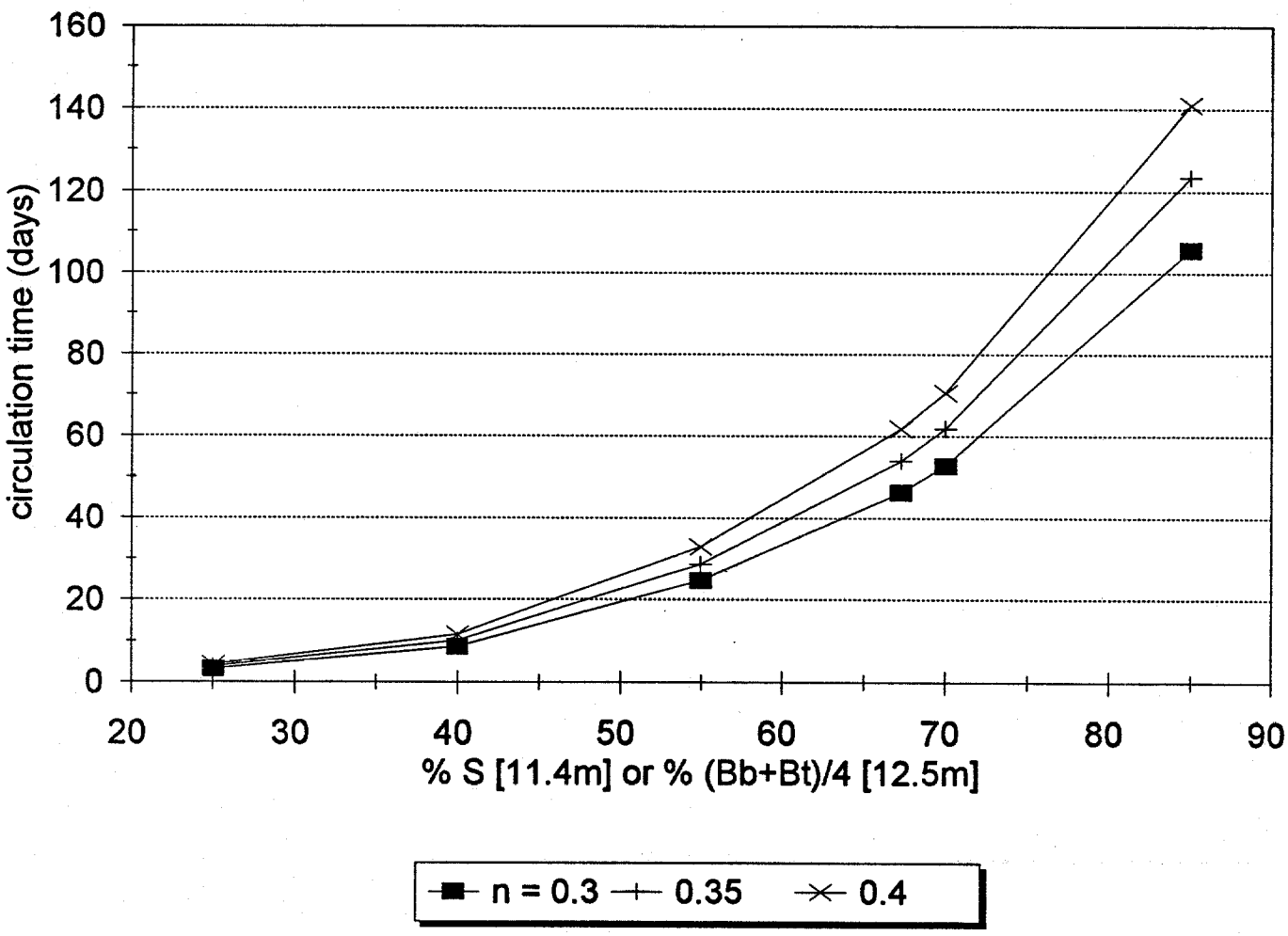
0 10

SCALE IN METERS

Title: Capture Zone, Release Zone, and Circulation Cell for KGB			Prepared for: SBP Camp Lejeune, NC
Scale: 1 in = 10 m	Drawing No.: 117cck.dwg	Project No.: 0117.15.94	Prepared by: IEG TECHNOLOGIES CORP. 1833-D Cross Beam Drive Charlotte, NC 28217
Date: 8/17/96	Description: KGB Circulation Cell		

FIGURE 4-21

SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA



5.0 EQUIPMENT

The main components of the UVB and KGB systems are described in the following sections, respectively. Specifications for the major pieces of equipment are provided in Appendix F.

5.1 Blowers

An ELEKTRO 2/5 centrifugal blower will be provided for the UVB system. A 5-horsepower (HP) blower is required to maintain a floating UVB 200 at a vacuum of 20 inches of water. The blower is a three phase, 230-volt unit and is equipped with a moisture knock-out vessel built into the high density polyethylene blower enclosure. An ELEKTRO 1/5 centrifugal blower will be provided for the KGB system. The blower is a three phase, 208-volt, 1.5-HP unit and is equipped with a moisture knock-out vessel built into the high density polyethylene blower enclosure. The off-gas effluent from the moisture knock-out will be discharged to an off-gas treatment unit consisting of two drum-type GAC units connected in series. The concentrations of VOCs in groundwater at Site 69 do not require the use of explosion proof equipment (i.e., contaminant concentrations in off-gas are expected to be well below their lower explosive limits).

5.2 Compressor

A Picolino Model VTEG compressor will be used to sparge air in the KGB well. The compressor will be used to supply 2-3 cfm of air at a pressure enough to depress the water column in the sparging pipe. An activated carbon air filter and a flowmeter will be attached to the compressor.

6.0 SAMPLING AND ANALYSIS PLAN (SAP)

Data collected during the treatability study will be used to assess the performance of the technology, potential need for pre- and post-processing of the wastestream, applicable types of contaminants and media, the potential operating problems, and approximate capital costs. Demonstration data can also provide insight into long-term operating and maintenance costs as well as long-term risks. Sampling and analysis procedures are therefore very critical. Approved quality assurance/quality control measures will be stringently followed throughout this treatability study.

This SAP provides the Field Sampling Plan (FSP) in Section 6.1 and the Field Monitoring Plan (FMP) in Section 6.2. This SAP applies to all sampling associated with the treatability study except for the sampling to be performed during and after installation of wells 69-GW15UW and 69-GW15DW. The Quality Assurance Project Plan (QAPP) is provided in Section 7.0. This SAP follows the guidelines presented in U.S. Environmental Protection Agency's (USEPA) Office of Research and Development (ORD) Risk Reduction Engineering Laboratory (RREL) Document "Preparation Aids for the Development of Category III: QAPP" EPA/600/8-91/005. It describes the methods that the subcontract laboratories will use to collect and analyze samples generated during this treatability study. Laboratory analysis will be performed by the following laboratories:

- Analysis of tracer dyes: Ozark Underground Laboratories (OUL)
- Volatile organic analysis: Laboratory Resources, Inc.
- Inorganic analysis: York Analytical Laboratories (formerly ELI)

6.1 Field Sampling Plan (FSP)

The FSP is comprised of the following components:

- Soil sampling (for geologic data only)
- Groundwater sampling for target VOCs and inorganics
- Groundwater sampling for dyes/tracers
- Sampling of GAC samplers for dyes/tracers
- Sampling of GAC for adsorbed VOCs
- Sampling of off-gases for target VOCs

Table 6-1 shows details of the samples to be collected under the FSP.

6.1.1 Sampling of Subsurface Soils for Geologic Records

Soil samples will be collected at the time of drilling of the pilot hole, monitoring wells and the UVB well. All soil samples collected in the field will be retained/archived for future geological reference. No subsurface soil sampling is proposed to determine contamination by target VOCs. Soil samples from continuous split spoon sampling will be collected during drilling of two deep monitoring wells located at a distance of 94 ft from the UVB and from the pilot borehole. Split spoon sampling will be performed from 12 ft bgs (after the surface casing) to 80 ft bgs in the two monitoring wells, and to 50 ft bgs in the pilot bore hole. Details about sampling equipment and logging procedures are described in the SOPs.

Samples will be numbered as **69SB-PH (14-16)** where:

- **69**: refers to Site 69
- **SB**: refers to soil boring
- **PH**: refers to pilot borehole (UW for UVB borehole if different from pilot borehole, E22 for the east arm deep monitoring well, S22 for the south arm deep monitoring well)
- **14-16**: refers to the depth, in ft bgs, where the sample was collected

In all, 18 cores will be collected from the pilot hole, and 48 cores from each of the two monitoring wells.

6.1.2 Groundwater Sampling Plan

Groundwater samples will be collected for analysis of VOCs, inorganics, and dye/tracers, as shown in Table 6-1.

Samples for VOCs analysis will be collected using a submersible pump in a 40 ml VOA vial. Prior to collecting the sample, the wells will be purged as described in the SOPs. Samples will be collected from 12 UVB monitoring wells, 2 UVB annulus wells, and 8 KGB monitoring wells. Samples will be collected at time zero followed by 2, 4, and 6-month intervals. Samples will be stored and shipped on ice after collection. Sample results will be provided by the laboratory on a 1-week turnaround basis.

VOCs in groundwater monitoring wells will be analyzed according to EPA method SW846 protocol. The method used will be EPA 8260 which is recommended for non-chlorinated and chlorinated VOCs. VOCs adsorbed on granular activated carbon will be first extracted in methanol. Analysis of extracted VOCs will be performed by method EPA 8260. All VOCs analyses will be performed by Laboratory Resources, Inc., which is a NEESA-certified laboratory. Details of analytical procedures are outlined in Appendix B.

Samples will be numbered as **69UVB-GW-VOC(0)-W 1,1** where:

- **69**: refers to Site 69
- **UVB**: refers to UVB monitoring wells (KGB for KGB monitoring wells)
- **GW**: refers to groundwater sample (TB for trip blank, IB for instrument blank)
- **VOC**: refers to sample for volatile organic analysis
- **(0)**: refers to time zero sample (2,4,& 6 for 2 month, 4 month, and 6 month sampling event)
- **S**: refers to a well in the south arm (E for a well in the east arm, UW for a UVB annulus well)
- **1,1**: refers to the shallow 25% ROI UVB well/shallow 50% ROI KGB well (1,2 for the deep 25% ROI UVB well/deep 50% ROI KGB well; 2,1 for the shallow 43% ROI UVB well/shallow 75% ROI KGB well; 2,2 for the deep 43% ROI UVB well/deep 75% ROI KGB well; 3,1 for the shallow 75% ROI UVB well; 3,2 for the deep 75% ROI UVB well, 0,1 for the shallow UVB well, 0,2 for the deep UVB well).

In addition to the samples described above, groundwater samples will be collected during the first two weeks after startup of the UVB system. Samples will be collected from the two UVB annulus wells (shallow and deep) at intervals of 1 day, 1 week, and 2 weeks after startup. These samples will be analyzed on a 24-hour turnaround basis to help SBP/IEG assess the performance of the system and make any necessary changes.

Samples will be numbered as **69UVB-GW-VOC(D1)-UW 0,1** where:

69: refers to Site 69
UVB: refers to UVB monitoring wells
GW: refers to groundwater sample
VOC: refers to sample for volatile organic analysis
(D1): refers to Day 1 sample (W1 and W2 for week 1 and week 2 samples, respectively)
UW: refers to samples from the UVB annulus wells.
0,1: for the shallow annulus well (0,2 for the deep annulus well)

In all, 96 samples will be collected (64 for UVB, 32 for KGB) for VOCs analysis during the study.

6.1.2.3 Sampling Plan for Inorganics

The inorganic analyses will be performed using standard procedures outlined in the QAPP document of Environmental Laboratories, Inc. in Appendix C.

The potential for corrosion or incrustation of groundwater well casings and screens may be estimated by considering several parameters which characterize the inorganic groundwater quality. These parameters include: pH, concentrations of dissolved gases (i.e., oxygen, hydrogen sulfide, and carbon dioxide), total dissolved solids (TDS), total suspended solids (TSS), chloride, carbonate hardness, iron, and manganese.

Potentially corrosive conditions are indicated by low pH, significant concentrations of the dissolved gases listed above, high total dissolved solids concentration, and high chloride concentration. Potentially encrusting conditions are indicated by high pH, high carbonate hardness, and significant levels of iron and manganese. In order to evaluate corrosion and incrustation potential at Site 69, SBP will analyze groundwater from two existing wells nearest to the proposed UVB/KGB systems for inorganic quality. Samples will be collected at time zero and 6 months later.

Parameters including pH, dissolved oxygen, and specific conductance will be measured in situ prior to any purging of the monitoring well. Probes will be lowered and held stationary at the midpoint of the screened interval. The inorganic quality parameters to be analyzed are cations (calcium, magnesium, potassium, sodium, and manganese), total dissolved iron, bicarbonate, sulfate, anions (chloride), and related parameters (pH, dissolved oxygen, specific conductance, and total dissolved solids).

The table below shows the analytical methods, sampling requirements, and procedures.

Parameter	Sample Volume	Preparation and Storage
Dissolved Iron	2 X 250 ml plastic bottle	(i) Filter with 0.45 m filter (ii) Preserve with nitric acid to below pH 2.0 (iii) Keep cool
Cations (Ca, Mg, Mn, Na, K)	2 X 250 ml plastic bottle	(i) Preserve with nitric acid to below pH 2.0 (ii) Keep cool
Chloride, sulfate, pH, TDS, and specific conductance	2 X 1L plastic bottle	(i) Filled to the top (ii) Keep cool
Bicarbonate	2 X 1L plastic bottle	(i) Filled to the top (ii) Keep cool

Method Numbers:

Bicarbonate:	ASTM D513
Total Dissolved Solids:	Standard Methods 2540-Part C
Specific Conductivity:	Standard Methods 2510
Sulfate:	Standard Methods 4500-SO_4 Part E
Chloride:	Standard Methods 4500-Cl Part B
Dissolved Iron:	EPA SW-846 Method 6010
Catons:	EPA SW-846 Method 6010

Samples will be numbered as **69UVB-GW-GA(0)-W 1,1** where:

69: refers to Site 69

UVB: refers to UVB monitoring wells (KGB for KGB monitoring wells)

GW: refers to groundwater sample (TB for trip blank, IB for instrument blank)

GA: refers to sample for group A inorganics analysis (GB for group B, BI for bicarbonates, DI for dissolved iron)

(0): refers to time zero sample (2,4,& 6 for 2 month, 4 month, and 6 month sampling event)

S: refers to a well in the south arm (E for a well in the east arm, UW for a UVB annulus well)

1,1: refers to the shallow 25% ROI UVB well/shallow 50% ROI KGB well (1,2 for the deep 25% ROI UVB well/deep 50% ROI KGB well; 2,1 for the shallow 43% ROI UVB well/shallow 75% ROI KGB well; 2,2 for the deep 43% ROI UVB well/deep

75% ROI KGB well; 3,1 for the shallow 75% ROI UVB well; 3,2 for the deep 75% ROI UVB well, 0,1 for the shallow UVB well, 0,2 for the deep UVB well)

In all, 4 samples will be collected for inorganic water quality analysis to be performed by York Analytical Laboratories.

6.1.2.4 Sampling Plan for Dyes in Groundwater

Two types of sampling will be conducted as part of the dye tracer analysis: groundwater sampling; and GAC, or charcoal sampling. Groundwater sampling will be performed to provide information on dye concentrations at a particular time at the monitoring stations. The charcoal sampling will help to provide information on the first arrival time of the dye at a particular station. The charcoal sampling will also help to minimize the frequency and number of water samples required for the tracer test. Groundwater dye sampling is discussed below, and the GAC dye sampling is described in Section 6.1.2.4.

Following dye injection, water samples will be collected weekly over a period of 10 weeks, and then bi-weekly for the next 10 weeks from the UVB monitoring wells. Water samples will be collected weekly for four weeks followed by bi-weekly for 12 weeks from the KGB monitoring wells after dye injection. Water samples will be collected at the same time when charcoal samples are collected, but analyzed for dyes only when the representative charcoal sample shows presence of dye. They will be collected using disposable bailers in plastic 50 ml research grade polypropylene copolymer Perfector Scientific vials. The bottles will be placed in the dark and refrigerated immediately after collection. They will be shipped on ice to OUL.

Samples will be numbered as **69UVB-GW-FLR(B1)-S1,1** where:

69: refers to Site 69

UVB: refers to UVB monitoring wells (KGB for KGB monitoring wells)

GW refers to groundwater sample, (TB for trip blank, IB for instrument blank)

FLR: refers to sample for fluorescein (RHD for rhodamine WT, ESN for eosine)

(B1): refers to week one background (B2 for week two background, 1, 2, ...n for week 1, 2, ... n after dye injection)

S: refers to a well in the south arm (E for a well in the east arm, UW for a UVB annulus well)

1,1: refers to the shallow 25% ROI UVB well/shallow 50% ROI KGB well (1,2 for the deep 25% ROI UVB well/deep 50% ROI KGB well; 2,1 for the shallow 43% ROI UVB well/shallow 75% ROI KGB well; 2,2 for the deep 43% ROI UVB well/deep 75% ROI KGB well; 3,1 for the shallow 75% ROI UVB well; 3,2 for the deep 75% ROI UVB well, 0,1 for the UVB shallow well, 0,2 for the UVB deep well)

In all, 260 water samples will be collected for analysis of dyes. Tracer dyes (rhodamine WT and fluorescein) will be analyzed using spectrofluorometry methods. Both, groundwater and charcoal

samplers will be analyzed using this method following extraction of the dyes in an organic solvent. Details on dye analytical procedures are outlined in Appendix A. All dye analyses will be performed by OUL.

6.1.3 Sampling of GAC Samplers for Dyes/Tracers

The following sections describe the procedures for performing the sampling of GAC samplers for dyes/tracers.

6.1.3.1 Description of the Samplers

The charcoal samplers are packets of fiberglass screening partially filled with approximately 4.25 grams of activated coconut charcoal. The charcoal used by the OUL is Barnebey and Sutcliffe coconut shell carbon, 6 to 12 mesh, catalog type AC. The samplers are typically about 4 inches long by two inches wide. Samplers are typically closed by heat sealing.

6.1.3.2 Placement of Samplers

Samplers (also called charcoal packets) are placed so as to be exposed to as much water as possible. The packets are attached using galvanized wire (electric fence wire is ideal); other types of anchoring wire can also be used, such as electrical wire with plastic insulation. Packets are attached so that they extend outward from the anchor rather than being flat against it.

Charcoal packets will be lowered into monitoring wells for sampling purposes. In general, if the well is screened, samplers will be placed approximately in the middle of the screened interval. A weight will be added near the charcoal packet to insure that it will not float. The weight will be of such a nature that it will not affect water quality, such as glass marbles sealed into packets of fiberglass screen. A nylon cord will be run from the top of the well to anchor the charcoal packet and its weight. Placement of samplers will be adjusted based on actual field conditions.

6.1.3.3 Rinsing of Charcoal Packets Prior to Sampling

Charcoal packets routinely contain some fine powder which washes off rapidly when they are placed in water. Since such material could remain in monitoring wells, charcoal packets to be placed in such wells will be triple rinsed with distilled, demineralized, or reagent water known to be free of tracer dyes. This rinsing is typically performed by soaking. Approximately 25 packets will be placed in one gallon of water and soaked for at least 10 minutes. The packets will be removed from the water, and excess water will be shaken off the packets. This procedure will be repeated two more times using fresh water. Triple rinsed packets are placed in plastic bags and are placed at sampling stations within three days.

6.1.3.4 Collection and Replacement of Samplers

Following dye injection, charcoal samples will be collected weekly over a period of 10 weeks, and then bi-weekly for the next 10 weeks from the UVB monitoring wells. Charcoal samples will be collected weekly for four weeks followed by bi-weekly for 12 weeks from the KGB monitoring wells after dye injection.

After the packets are removed from the well, they will be shaken to remove excess water. Next, the packet (or packets) will be placed in a plastic bag (Whirl-Pak bags are ideal). The bag will be labeled on the outside with a permanent type felt marker pen. The notations will include station name or number and the date and time of collection. Labels will not be inserted inside the sample bags. New charcoal samplers will be placed when used charcoal packets are collected. Collected samplers will be kept on ice, and in the dark to minimize algal growth on the charcoal prior to analysis. The samplers will be shipped refrigerated by overnight express to OUL.

Each shipment of charcoal samplers or water samples will be accompanied by a sample tracking sheet. These sheets (which bear the title "Samples for Fluorescence Analysis") are provided by the laboratory and summarize placement and collection data. These sheets will be augmented by SBP's chain-of-custody forms or any other relevant documentation.

Samples will be numbered as **69UVB-AC-FLR(B1)-S1,1** where:

- **69**: refers to Site 69
- **UVB**: refers to UVB monitoring wells (KGB for KGB monitoring wells)
- **AC**: refers to activated carbon samplers
- **S**: refers to a well in the south arm (E for a well in the east arm, UW for a UVB annulus well)
- **1,1**: refers to the shallow 25% ROI UVB well/shallow 50% ROI KGB well (1,2 for the deep 25% ROI UVB well/deep 50% ROI KGB well; 2,1 for the shallow 43% ROI UVB well/shallow 75% ROI KGB well; 2,2 for the deep 43% ROI UVB well/deep 75% ROI KGB well; 3,1 for the shallow 75% ROI UVB well; 3,2 for the deep 75% ROI UVB well, 0,1 refers to UVB shallow well, 0,2 refers to UVB deep well).

In all, 215 charcoal samples will be collected for dye analysis.

6.1.4 Sampling of GAC for Adsorbed VOCs from Off-Gases

A total of four GAC drums will be used, a set of two in series connected to each blower (UVB and KGB). All GAC drums will be monitored weekly for breakthrough using a photo-ionization detector (PID). Whenever a GAC can reaches breakthrough, it will be taken out of service. A fresh GAC can will then be added to the off-gas treatment system as the lead unit (GAC1), and the former lead unit will become the new lag unit (GAC2). Spent carbon samples will be collected from the used drums

in duplicate, and shipped to Laboratory Resources for analysis. If the carbon does not reach breakthrough by the end of the demonstration period, sampling and analysis will be performed at the end before disposal of GAC drums.

Samples will be numbered as **69UVB-GAC-1** where:

- **69**: refers to Site 69
- **UVB**: refers to UVB off-gas treatment (KGB for KGB off-gas treatment)
- **GAC**: refers to granular activated carbon sample)
- **1**: refers to sample from the first can in series (2,3,..n for 2nd, 3rd,..nth can)

Number of samples collected will depend on the carbon breakthrough.

6.1.5 Air Sampling

In addition to analysis of the GAC, air streams processed by the GAC units (influent and effluent) will be analyzed periodically for both UVB and KGB systems. Analysis of the influent air streams will provide information on the performance of each system (i.e., degree of VOC removal from the groundwater). Analysis of the effluents will provide data on the performance of the GAC units. Six (6) sampling events are planned for air analysis. As shown in Table 6-1, samples will be collected at 1 day, 1 week, 2 weeks, 2 months, 4 months, and 6 months after startup. Samples will be collected on solvent desorption carbon tubes. A given volume of air stream (as specified by the manufacturer) will be pumped through these tubes using an air sampling pump. VOCs adsorbed on the carbon will be extracted in a solvent and analyzed by gas chromatography for specific VOCs using method EPA 8260.

Samples will be numbered as **69UVB-AIR-VOC-0-1** where:

- **69**: refers to Site 69
- **UVB**: refers to UVB monitoring wells (KGB for sample out of the KGB)
- **AIR**: refers to air sample
- **VOC**: refers to sample for volatile organic analysis
- **0**: refers to sample out of the UVB or KGB (1 for sample out of GAC1, 2 for sample out of GAC2)
- **1**: refers to sampling event 1 (2,3,4,5, & 6 for 1 week, 2 week, 2 month, 4 month, and 6 month sampling event)

6.1.6 Sample Handling, Labeling, Shipping, and Documentation

This section presents the procedures for handling, labeling, and transport of environmental and waste samples as well as field recording practices necessary for reconstruction of the sampling event. The

possession and handling of all samples collected will be traceable from the time of collection through analysis, until final disposition. Documentation of the sample history is referred to as "chain-of-custody." Components of the chain-of-custody (i.e., sample seals, field logbook, chain-of-custody record, and sample analysis request form) and procedures for their use are described in the following sections.

A sample is considered to be under a person's custody if it is: 1) in a person's physical possession, 2) in view of the person after he or she has taken possession, 3) secured by the person so that no one can tamper with the sample, or 4) in a secure area. A person who has samples under custody must comply with the procedures described in the following sections.

6.1.6.1 Chain-Of-Custody Records

To establish the documentation necessary to trace sample possession from the time of collection, a chain-of-custody record must be filled out in triplicate and must accompany every sample or group of individually identified samples. Chain-of-custody records will contain the following information:

- Sample Identification Number
- Date and Time of Sample Collection
- Signature or Initials of Sample Collector
- Matrix Type
- Number of Containers
- Signatures of People in the Chain-of-Custody
- Date and Time of Each Change in Custody
- Method of Shipment
- Condition of Samples when Received by Laboratory
- Project Name
- Project Number
- Sampling Location

A typical chain-of-custody form is shown in the SOPs. Each person who has custody must sign the form. Samples cannot be left unattended unless they are secured and sealed.

6.1.6.2 Sample Labels

Sample labels are necessary to prevent misidentification of samples. An example sample label is shown in the SOPs. Gummed paper labels or tags will be used and will include at least the following information:

- Sample number (referenced to a sampling location) including a sample code that distinguishes field samples, duplicates, spikes, or blanks. The laboratory should not be cognizant of the code.

- Signature or initials of sample collector.

- Date and time of sample collection.

- Location of sample collection.

- Type of preservative used, or "None" as necessary.

Labels will be affixed to sample containers prior to or at the time of sampling. The labels will be filled out at the time of sample collection. The exact sample location and type of sample will be recorded in the field logbook.

All boxes used for archiving or sample storage will be labeled at the end and top with an indelible marking pen. Box labeling will include the following:

- Job Number (e.g., 00367-109)
- Location (e.g., SWMU 5)
- Site (e.g., SBP)
- Date (e.g., February 16, 1991)
- Disposition (e.g., archived)

Sample seals are used to detect improper handling of samples following sample collection up to the time of analysis. Items such as gummed paper seals and custody tape will be used for this purpose. Signed and dated seals will be attached so that they must be broken to open either the individual sample containers or shipping containers. Seals will be affixed to containers before the samples leave the custody of the sampling personnel.

6.1.6.3 Shipping of Samples

Samples will be packaged and shipped in ice chests in accordance with U.S. Department of Transportation and EPA regulations. Samples will be delivered to the laboratory so that the requested analyses can be performed within the specified allowable holding time (see Table 6-1 for allowable holding times). Samples will be accompanied by the chain-of-custody record. The chain-of-custody record received will list the variables to be analyzed by the laboratory and total number and type of samples shipped for analysis. Authorized laboratory personnel will acknowledge receipt of shipment by signing and dating the form and returning a copy to the project manager. The laboratory will also sign and date the airbill accompanying the samples and keep it on file with the sample information.

6.1.6.4 Field Logbook

Information pertinent to the sampling effort will be recorded in a field sampling log. The book shall be bound. All entries will be made in indelible ink and all corrections will follow error correction protocol of one line through the error and initial and date of correction. At a minimum, entries in a logbook will include the following:

- Purpose of sampling
- Location, description, and photographs of the sampling point
- Details of the sampling site (for sample, the elevation of the casing, casing diameter and depth, integrity of the casing, etc.)
- Name and address of field contact
- Documentation of procedures for preparation of reagents or supplies which become an integral part of the sample (e.g., filters and absorbing reagents)
- Identification of sampling crew members
- Type of sample (e.g., ground water, soil, sludge, or waste water)
- Suspected waste composition, including estimated concentrations
- Number and volume of sample taken
- Sampling methodology
- Sample preservation
- Date and time of collection
- Collector's sample identification number(s).
- Sample distribution and transportation method (e.g., name of the laboratory and cartage agent - Federal Express, United Parcel Service, etc.)
- References such as maps of the sampling site.

- Field observations
- Any field measurements made (e.g., pH, flammability, explosivity, and water depth).
- Signature and date by the personnel responsible for observations.
- Decontamination procedures.

Sampling situations vary widely. No general rules can specify the extent of information that must be entered in a logbook. However, records shall contain sufficient information so that someone can reconstruct the sampling activity without relying on the collector's memory.

6.2 Field Monitoring Plan (FMP)

The FMP is comprised of the following components:

- Monitoring of field parameters
- Monitoring of UVB parameters
- Monitoring of KGB parameters

This plan describes the techniques to be implemented for the above parameters to be measured in the field. Table 6-2 show the details of the monitoring activities under the FMP. At a minimum, instruments will be calibrated at the beginning of each work day and at any time the calibration range is exceeded during measurements.

6.2.1 Water Parameters

6.2.1.1 Water Level Measurements

Water levels will be measured using a portable well gauging probe. Water level measurements will be referenced to a known elevational datum. The measuring point at the top of the casing will be permanently marked and surveyed. Water level measurements will be consistently taken from the same marked point. Water levels will be measured by lowering the probe or tape measure into the well until contact with the water surface is indicated. The electric tape will be marked at the reference measuring point and partly withdrawn; the distance from the mark to the nearest tape band will be measured and added to (or subtracted from) the band reading to obtain the depth to water below the reference point. Readings will be verified by repeating the procedure until successive measurements differ less than 0.01 foot. Measuring devices will be decontaminated prior to and after each monitoring in accordance with the SOPs.

Water level measurements will be taken in the 18 UVB monitoring wells, eight KGB monitoring wells, existing nearby monitoring wells, and the UVB well. Water level measurements will be performed once every week.

6.2.1.2 Dissolved Oxygen and Temperature

These parameters will be measured in situ using a portable field sensor. The sensor will be calibrated according to the procedures outlined by the manufacturer. Water temperature will be recorded first, followed by dissolved oxygen. The instrument will be corrected for temperature compensation before reading dissolved oxygen. Multiple readings will be taken until two identical readings or readings with ± 10% variance are recorded. Dissolved oxygen measurements will be performed in 18 UVB monitoring wells, eight KGB monitoring wells and the UVB well. Dissolved oxygen measurements will be performed once every week.

6.2.1.3 pH and Specific Conductivity

These parameters will be determined by lowering in situ probes in monitoring wells. Multiple readings will be taken until two identical readings, or readings with ± 10% variance, are recorded. Measurements for pH and specific conductivity will be performed once every week in the 18 UVB monitoring wells, eight KGB monitoring wells, and the UVB well.

6.2.2 Soil Parameters

6.2.2.1 VOCs in Soil

Soil VOCs will be measured using a portable PID. This method provides a quick and accurate method of determining the presence of volatile organic compounds in soils while drilling and/or soil sampling in the field. This monitoring is part of the Health and Safety requirements outlined in the HASP. Drill cuttings and core samples collected for archiving will be screened using this method for potential exposure hazard.

Procedure:

- The PID will be calibrated each day before the start of field activities.
- Background levels of volatile organic compounds will be established with the PID each day before field activities start.
- When monitoring for VOCs from drill cuttings/drilling fluids, measurements will be performed at the source (not more than 12-inch away from the generated waste). At least three measurements will be performed in the vicinity.

- When monitoring for VOCs in samples collected by split-spoon samplers, measurements will be performed at the surface of the soil sample immediately after the spoon has been split opened. Three measurements will be taken across the length of the sample.

- The PID reaches a peak response within approximately 5 seconds; therefore, the reading should be taken between 5 and 10 seconds after the tip is exposed to the sample. Resulting PID readings are in ppm of total ionizable volatile organic compounds.

- Based on the permissible exposure level criteria (to be determined), the Health and Safety Officer will decide the level of personal protection required in accordance with the HASP.

- Decontaminate all equipment as described in Section 4.6.

6.2.3 Measurement of UVB Parameters

Table 6-3 shows the details of the UVB specific field monitoring plan.

6.2.3.1 UVB Vapor Parameters

All parameters listed below will be measured from the pressure (UVB effluent port) side of the UVB Blower prior to off-gas entry to the GAC unit.

- Relative air humidity (% moisture)

- Air temperature (°C)

- Air flow out of the UVB (acfm or actual cubic feet per minute, at recorded temperature and pressure)

- Off-gas concentration of VOCs stripped from groundwater (ppm of ionizable volatile organic compounds using PID)

All parameters listed below are measured from the top of the UVB air intake pipe (UVB Influent Port).

- Ambient relative humidity (% moisture)

- Ambient air temperature (°C)

- Air flow into the UVB (actual cubic feet per min, acfm, specify recorded temperature and pressure)

- Vacuum (mbars) in UVB well with fresh air pipe open

- Vacuum (mbars) in UVB well with fresh air pipe covered

All parameters listed below are measured at the GAC unit effluent port.

- Off-gas concentration of VOCs exiting the GAC unit(s) (ppm of ionizable volatile organic compounds using the PID)

- Effluent air flow through the GAC unit(s) (actual cubic feet per min, acfm, specify recorded temperature and pressure)

From the above data, using a time weighted measurement of volatiles organics in ppm, the amount of hydrocarbons extracted by the remediation systems in pounds per day may be calculated and graphically represented as pounds per day versus time of operation.

6.2.3.2 UVB Groundwater Parameters

The following parameters will be measured in the UVB well:

- Water levels (in feet) as a base line (initial measurement only)

- Water levels (in feet) in the UVB well, and the UVB deep and shallow annulus wells with the system on.

- Water levels (in feet) in the UVB well, and the UVB deep and shallow annulus wells with the system off (1 hour after the blower has been turned off)

- Groundwater recirculation flow rate (gallons per minute, gpm)

6.2.4 Measurement of the KGB Parameters

Table 6-4 shows details of the KGB specific field monitoring plan.

6.2.4.1 KGB Vapor Parameters

All parameters listed below are measured at the GAC unit effluent port.

- Off-gas concentration of VOCs exiting the GAC unit(s) (ppm of ionizable volatile organic compounds using the PID)

- Effluent air flow through the GAC unit(s) (actual cubic feet per min, acfm, specify recorded temperature and pressure)

From the above data, using a time weighted measurement of volatiles organics in ppm, the amount of hydrocarbons extracted by the remediation systems in pounds per day may be calculated and graphically represented as pounds per day versus time of operation.

6.2.4.2 KGB Groundwater Parameters

The following KGB groundwater parameters will be measured:

- Water levels (in feet) as a base line (initial measurement only)

- water levels (in feet) in the KGB deep and shallow wells with the system on (both blower and compressor)

- water levels (in feet) in the KGB deep and shallow wells with the system off (1 hour after the blower and the compressor have been turned off)

SECTION 6.0 TABLES

TABLE 6-1: SUMMARY OF SAMPLING AND ANALYSIS PLAN

MATRIX	LOCATION	ANALYSIS/METHOD	FREQUENCY	CONTAINER/SIZE	LAB	HOLDING TIME
Soil	Pilot Hole	None / Archiving	Every 2 ft, (14'-50')	2' Plastic Cores	NA	NA
Soil	69UWSE-22	None / Archiving	Every 2 ft, (14'-80')	2' Plastic Cores	NA	NA
Soil	69UWSW-22	None / Archiving	Every 2 ft, (14'-80')	2' Plastic Cores	NA	NA
Water	18 UVB Wells	VOCs / EPA 8260	0,2,4,6 months	40 ml VOA	LR	2 Weeks
Water	8 KGB Wells	VOCs / EPA 8260	0,2,4,6 months	40 ml VOA	LR	2 Weeks
Water	18 UVB Wells	Dyes / UV-VIS	2 Weeks Background	50 ml Polypropylene	OUL	4 Weeks
			Weekly for 10 Weeks	50 ml Polypropylene	OUL	4 Weeks
			Bi-weekly for 10 Weeks	50 ml Polypropylene	OUL	4 Weeks
Water	8 KGB Wells	Dyes / UV-VIS	2 Weeks Background	50 ml Polypropylene	OUL	4 Weeks
			Weekly for 4 Weeks	50 ml Polypropylene	OUL	4 Weeks
			Bi-weekly for 12 Weeks	50 ml Polypropylene	OUL	4 Weeks
Water	UVB Annulus Wells	VOCs / EPA 8260	Samples to be taken	40 ml VOA	LR	2 Weeks
	(deep and shallow)		1 day,1 week, & 2weeks			
			after start up			
Water	69UVB-01	Inorganics Group A	0, 6 months	250 ml Plastic	York	2 Weeks
		Inorganics Group B	0,6 months	1000 ml Plastic	York	2 Weeks
		Dissolved Iron	0, 6 months	250 ml Plastic	York	2 Weeks
		Bicarbonate	0, 6 months	1000 ml Plastic	York	2 Weeks
		Dissolved O2	Weekly	In Well		
		Dissolved H2S	0, 6 months	250 ml Plastic	York	2 Weeks
		Dissolved CO2	0, 6 months	250 ml Plastic	York	2 Weeks
		TSS	0,6 months	250 ml Plastic	York	2 Weeks
		TDS	0,6 months	250 ml Plastic	York	2 Weeks

TABLE 6-1: SUMMARY OF SAMPLING AND ANALYSIS PLAN (CONTINUED)

MATRIX	LOCATION	ANALYSIS/METHOD	FREQUENCY	CONTAINER/SIZE	LAB	HOLDING TIME
Water	69UVB-02	Inorganics Group A	0, 6 months	250 ml Plastic	York	2 Weeks
		Inorganics Group B	0,6 months	1000 ml Plastic	York	2 Weeks
		Dissolved Iron	0, 6 months	250 ml Plastic	York	2 Weeks
		Bicarbonate	0, 6 months	1000 ml Plastic	York	2 Weeks
		Dissolved O2	Weekly	In Well		
		Dissolved H2S	0, 6 months	250 ml Plastic	York	2 Weeks
		Dissolved CO2	0, 6 months	250 ml Plastic	York	2 Weeks
		TSS	0,6 months	250 ml Plastic	York	2 Weeks
		TDS	0,6 months	250 ml Plastic	York	2 Weeks
Air	UVB effluent	VOCs / EPA 8260			LR	2 Weeks
	UVB-GAC1 effluent	VOCs / EPA 8260	Day1, Week1, Week2,	Solvent Desorption	LR	2 Weeks
	UVB-GAC2 effluent	VOCs / EPA 8260	Month2, Month4, and	Carbon Tubes	LR	2 Weeks
Air	KGB effluent	VOCs / EPA 8260	Month6 after start up		LR	2 Weeks
	KGB-GAC1 effluent	VOCs / EPA 8260			LR	2 Weeks
Charcoal	18 UVB Wells	Dyes / UV-VIS	2 Weeks Background	Polypropylene Bag	OUL	4 Weeks
			Weekly for 10 Weeks	Polypropylene Bag	OUL	4 Weeks
			Bi-weekly for 10 Weeks	Polypropylene Bag	OUL	4 Weeks
Charcoal	8 KGB Wells	Dyes / UV-VIS	2 Weeks Background	Polypropylene Bag	OUL	4 Weeks
			Weekly for 4 Weeks	Polypropylene Bag	OUL	4 Weeks
			Bi-weekly for 12 Weeks	Polypropylene Bag	OUL	4 Weeks
GAC	UVB GAC Unit	VOCs / EPA 8260	At Breakthrough	8 oz Jars	LR	2 Weeks
GAC	KGB GAC Unit	VOCs / EPA 8260	At Breakthrough	8 oz Jars	LR	2 Weeks

NOTE: *Group A (Na, K, Mn, Mg & Ca); Group B (Chloride, Sulfate, Specific Conductance & TDS)*

TABLE 6-2
SUMMARY OF FIELD MONITORING PLAN
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

SOIL AND GROUNDWATER

Matrix	Parameter	Location	Frequency	Method
Water	Groundwater Levels	18 UVB Wells	Weekly	Well Gauging Probe
		8 KGB Wells	Weekly	Well Gauging Probe
Water	Dissolved Oxygen	18 UVB Wells	Weekly	YSI In-Well Probe
		8 KGB Wells	Weekly	YSI In-Well Probe
Water	Temperature	18 UVB Wells	Weekly	YSI In-Well Probe
		8 KGB Wells	Weekly	YSI In-Well Probe
Water	pH	18 UVB Wells	Weekly	In-Well Probe
		8 KGB Wells	Weekly	In-Well Probe
Water	Specific Conductivity	18 UVB Wells	Weekly	In-Well Probe
		8 KGB Wells	Weekly	In-Well Probe
Soil	Ionizable VOCs	UVB Well	During Drilling	
		KGB Well	and	
		Pilot Hole	Split-Spoon	PID / OVA
		18 UVB Wells	Sampling	
		8 KGB Wells	Activities	

TABLE 6-3
SUMMARY OF UVB FIELD MONITORING PLAN
SITE 69 TREATABILITY STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

Matrix	Parameter	Location	Frequency	Method	Condition
Air	Humidity	GAC Off-Gas Influent Port	Weekly	Portable Meter	
	Temperature	GAC Off-Gas Influent Port	Weekly	Portable Meter	
	Flow Rate	GAC Off-Gas Influent Port	Weekly	Velocity Meter	
	VOCs	GAC Off-Gas Influent Port	Weekly	PID/OVA	
Air	Humidity	GAC Off-Gas Effluent Port	Weekly	Portable Meter	
	Temperature	GAC Off-Gas Effluent Port	Weekly	Portable Meter	
	Flow Rate	GAC Off-Gas Effluent Port	Weekly	Velocity Meter	
	VOCs	GAC Off-Gas Effluent Port	Weekly	PID/OVA	
Air	Humidity	UVB Air Intake Port	Weekly	Portable Meter	
	Temperature	UVB Air Intake Port	Weekly	Portable Meter	
	Flow Rate	UVB Air Intake Port	Weekly	Velocity Meter	
Air	Vacuum	UVB Well	Weekly	Flange Gauge	Air Intake Port Open
	Vacuum	UVB Well	Weekly	Flange Gauge	Air Intake Port Closed
Water	Level	Shallow UVB Annulus Well	Weekly	Well Gauging Tape	Blower and Pump On
		Deep UVB Annulus Well	Weekly	Well Gauging Tape	Blower and Pump On
		UVB Well	Weekly	Well Gauging Tape	Blower and Pump On
Water	Level	Shallow UVB Annulus Well	Weekly	Well Gauging Tape	Blower and Pump Off
		Deep UVB Annulus Well	Weekly	Well Gauging Tape	Blower and Pump Off
		UVB Well	Weekly	Well Gauging Tape	Blower and Pump Off
Water	Flow Rate	UVB	Weekly	Meter	

TABLE 6-4
SUMMARY OF KGB FIELD MONITORING PLAN
SITE 69 STUDY - MCB CAMP LEJEUNE, NORTH CAROLINA

Matrix	Parameter	Location	Frequency	Method	Condition
Air	Humidity	GAC Off-Gas Influent Port	Weekly	Portable Meter	
	Temperature	GAC Off-Gas Influent Port	Weekly	Portable Meter	
	Flow Rate	GAC Off-Gas Influent Port	Weekly	Velocity Meter	
	VOCs	GAC Off-Gas Influent Port	Weekly	PID/OVA	
Air	Humidity	GAC Off-Gas Effluent Port	Weekly	Portable Meter	
	Temperature	GAC Off-Gas Effluent Port	Weekly	Portable Meter	
	Flow Rate	GAC Off-Gas Effluent Port	Weekly	Velocity Meter	
	VOCs	GAC Off-Gas Effluent Port	Weekly	PID/OVA	
Air	Humidity	Ambient	Weekly	Portable Meter	
	Temperature	Ambient	Weekly	Portable Meter	
	Flow Rate	Compressor	Weekly	Velocity Meter	
	Pressure	Compressor	Weekly	Pressure Gauge	

7.0 QUALITY ASSURANCE PROJECT PLAN (QAPP)

The following sections comprise the QAPP for the sampling and associated analytical procedures to be performed during the treatability study.

7.1 Quality Assurance Objectives

The data quality objectives established are based on project requirements and are designed to ensure that the data generated during the demonstration are of known and acceptable quality to achieve the projects objectives. This section of the QAPP delineates the Quality Assurance (QA) objectives for each of the crucial measurements (VOCs in groundwater, VOCs adsorbed on GAC, dyes in groundwater, and dyes adsorbed on charcoal samplers) in terms of the data quality indicators: precision, accuracy, method detection limits, completeness, representatives, and comparability. The quality assurance objectives established for this QAPP are measured by the analysis of the Quality Control (QC) samples. The QAPP will also present the actual acceptance criteria for the various QA/QC analyses associated with each method; the objectives outlined below apply to overall project analyses. Laboratory-specific QAPPs are provided in Appendices A through C. The data quality indicators are described below.

Precision: Precision is the ability of the measurement system to generate reproducible data. Precision objectives for most measurements are expressed as the relative percent difference (RPD) between laboratory duplicate analyses or matrix spike/matrix spike duplicates (MS/MSDs). Acceptance criteria are generally based on the precision guidelines of the referenced method, or laboratory generated control limits calculated from a statistical treatment of historical data.

The precision of VOC measurements will be evaluated by the analysis of MS/MSD pairs performed on project samples (for both water and GAC). The precision of dyes measurement will be evaluated by analysis of 5% duplicate samples (for both water and charcoal samplers). Field measurements of air flow rate will be assessed by duplicate measurements using air velocity meters or rotameters in the field.

Accuracy: Accuracy is defined as the nearness of the analytical result to the "true" value. Matrix spike recoveries will be used to assess the accuracy of the VOC /dye measurements, and reported as percent recovery:

Method Detection Limits: Method detection limits (MDLs) are determined based on the analysis of extracted low level spiked blanks. Multiple spiked blanks at concentration approaching the estimated MDL are extracted and analyzed according to method protocols. The MDLs are determined by calculating the standard deviation of the analyses times the student "t" value at n-1 degrees of freedom. The detection limits are based on SW 846 protocols. All MDLs will be adjusted as necessary based on required dilution, etc. Detection limits for dyes and VOCs are explained in their respective laboratory QAPPs (Appendices A and B).

Completeness: Data completeness is a measure of the extent to which the database resulting from a measurement effort fulfills the objective for the amount of data required. For this program, completeness is defined as the percentage of valid data compared to the number of tests planned. Objectives for data capture, expressed as completeness, are 90-95% for the various parameters.

Representatives: A well-defined sampling strategy ensures that the samples collected are representative of the site at that stage of the technology process. The sampling strategy for this demonstration is discussed in the SAP (Section 6.0). Field QC samples will be used to assess the representatives of sampling activities. Equipment, field, and trip blanks, discussed in Section 8.2, will be used to ensure representative samples.

Comparability: The use of standard, validated EPA methods achieves comparability measurement data. Reporting the data in standard units of measure as specified in the methods, adhering to the method-defined calibration procedures and, when possible, meeting the method detection limit contribute to the comparability of the data.

7.2 Internal Quality Control

This section summarizes and defines the various QC analyses employed as part of the quality assurance program.

7.2.1 Quality Control for Field Activities

Three types of field blanks will be collected during this demonstration. Equipment blanks consist of reagent water exposed to the decontaminated sampling equipment in a manner similar to the actual samples. Field blanks consist of reagent water exposed to ambient conditions. Trip blanks consist of volatile organic analyte (VOA) vials filled with reagent water, store at the site with the sample vials, and shipped with the samples in coolers back to the lab to monitor cross-contamination.

Field duplicates are two samples collected from as near as possible to the same location and analyzed by the laboratory.

7.2.2 Quality Control for Laboratory Activities

This section describes the scheduled QC and calibration procedures to be employed during the analytical effort.

The use of a matrix spike and matrix spike duplicate is a means of measuring both precision and accuracy in an analysis. The three sample portions are prepared and analyzed in the same manner. The analysis of the unspiked aliquot produces sample data, and the analysis of the two spiked aliquot generates recovery data. Comparison of the results of the two spiked aliquots allows the calculation of the relative percent difference between the two measurements. This type of QC sample is used

for volatile organic analysis, and is analyzed following every ten samples and following highly concentrated samples to monitor for any carryover in the analytical system.

A sample duplicate is analyzed every 10 samples or at least one per analytical batch, whichever frequency is greater, to determine the analytical precision. The relative percent difference in the analyte concentration from the duplicates must be < 30%.

A Quality Assurance Spike, or Laboratory Control Sample, consisting of an aliquot, is analyzed at least one per analytical batch, or one every 12 hours, whichever frequency is greater. A secondary QA standard will be prepared by the laboratory for compounds not contained in the NIST standard. If the % recovery for any critical analyte fails to fall within this acceptable range, the analytical system is considered "out of control" and corrective action, up to and including recalibration, must be performed and the analysis repeated until acceptable % recovery data are obtained. Reanalysis of all affected samples is required.

7.3 QA/QC Samples

All laboratory analyses will follow the internal quality and quality assurance plan as described in Appendices A through C. In addition, matrix duplicate, instrument blank, trip blank, and field blank samples will be collected and analyzed periodically to assure quality data.

7.3.1 Matrix Duplicates

At each groundwater sampling event two matrix duplicate samples will be collected from the UVB monitoring wells (one each from the shallow and deep wells), and one matrix duplicate sample will be collected from the KGB monitoring wells.

At each charcoal sampler sampling event, two matrix duplicate samples will be collected from the UVB monitoring wells (one each from the shallow and deep wells), and one matrix duplicate sample will be collected from the KGB monitoring wells.

At each GAC sampling event, one matrix duplicate sample will be collected from the UVB GAC as well as the KGB GAC units.

7.3.2 Trip Blanks

One trip blank will be included per cooler for each type of analysis/matrix sample.

7.3.3 Equipment Blanks

At each groundwater sampling event for VOCs, two equipment blank samples will be collected during the sampling of the UVB monitoring wells, and one equipment blank sample will be collected during the sampling of KGB monitoring wells.

Sampling of groundwater for dyes will be performed with dedicated disposable bailers. Consequently, no equipment blanks will be collected for dye analyses.

7.3.4 Field Blanks

At each groundwater sampling event, one field blank will be collected during the sampling of UVB monitoring wells, and one field blank will be collected during the sampling of KGB monitoring wells.

At each charcoal sampler sampling event, one field blank will be collected during the sampling of UVB monitoring wells, and one field blank will be collected during the sampling of KGB monitoring wells.

At each GAC sampling event, one field blank will be collected during sampling of the UVB GAC and/or the KGB GAC units.

7.4 Data Reporting

All original laboratory data will be recorded in a permanent manner, and will be readily traceable through all steps of the data generation/reduction/validation/review process. Field measurements will be recorded in appropriate field notebooks and results will be reported in tabulated summary form.

Laboratory data are originally reported by the analyst-specific report forms. These data are reviewed, validated, and approved for reporting by a senior technical staff member. Critical analysis data will be retained by the lab for period of 3 years. Samples will be retained by the lab for 3 months after the report is issued.

The laboratory will compile a report that contains a narrative summary, a listing of sample identifications and cross references, a holding time summary, and quality assurance discussion for each parameter. Any deviations from the approved methods and/or other QAPP specifications will be pointed out in this summary. Anomalies in the data or unusual sample characteristics will be discussed and any data that do not meet QC criteria will be identified. Also in this section, the laboratory will discuss any corrective actions taken to bring problems into control and the impact on the data from any samples which were lost or broken or have a non-usable results.

Where applicable, the laboratory shall report the data for volatiles using the procedures and forms, or equivalent, as described for the Level III (Navy's Level C) Data Quality. Where applicable, all

matrix spike, duplicate, method blank, and calibration analyses will be reported on standardized forms and the QC raw data submitted.

Following the narrative summary and discussions, the analytical raw data will be presented for each parameter. Included for all parameters, where applicable: surrogate recovery summary form, matrix spike summary and raw data for matrix spike, method blank summary form and raw data, GC/MS tuning form and raw data, internal standard summary, initial calibration summary form, daily calibration summary and raw data, laboratory duplicate results summary and laboratory control sample results summary.

8.0 RESIDUALS MANAGEMENT

Investigation derived wastes (IDW) will be generated during the drilling and sampling activities associated with the treatability study. The IDW to be generated will include soil and mud cuttings, purge and development groundwater, spent decontamination fluid, and personal protective equipment (PPE) and clothing (PPC).

8.1 Soil IDW Management

Soil cuttings (and drilling mud) generated during soil boring and monitoring well installations, and spoil generated from trench excavations will be managed in one of three ways. Soil cuttings and spoils obtained from soil borings and excavations will be backfilled into the boreholes or trenches upon completion. Soil cuttings obtained during shallow (or intermediate) well installation will be spread on the ground surface near the borehole. Lastly, soil and mud cuttings obtained during deep well installation will be temporarily containerized in roll-off boxes, sampled, and disposed either on site (if determined to be nonhazardous) or off site (if determined to be hazardous). One composite soil sample will be collected from each roll-off box and analyzed for full TCLP, TCL PCBs, and RCRA hazardous waste characteristics.

8.2 Groundwater IDW Management

Groundwater generated during well development and purging activities will be managed in one of two ways. Groundwater obtained during purging of existing site wells will be discharged to the ground surface near the monitoring well. For all newly installed monitoring wells and existing wells, the development and purge groundwater will be temporarily containerized in tanks, sampled, and analyzed for TCL organic, TAL metals, and RCRA hazardous waste characteristics. Hazardous groundwater will be transported and disposed off site and nonhazardous groundwater will be discharged on the ground surface. Note that groundwater exhibiting visual indications of contamination will be containerized in the tanks and subject to analysis.

8.3 Decontamination IDW Management

Spent decontamination fluids will be containerized temporarily in drums at each site, sampled, and analyzed for TCL organic, TAL metals, and RCRA hazardous waste characteristics. Upon receipt of analytical data, the fluids will be either discharged on the ground surface (nonhazardous) or transported off site for disposal (hazardous).

8.4 PPE and PPC IDW Management

PPE (e.g., spent respirator cartridges) and PPC (e.g., tyvex) will be double-bagged, labeled, and disposed of as solid waste. If the PPE or PPC is exposed to potentially hazardous substances or excessively contaminated soil or groundwater, it will be placed in a drum and disposed of in a solid waste landfill.

9.0 COMMUNITY RELATIONS

Community relations activities and requirements are outlined in the Base-wide Community Relations Plan prepared by Baker for the CERCLA RI/FS activities being performed on-Base. A Technical Review Committee (TRC) has been established for the MCB Camp Lejeune CERCLA activities, which includes LANTDIV, Base, USEPA, DEHNR personnel, and local citizens. The TRC reviews CERCLA documents and participates in periodic meetings with Baker to discuss ongoing CERCLA activities.

10.0 REPORTS

Two main reports are associated with the treatability study effort: this Treatability Study Work Plan; and the Treatability Study Report, which will document the treatability study results and conclusions. Submission and review of these two reports are discussed in the following sections.

10.1 Treatability Study Work Plan

The Draft Treatability Study Work Plan (April 1995), which details the scope of the treatability study activities to be performed, was submitted to the Navy, USEPA Region IV, and NC DEHNR for review. Comments were received from the NC DEHNR and USEPA Region IV, addressed, and incorporated, as appropriate, into this Final Treatability Study Work Plan. Baker has distributed the appropriate number of copies of the Final Treatability Study Report to the Navy, USEPA Region IV, NC DEHNR, and the other members of the TRC.

10.2 Treatability Study Report

Upon completion of the on-site UVB pilot study, a Treatability Study Report shall be prepared in accordance with USEPA's "Guide for Conducting Treatability Studies under CERCLA" (USEPA, October 1992). The Treatability Study Report will provide a presentation and evaluation of the treatability study test results. The Treatability Study Report will also include engineering and design-related information needed for evaluating the short- and long-term effectiveness, implementability (including long-term operation and maintenance requirements), and cost (both capital and operation and maintenance) of implementing full-scale UVB and KGB systems on site.

Two versions of the Treatability Study Report will be prepared as follows: a Draft Treatability Study Report for review by the Navy, USEPA, and NC DEHNR; and a Final Treatability Study Report, which will incorporate review comments from the Navy and regulatory agencies. Upon completion, Baker will distribute the appropriate number of copies of the Final Treatability Study Report to the Navy, USEPA Region IV, NC DEHNR, and the other members of the TRC.

11.0 SCHEDULE

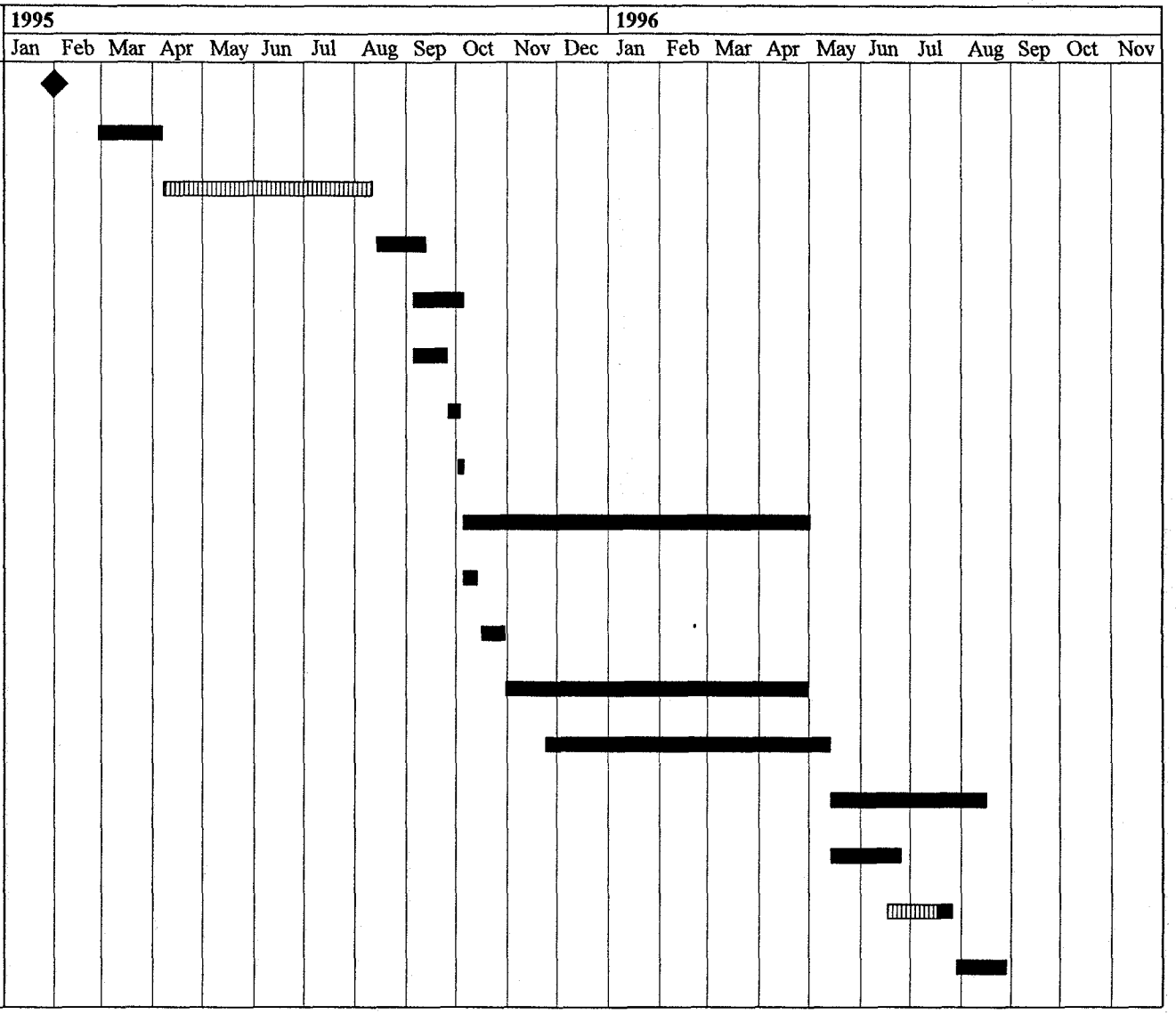
A preliminary schedule depicting the treatability study process is provided in Figure 11-1. As shown in Figure 11-1, the on-site operational period for the UVB and KGB pilot systems is approximately six months, whereas, the entire treatability study process, which includes development and review of the Treatability Study Work Plan and Treatability Study Report, is expected to require a total of 19 months to complete.

SECTION 11.0 FIGURES

FIGURE 11-1

UVB Treatability Study Schedule
Site 69, Operable Unit No. 14
Marine Corps Base, Camp Lejeune, North Carolina

UVB Treatability Study	Start	Finish
Work Plan	**2/1/95**	**2/1/95**
Draft Treatability Study Work Plan	2/27/95	4/6/95
Navy/EPA/State Review	4/7/95	8/11/95
Final Treatability Study Work Plan	8/14/95	9/12/95
Pre-Study Site Characterization	**9/5/95**	**10/5/95**
Mobilization	9/5/95	9/25/95
Well Installation/Sampling	9/26/95	10/3/95
Laboratory Analysis	10/2/95	10/5/95
Treatability Study	**10/5/95**	**5/1/96**
Mobilization	10/5/95	10/13/95
On-Site Pilot System Construction	10/16/95	10/30/95
On-Site Pilot Study	10/31/95	4/30/96
Laboratory Analysis	11/24/95	5/13/96
Treatability Study Report	**5/14/96**	**8/16/96**
Draft Treatability Study Report	5/14/96	6/25/96
Navy/EPA/State Review	6/26/96	7/26/96
Final Treatability Study Report	7/29/96	8/28/96



12.0 MANAGEMENT AND STAFFING

As previously discussed, the treatability study scope of work has been developed jointly by Baker and SBP. SBP is currently under contract with Baker for development of the Treatability Study Work Plan and will be performing the on-site treatability study activities under subcontract with Baker. IEG Technologies, the developer of the UVB and KGB technologies, will provide technical support to SBP. All drilling and laboratory work will be performed by second-tier subcontractors under contract with SBP. A project organization chart is provided in Figure 12-1.

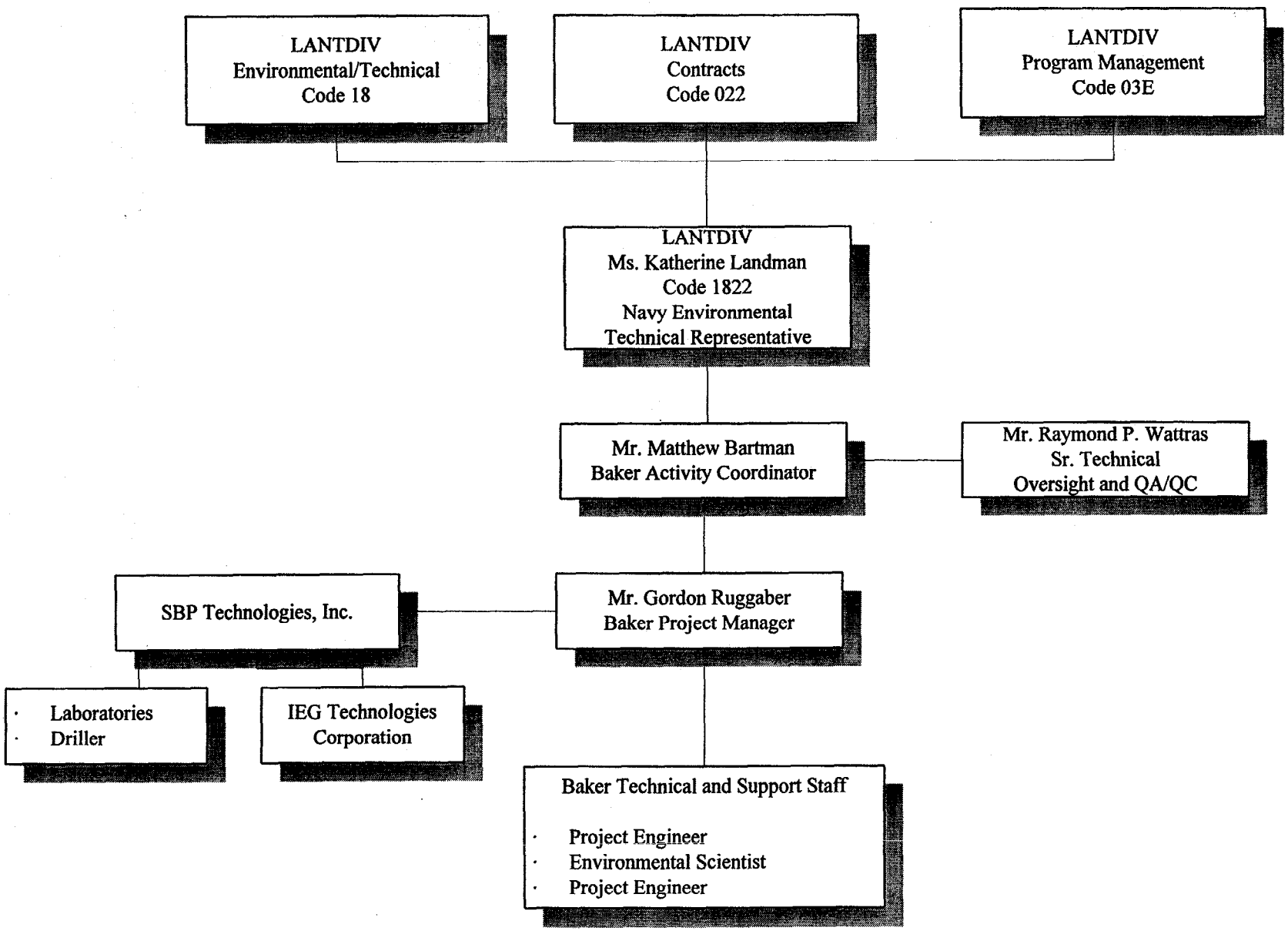
Telephone numbers for Baker, SBP, and IEG support staff are listed below:

Mr. Gordon Ruggaber, P.E., Baker	Telephone: (412) 269-4697	Fax: (412) 269-2002
Mr. Matthew Bartman, Baker	Telephone: (412) 269-2053	Fax: (412) 269-2002
Dr. Fayaz Lakhwala, SBP	Telephone: (904) 934-2476	Fax: (904) 934-2420
Dr. Clayton Page, SBP	Telephone: (504) 753-5255	Fax: (504) 753-5256
Dr. Eric Klingel, IEG	Telephone: (704) 599-4818	Fax: (704) 599-4815

SECTION 12.0 FIGURES

FIGURE 1

PROJECT ORGANIZATION
SITE 69 TREATABILITY STUDY
MARINE CORPS BASE, CAMP LEJEUNE, NORTH CAROLINA



APPENDIX A
OZARK UNDERGROUND LABORATORY QAPP

APPENDIX A

QAPP FOR DYE/TRACER ANALYSIS
OZARK UNDERGROUND LABORATORY

OZARK UNDERGROUND LABORATORY

1572 Aley Lane • Protem, Missouri 65733 • (417) 785-4289

PROCEDURES AND CRITERIA ANALYSIS OF FLUORESCEIN, EOSINE, AND RHODAMINE WT DYES IN WATER OR CHARCOAL SAMPLERS

February 22, 1994

Thomas Aley, PHG 179
President
Ozark Underground Laboratory

OZARK UNDERGROUND LABORATORY

1572 Aley Lane • Protem, Missouri 65733 • (417) 785-4289

CHARGE RATES OF THE OZARK UNDERGROUND LABORATORY

September, 1994

Professional Services

Thomas Aley, $80.00/hour
Catherine Aley, $65.00/hour
Technician, $40.00/hour

Travel and Incidental Expenses

Meals and lodging at cost.
Airline tickets, car rental, rental car gas at cost.
Mileage by OUL vehicle, $0.38/mile.
All other expenses at cost.

Dye Analysis Charges

Note: We supply unused samplers for all dye analysis work. All analysis work is in accordance with our written procedures and protocols and is conducted on either a Shimadzu RF-5000U or Shimadzu RF-540 Spectrofluorophotometer operated under a synchronous scan mode.

Analysis of optical brighteners and/or Direct Yellow 96 from cotton sampler. $25.00/sample.
Analysis for fluorescein, eosine, or Rhodamine WT from charcoal sampler or water sample. $25.00/sample.

Sampling materials (such as Whirl-Pak bags, sample bottles, etc.) at cost.

Clean and return coolers. $12.50 per cooler.

Tracing Materials

Note: No charge for cotton or charcoal samplers if analysis work is to be done by the Ozark Underground Laboratory.

Standardized fluorescein dye (powder form). $25.00/pound.
Standardized Rhodamine WT dye (20% liquid form). $35.00/pound.
Standardized eosine dye (powder form). $50.00/pound.

Note: No charge is made for analysis of daily standards if the dye used in the trace is supplied by the OUL.

Work Product from Dye Analysis

Clients are provided with photocopies of the analysis graph for each sample submitted. On larger projects these photocopies are included with the final report. On smaller projects these photocopies are included with a signed Certificate of Analysis. Dye concentrations and peak wavelengths are calculated for all water and charcoal samples; peak wavelengths are determined for all cotton samplers.

PROCEDURES

Description of the Samplers

The charcoal samplers are packets of fiberglass screening partially filled with approximately 4.25 grams of activated coconut charcoal. The charcoal used by the Ozark Underground Laboratory is Barnebey and Sutcliffe coconut shell carbon, 6 to 12 mesh, catalog Type AC. The samplers are typically about four inches long by two inches wide. Samplers are typically closed by heat sealing.

Placement of Samplers

Samplers (also called charcoal packets) are placed so as to be exposed to as much water as possible. In springs and streams they are typically attached to a rock or other anchor in a riffle area. Attachment of the packets uses galvanized wire (electric fence wire is ideal); other types of anchoring wire can be used. Electrical wire with plastic insulation is also good. Packets are attached so that they extend outward from the anchor rather than being flat against it. Two or more separately anchored packets are typically used for sampling springs and streams.

When pumping wells are being sampled, the samplers are placed in sample holders made of PVC pipe fittings. Brass hose fittings are installed at the end of the sample holders so that the sample holders can be installed on outside hose bibs and water which has run through the samplers can be directed to waste through a connected garden hose. The samplers can be unscrewed in the middle so that charcoal packets can be changed. The middle portions of the samplers consists of 1.5 inch diameter pipe and pipe fittings.

Charcoal packets can also be lowered into monitoring wells for sampling purposes. In general, if the well is screened, samplers should be placed approximately in the middle of the screened interval. Some sort of weight should be added near the charcoal packet to insure that it will not float. The weight should be of such a nature that it will not affect water quality. In some cases (but not all cases) we use glass marbles sealed into packets of fiberglass screening as dedicated weights at a sampling well. We typically run nylon cord from the top of the well to the charcoal packet and its weight.

Placement of samplers requires adjustment to field conditions. The above placement comments are intended as guidance, not firm requirements.

Rinsing of Charcoal Packets Prior to Sampling

Charcoal packets routinely contain some fine powder which washes off rapidly when they are placed in water. Since such material could remain in monitoring wells, charcoal packets to be placed in such wells are triple rinsed with distilled, demineralized, or reagent water known to be free of tracer dyes. This rinsing is typically done by soaking. With this approach, approximately 25 packets are placed in one gallon of water and soaked for at least 10 minutes. The packets

are then removed from the water and excess water is shaken off the packets. The packets are then placed in a second gallon of water and again soaked for at least 10 minutes. After this soaking they are removed from the water and excess water is shaken off the packets. The packets are then placed in a third gallon of water and the procedure is again repeated. Rinsed packets are placed in plastic bags and are placed at sampling stations within three days. Packets can also be rinsed in jets of water for about one minute; this requires more water and is typically difficult to do in the field with water known to be free of tracer dyes.

Collection and Replacement of Samplers

Samplers are routinely collected and replaced from each of the sampling stations. The frequency of sampler collection and replacement is determined by the nature of the study. Collections at one week intervals are common, but shorter or longer collection frequencies are acceptable and sometimes more appropriate. Shorter sampling frequencies are often used in the early phases of a study to better characterize time of travel. As an illustration, we often collect and change charcoal packets 1, 2, 4, and 7 days after dye injection. Subsequent sampling is then weekly.

Where convenient, the collected samplers should be briefly rinsed in the water being sampled. This is typically not necessary with well samples. The packets are shaken to remove excess water. Next, the packet (or packets) are placed in a plastic bag (Whirl-Pak bags are ideal). The bag is labelled on the outside with a permanent type felt marker pen. The notations include station name or number and the date and time of collection. Labels are <u>not</u> inserted inside the sample bags.

Collected samplers are kept in the dark to minimize algal growth on the charcoal prior to analysis work. We prefer (and in some studies require) that samples be placed on ice upon collection and that they be shipped refrigerated by overnight express. Our experience indicates that it is not essential for samplers to be maintained under refrigeration, yet maintaining them under refrigeration clearly minimizes some potential problems.

New charcoal samplers are routinely placed when used charcoal packets are collected. The last set of samplers placed at a stream or spring is commonly not collected.

Water samples are sometimes collected. They should be collected in either glass or plastic; the Ozark Underground Laboratory routinely uses 50 ml research grade polypropylene copolymer Perfector Scientific vials (Catalog Number 2650) for such water samples. The vials should be placed in the dark and refrigerated immediately after collection. They should be refrigerated until shipment.

When water or charcoal samplers are collected for shipment to the Ozark Underground Laboratory they should be shipped promptly. We receive good overnight and second day air service from both UPS and Fed Ex; Airborne Service is excessively slow, and the Postal Service does not provide next day service to us.

Each shipment of charcoal samplers or water samples must be accompanied by a sample tracking sheet. These sheets (which bear the title "Samples for Fluorescence Analysis") are provided by the Ozark Underground Laboratory and summarize placement and collection data. These sheets can be augmented by a client's chain of custody forms or any other relevant documentation.

Receipt of Samplers

Samplers shipped to the Ozark Underground Laboratory are refrigerated upon receipt. Prior to cleaning and analysis, samplers are assigned a laboratory identification number. All samples are logged in upon receipt.

Cleaning of Samplers

Samplers are cleaned by spraying them with jets of clean water. At the Laboratory we use unchlorinated water for the cleansing to minimize dye deterioration. Effective cleansing cannot generally be accomplished simply by washing in a conventional laboratory sink even if the sink is equipped with a spray unit. A garden hose with a pistol grip spray nozzle will provide effective packet cleansing.

The duration of packet washing depends upon the condition of the sampler. Very clean samplers may require less than a minute of washing; dirtier samplers may require several minutes of washing.

After washing, the packets are shaken to remove excess water. Next, the packets are cut open and the charcoal is emptied into an unused disposable plastic beaker. The beaker has been pre-labelled with the laboratory identification number. The charcoal is now ready for elution. The emptied fiberglass screen packet is discarded. At stations where two or more charcoal packets are collected, one is selected for analysis and the other is frozen and retained until the under of the study. In some studies the analysis protocol stipulates that 5% of the samples should be duplicates; in these cases the second charcoal packet is separately analyzed. Note that these are duplicate samples, not replicate samples since each packet is, of necessity, placed in a somewhat different location and is therefore exposed to somewhat different conditions.

Cleaning of Glassware

Most of our work uses disposal plastic containers. A small amount of glassware is occasionally used for dilution of particularly large dye concentrations in samples. Such glassware is carefully cleaned before re-use. Containers are rinsed several times in clean water. Glassware which may be contaminated with dyes is washed with detergent, and then again rinsed. Next, the glassware is soaked for one hour or more in a bleach and water solution. Upon removal from this soaking, the glassware is rinsed again and allowed to air dry. Glassware which comes in contact with dyes is dedicated to dye use.

Elution of the Charcoal

There are various eluting solutions which can be used for the recovery of tracer dyes. The solutions typically include an alcohol, some water, and a strong basic solution such as aqueous ammonia.

The standard elution solution now used at the Ozark Underground Laboratory is a mixture of 5% aqua ammonia and 95% isopropyl alcohol solution. The isopropyl alcohol is 70% alcohol and 30% water. The aqua ammonia solution is 29% ammonia. Preparation of eluting solutions uses dedicated glassware which is never used in contact with dyes or dye solutions.

The eluting solution we use will elute fluorescein, eosine, and rhodamine WT dyes. It is also suitable for separating fluorescein peaks from peaks of some naturally present materials found in some samplers.

15ml of the eluting solution is poured over the washed charcoal in a disposable sample beaker. The sample beaker is capped. The sample is allowed to stand for 60 minutes. After this time, the liquid is carefully poured off the charcoal into a new disposable beaker which has been appropriately labelled with the laboratory identification number. A few grains of charcoal may inadvertently pass into the second beaker; no attempt is made to remove these from the second sample beaker. After the pouring, a small amount of the elutant will remain in the initial sample beaker. After the transfer of the elutant to the second sample beaker, the contents of the first sample beaker (the eluted charcoal) are discarded.

Analysis on the Shimadzu RF-540 or RF-5000U

The Laboratory uses both a Shimadzu RF-540 and a Shimadzu RF-5000U Spectrofluorophotometer capable of syncronous scanning.

A sample of the elutant is withdrawn from the sample container using a disposable polyethylene pipette. Approximately 3 ml of the elutant is then placed in disposable rectangular polystyrene cuvette. The cuvette has a maximum capacity of 3.5 ml. The cuvette is designed for fluorometric analysis; all four sides and the bottom are clear. The spectral range of the cuvettes is 340 to 800 nm. The pipettes and cuvettes are discarded after one use.

The cuvette is then placed in the RF-540 or the RF-5000U. Both instruments are controlled by a programmable computer. Each instrument is capable of conducting substantial data analysis.

Our instruments are operated and maintained in accordance with the manufacturer's recommendations. On-site installation of the instruments and a training session on the instrument was provided by Delta Instrument Company, the dealer for Shimadzu Instruments.

Our typical analysis of an elutant sample where fluorescein, eosine, or rhodamine WT dyes may be present includes synchronous scanning of excitation

and emission spectra with a 17 nm separation between excitation and emission. The excitation scan is from 443 to 613 nm; the emission scan is from 460 to 630 nm. The emission fluorescence from the scan is plotted on a graph. The typical scan speed is "very fast;" typical sensitivity is "high."

The excitation slit for charcoal packet elutants is typically 5 nm, the emission slit is typically 2 nm on the RF-540 and 3 nm on the RF-5000U. This is because the RF-540 does not provide a 3 nm slit setting and the RF-5000U does not provide a 2 nm slit setting. For water samples, the excitation slit is typically 5 nm, and the emission slit is typically 10 nm.; the same settings are used for both instruments. The abscissa scale is typically set so as to keep the resulting chart to a size which can readily be photocopied. The ordinate scale selected is designed to provide good data resolution while not exceeding the upper limit of the resulting graph.

A plot of the synchronous scan for each sample is produced by the instrument; the plot shows emission fluorescence only. It is photocopied as a part of the final record. On the RF-540 the synchronous scan is subjected to computer peak picks; peaks are picked to the nearest 0.1 nm and to the nearest 0.1 units on the ordinate (magnitude) scale. On the RF-5000U, peaks consistent with the dyes being used are picked on the RF-5000U monitor and a vertical line is drawn indicating the peak emission fluorescence wavelength.

The original RF-540 plots are on pressure sensitive chart paper. During analysis, identification numbers and other notes are made on the original charts. All samples run on the RF-5000U are stored on disk and printed on normal typing paper with a laser printer.

Quantification

We routinely calculate the magnitude of fluorescence peaks for fluorescein, eosine, and rhodamine WT dyes. Dye quantities are expressed in parts per billion. On the RF-540 the dye concentrations are calculated by separating fluorescence peaks due to dyes from background fluorescence on the charts, and then measuring the height of the peak due to the dye. These heights are proportional to those obtained from standard solutions. On the RF-5000U the dye concentrations are calculated by separating fluorescence peaks due to dyes from background fluorescence on the charts, and then calculating the area within the fluorescence peak. This area is proportional to areas obtained from standard solutions.

We run dye concentration standards each day the machine is used. Four separate standards are used; the standard or standards appropriate for the analysis work being conducted is selected. All standards are based upon the as-sold weights of the dyes. The standards are as follows:

1) 10 ppb fluorescein and 100 ppb rhodamine WT in well water from the Jefferson City-Cotter Formation.

2) 10 ppb eosine in well water from the Jefferson City-Cotter Formation.

3) 10 ppb fluorescein and 100 ppb rhodamine WT in the standard elutant.

4) 10 ppb eosine in the standard elutant.

Quality Control

Laboratory blanks are run for every sample where the last two digits of the laboratory numbers are 00, 20, 40, 60, or 80. A charcoal packet is placed in a pumping well samplers and at least 25 gallons of water is passed through the sampler at a rate of about 2.5 gallons per minute. The sampler is then subjected to the same analytical protocol as all other samplers.

System functioning tests of the analytical instruments are conducted in accordance with the manufacturer's recommendations. At a minimum such tests are conducted quarterly.

Reports

Reports are provided in accordance with the needs of the client. At a minimum we provide copies of the RF-540 (and/or RF- 5000U) plots and a listing of stations and samples where dye was detected. The reports indicate dye concentrations.

Work at the Ozark Underground Laboratory is directed by Mr. Thomas Aley. Mr. Aley has 30 years of professional experience in hydrology and hydrogeology. He is certified as a Professional Hydrogeologist (Certificate #179) by the American Institute of Hydrology. Mr. Aley has 28 years of professional experience in groundwater tracing with fluorescent tracing agents.

CRITERIA FOR DETERMINATION OF POSITIVE DYE RECOVERIES

Table 1. RF-540 Spectrofluorophotometer. Normal emission wavelength ranges and detection limits for fluorescein, eosine, and Rhodamine WT dyes in water and elutant samples. The normal acceptable wavelength range equals the mean plus and minus two standard deviations; these values are from actual groundwater tracing studies previously conducted by the Ozark Underground Laboratory (OUL). Detection limits are based upon the as-sold weight of the dye normally used by the OUL.

Dye and Medium	Normal Acceptable Emission Wavelength Range (nm)	Detection Limit (ppb)
Fluorescein in Elutant	515.3 to 519.6	0.015
Fluorescein in Water	509.2 to 514.1	0.0005
Eosine in Elutant	538.0 to 544.6	0.03
Eosine in Water	534.0 to 542.8	0.001
Rhodamine WT in Elutant	567.2 to 574.4	0.235
Rhodamine WT in Water	574.5 to 579.9	0.01

Table 2. RF-5000U Spectrofluorophotometer. Normal emission wavelength ranges and detection limits for fluorescein, eosine, and Rhodamine WT dyes in water and elutant samples. The normal acceptable wavelength range equals the mean plus and minus two standard deviations; these values are from actual groundwater tracing studies previously conducted by the Ozark Underground Laboratory (OUL). Detection limits are based upon the as-sold weight of the dye normally used by the OUL.

Dye and Medium	Normal Acceptable Emission Wavelength Range (nm)	Detection Limit (ppb)
Fluorescein in Elutant	510.7 to 515.0	0.01
Fluorescein in Water	505.6 to 510.5	0.0005
Eosine in Elutant	533.0 to 539.6	0.02
Eosine in Water	529.6 to 538.4	0.001
Rhodamine WT in Elutant	561.7 to 568.9	0.155
Rhodamine WT in Water	569.4 to 574.8	0.007

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive Fluorescein Dye Recoveries in Elutants from Charcoal Samplers.

There is often some fluorescence background in the range of fluorescein dye present at some of the stations used in groundwater tracing studies. We routinely conduct background sampling prior to the introduction of any tracer dyes to characterize this background fluorescence and to identify the existence of any tracer dyes which may be present in the area. For charcoal packet elutant samples subjected to analysis on the RF-540 we routinely identify all fluorescence peaks with wavelengths between 508.5 and 525.5 nm. For charcoal packet elutant samples subjected to analysis on the RF-5000U we routinely identify all fluorescence peaks with wavelengths between 503.9 and 520.9 nm. The fact that a fluorescence peak is identified in our analytical results is not proof that it is fluorescein dye or that it is fluorescein dye from the trace of concern. The following 4 criteria are used to identify wavelength peaks which are deemed to be fluorescein dye recoveries from our tracing work.

Criterion 1. There must be at least one fluorescence peak at the station in question in the range of 515.3 to 519.6 nm for samples analyzed by the RF-540. The range must be 510.7 to 515.0 for samples analyzed by the RF-5000U.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. For the RF-540 the fluorescein detection limit in elutant samples is 0.015 ppb, thus this dye concentration limit equals 0.045 ppb. For the RF-5000U the fluorescein detection limit in elutant samples is 0.010 ppb, thus this dye concentration limit equals 0.030 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of fluorescein. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of fluorescein. In addition, there must be no other factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work.

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive Fluorescein Dye Recoveries in Water Samples.

There is commonly some fluorescence background in the general range of fluorescein dye at some sampling stations used in groundwater tracing studies. The following criteria are used to identify wavelength peaks which are deemed to be fluorescein dye in water.

Criterion 1. The associated charcoal samplers for the station should also contain fluorescein dye in accordance with the criteria listed above. This criteria may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work. For samples analyzed on the RF-540, the fluorescence peak should generally be in the range of 509.2 to 514.2. For samples analyzed on the RF-5000U, the fluorescence peak should generally be in the range of 505.6 to 510.5 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our fluorescein detection limit in water samples is 0.0005 ppb, thus this dye concentration limit equals 0.0015 ppb.

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive Eosine Dye Recoveries in Elutants from Charcoal Samplers.

There is generally little or no detectable fluorescence background in the general range of eosine dye encountered in most groundwater tracing studies. The following four criteria are used to identify wavelength peaks which are deemed to be eosine dye.

Criterion 1. There must be at least one fluorescence peak at the station in question in the range of 538.0 to 544.6 nm for samples analyzed by the RF-540. The range must be 533.0 to 539.6 nm for samples analyzed by the RF-5000U.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. For the RF-540 the eosine detection limit in elutant samples is 0.030 ppb, thus this dye concentration limit equals 0.090 ppb. For the RF-5000U the eosine detection limit in elutant samples is 0.020 ppb, thus this dye concentration limit equals 0.060 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of eosine. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of eosine. In addition, there must be no other factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work.

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive Eosine Dye Recoveries in Water Samples.

There is generally little or no detectable fluorescence background in the general range of eosine dye encountered in most groundwater tracing studies. The

following three criteria are used to identify wavelength peaks which are deemed to be eosine dye.

Criterion 1. The associated charcoal samplers for the station should also contain eosine dye in accordance with the criteria listed above. This criteria may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work. For samples analyzed on the RF-540, the fluorescence peak should generally be in the range of 534.0 to 542.8 nm. For samples analyzed on the RF-5000U, the fluorescence peak should generally be in the range of 529.6 to 538.4 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our eosine detection limit in water samples is 0.001 ppb, thus this dye concentration limit equals 0.003 ppb.

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive Rhodamine WT Dye Recoveries in Elutants from Charcoal Samplers.

There is generally little or no detectable fluorescence background in the general range of Rhodamine WT dye encountered in most groundwater tracing studies. The following four criteria are used to identify wavelength peaks which are deemed to be Rhodamine WT.

Criterion 1. For samples analyzed on the RF-540, there must be at least one fluorescence peak at the station in question in the range of 567.0 to 574.4 nm. For samples analyzed on the RF-5000U, there must be at least one fluorescence peak at the station in question in the range of 561.7 to 568.9 nm.

Criterion 2. The dye concentration associated with the Rhodamine WT peak must be at least 3 times the detection limit. For the RF-540 the detection limit in elutant samples is 0.235 ppb, thus this dye concentration limit equals 0.705 ppb. For the RF-5000U, the detection limit in elutant samples is 0.155 ppb, thus this dye concentration limit equals 0.465 ppb.

Criterion 3. The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

Criterion 4. The shape of the fluorescence peak must be typical of Rhodamine WT. In addition, there must be no other factors which suggest that the fluorescence peak may not be dye from the groundwater tracing work under investigation.

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive Rhodamine WT Dye Recoveries in Water Samples.

The following criteria are used to identify wavelength peaks which are deemed to be Rhodamine WT dye in water.

Criterion 1. The associated charcoal samplers for the station should also contain Rhodamine WT dye in accordance with the criteria listed above. This criteria may be waived if no charcoal sampler exists.

Criterion 2. There must be no factors which suggest that the fluorescence peak may not be Rhodamine WT dye from the tracing work under investigation. For samples analyzed with the RF-540, the fluorescence peak should generally be in the range of 574.5 to 579.9 nm. For samples analyzed with the RF-5000U, the fluorescence peak should generally be in the range of 569.4 to 574.8 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our Rhodamine WT detection limit in water samples is 0.007 ppb, thus this dye concentration limit equals 0.021 ppb.

EXAMPLES OF DYE ANALYSIS CHARTS

OUL Number C8073. Characoal sampler with no tracer dyes present

OUL Number C9225. Charcoal sampler with 26.6 ppb fluorescein dye present

OUL Number C9696. Water sample with 0.166 ppb fluorescein dye present

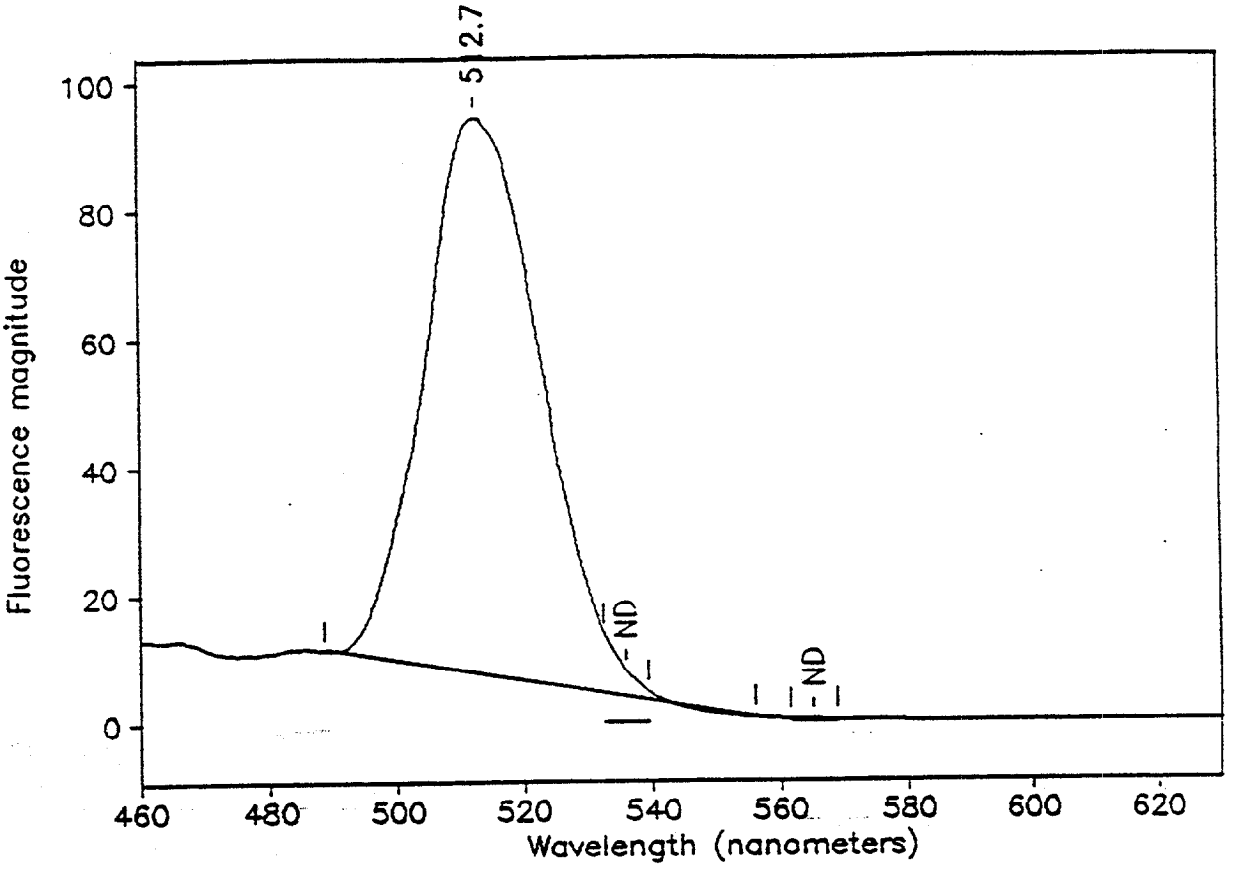
OUL Number C8846. Charcoal sampler with eosine dye present. Note that the sample has received a 50 fold dilution. As a result, the dye concentration is 14.5 ppb X 50 = 725 ppb eosine.

OUL Number C9201. Charcoal sampler with 1,090 ppb rhodamine WT dye present.

OUL Number C8821. Water sample with 7.10 ppb rhodamine WT dye present.

OUL Number D0161. Water sample with 0.535 ppb eosine and 1.62 ppb rhodamine WT present.

Ozark Underground Laboratory

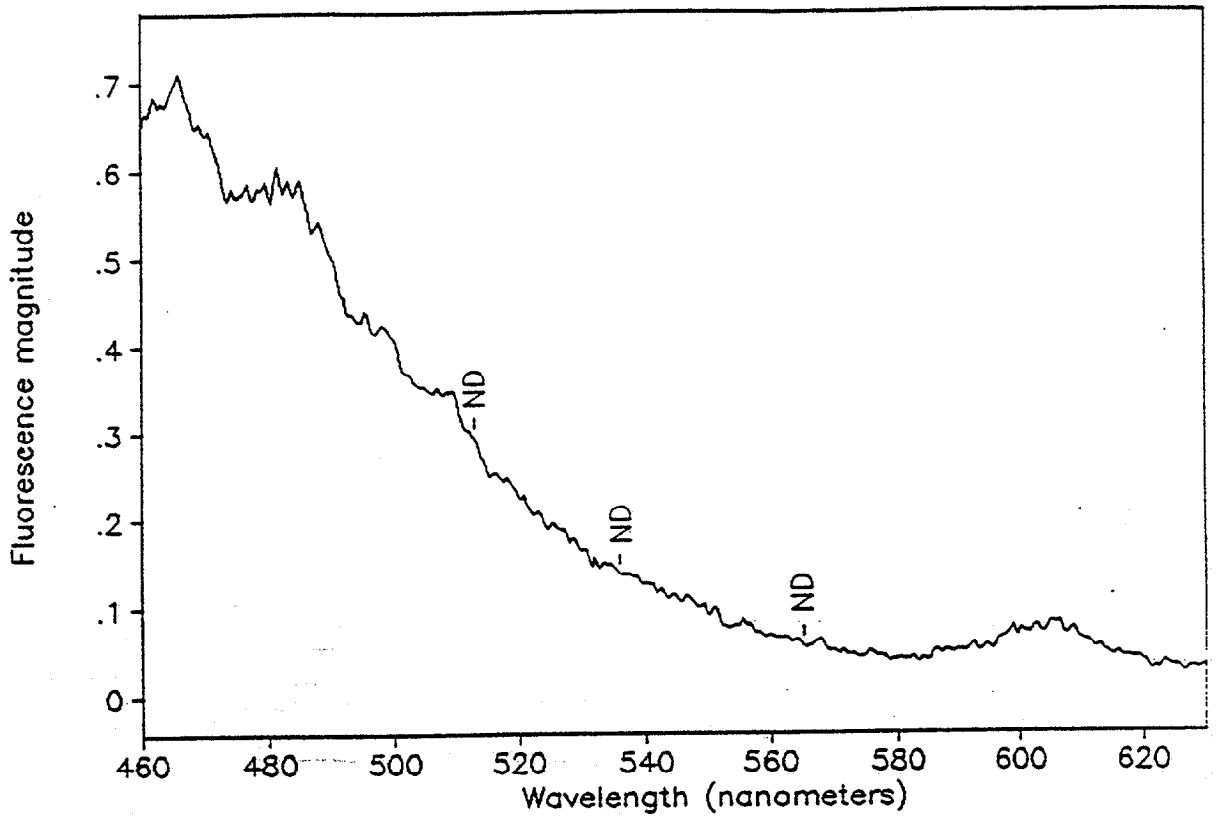


Station 325: Dozens Spring
OUL number: C9225 Type: Charcoal Analyzed: 6-28-1994
Date placed: 6-2-1994 Date recovered: 6-16-1994
Time placed: 1345 Time recovered: 1150

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.7	488.4	556.0	87.11	1860.12	0.05	26.6
535.9	532.6	539.2	0	0	0	ND
565.1	561.5	568.7	0	0	0	ND

Ozark Underground Laboratory

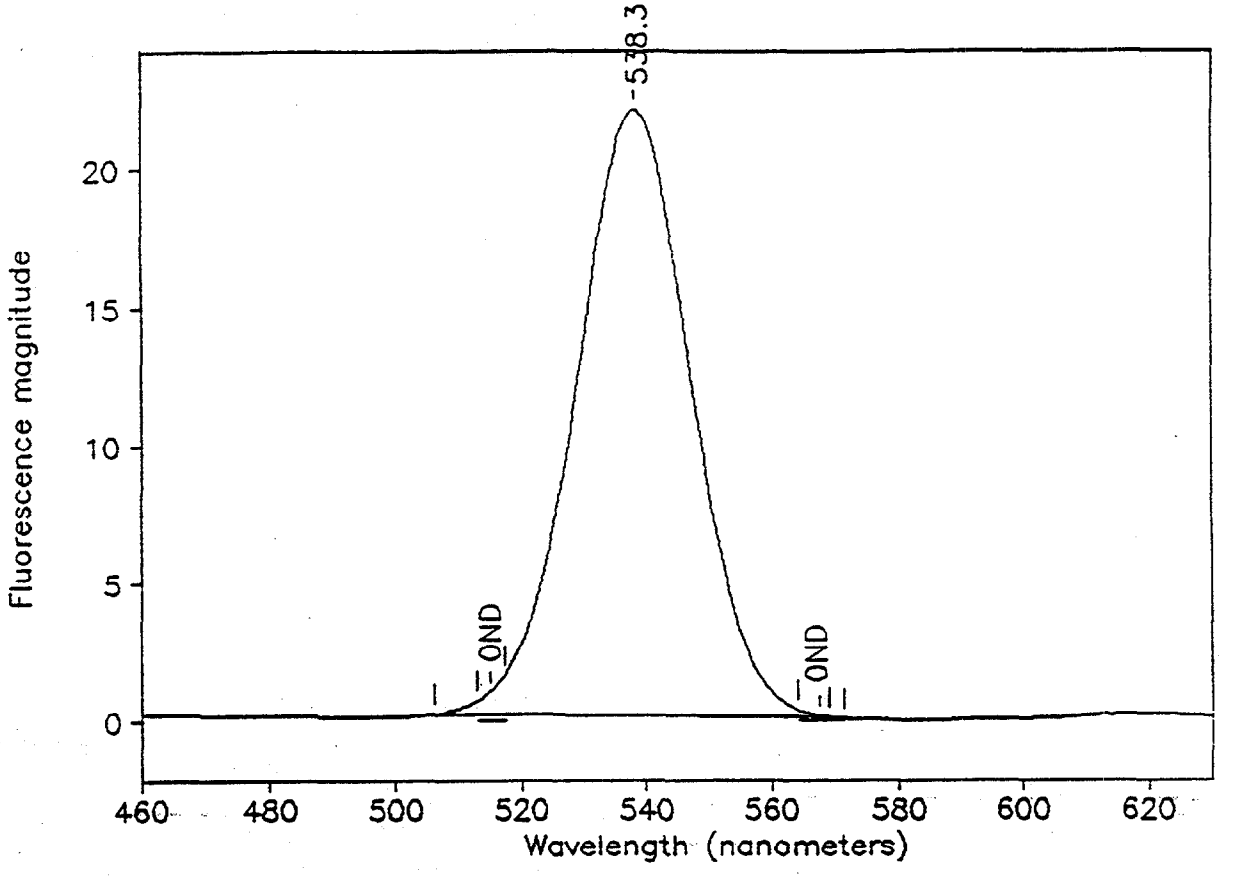


Station 201: Well EW-1
OUL number: C8073 Type: Charcoal Analyzed: 6-2-1994
Date placed: 5-17-1994 Date recovered: 5-23-1994
Time placed: 0910 Time recovered: 1653

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
512.8	510.7	515.0	0	0	0	ND
536.0	532.8	539.4	0	0	0	ND
565.2	561.7	568.9	0	0	0	ND

Ozark Underground Laboratory

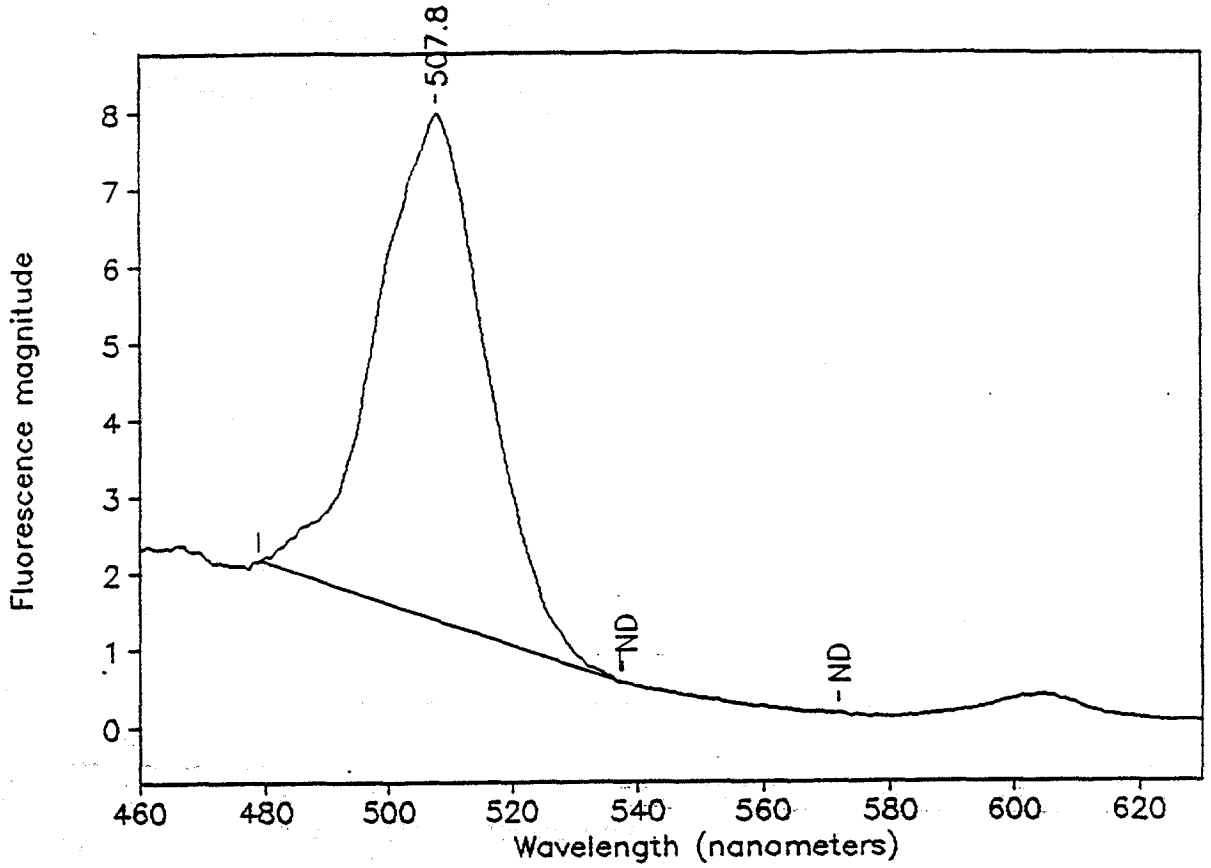


Station 242: Well 88-1
OUL number: C8846 Type: Charcoal Analyzed: 06-22-1994 Diluted 1:50
Date placed: 06-11-1994 Date recovered: 06-14-1994
Time placed: 1350 Time recovered: 1145

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
515.0	512.9	517.2	0	0	0	ND
538.3	506.1	569.0	21.93	469.41	0.05	14.5
567.6	564.1	571.3	0	0	0	ND

Ozark Underground Laboratory

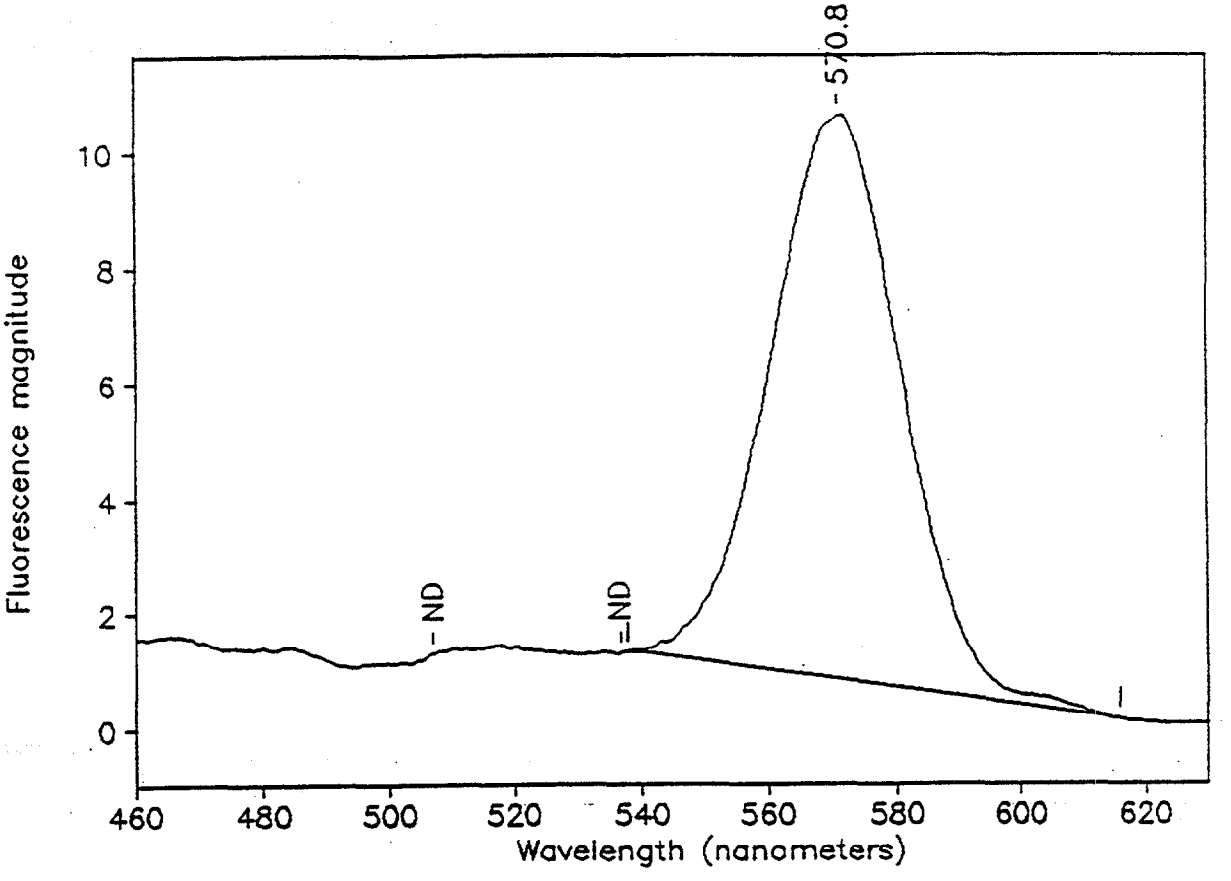


Station 325: Dozens Spring
OUL number: C9696 Type: Water Analyzed: 7-1-1994
Date collected: 6-22-1994 Time collected: 1500

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
507.8	479.0	537.2	6.60	138.79	0.05	0.166
537.6	529.7	544.7	0	0	0	ND
571.7	569.1	574.5	0	0	0	ND

Ozark Underground Laboratory

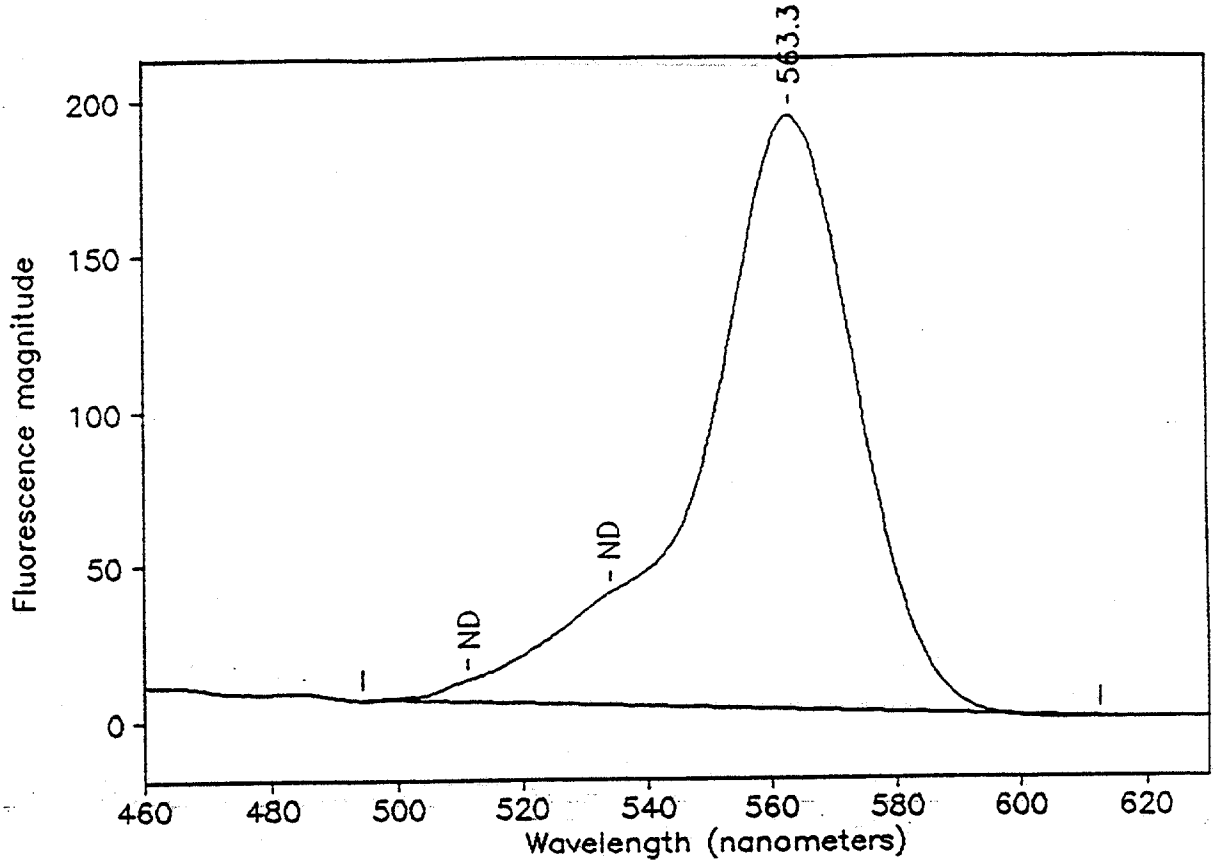


Station 299: Rowe Spring
OUL number: C8821 Type: Water Analyzed: 6-17-1994
Date collected: 6-11-1994 Time collected: 1530

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
506.9	504.5	509.4	0	0	0	ND
536.8	528.8	543.8	0	0	0	ND
570.8	537.9	615.9	9.82	235.96	0.04	7.1

Ozark Underground Laboratory

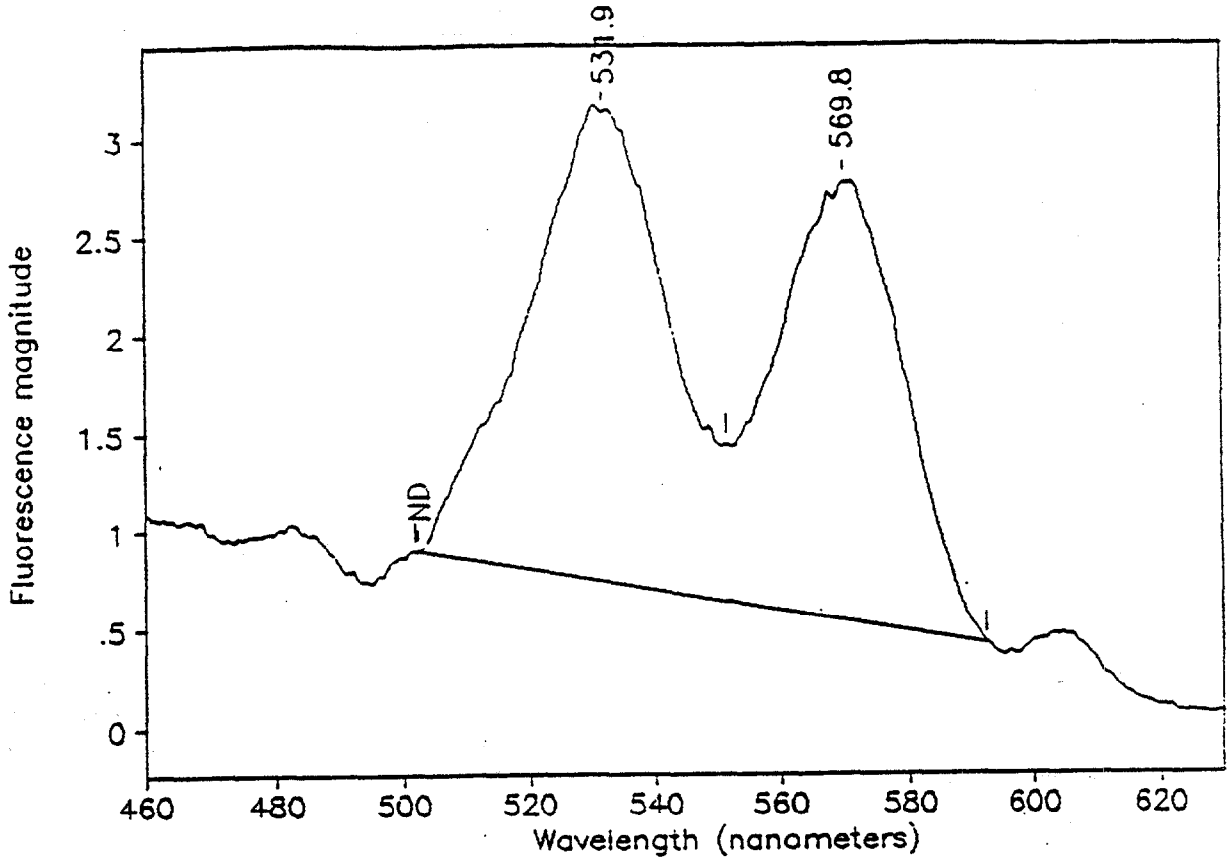


Station 299: Rowe Spring
OUL number: C9201 Type: Charcoal Analyzed: 6–28–1994
Date placed: 6–2–1994 Date recovered: 6–14–1994
Time placed: 1817 Time recovered: 1810

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
511.1	508.9	513.2	0	0	0	ND
534.2	530.9	537.5	0	0	0	ND
563.3	494.3	612.7	191.74	5658.41	0.03	1090

Ozark Underground Laboratory



Station 299: Rowe Spring
OUL number: D0161 Type: Water Analyzed: 7-11-1994
Date collected: 6-30-1994 Time collected: 0715

Peaks within normal range of tracer dyes:

Peak nm	Left X	Right X	Height	Area	H/A	Conc.
502.3	499.9	504.7	0	0	0	ND
531.9	501.8	551.4	2.40	64.49	0.04	0.535
569.8	551.4	592.3	2.24	52.25	0.04	1.62

APPENDIX B
LABORATORY RESOURCES, INC. QAPP

APPENDIX B

QAPP FOR VOCs ANALYSIS
LABORATORY RESORCES, INC.

Laboratory
Resources INC.
100 Hollister Road, Teterboro, NJ 07608, 201-288-3700

April 26, 1994

CORPORATE QUALITY ASSURANCE MANUAL

Prepared by: _____
Lee F. Cramer
Quality Assurance Director

Approved by: _____
August F. Percocco
President

TABLE OF CONTENTS

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Expiration date _____

SCOPE OF THE CORPORATE QUALITY ASSURANCE MANUAL

This Corporate Quality Assurance Manual contains general quality assurance information necessary to implement the Laboratory Resources, Inc. (LRI) Quality Assurance Program. All LRI management and analytical personnel are required to be familiar with the contents of this manual and are responsible for implementation of the Quality Assurance Program within their respective domains.

This manual does not, however, include all the information necessary for complete implementation of the Quality Assurance Program. Additional information and procedures are found in the following LRI manuals.

1. *Statement of Qualifications:* Information about LRI facilities, instrumentation, organization, and resumes for key personnel

2. *Sample Management Manual:* Procedures for sample management, including sample login, storage, and chain of custody

3. *Corporate Data Management Manual:* Procedures for data management, including data review, validation, deliverables generation, and compliance screening

4. *Standard Operating Procedures for Analyses:* Method-specific quality control requirements

Appendices

A	Math and Statistics	April 26, 1994
B	Audit Forms	April 26, 1994

QUALITY ASSURANCE OBJECTIVES

Prepared by: _____
Quality Assurance Director

Reviewed and approved by: _____
President

Results generated by environmental laboratory analyses are used to make decisions involving the expenditure of large amounts of time and money, and could even lead to the incarceration of responsible parties. It is imperative, therefore, that the data supplied by the laboratory are of known and measurable quality. The following quality assurance objectives ensure that data produced by Laboratory Resources, Inc., (LRI) will meet these requirements.

- Ensure compliance with certification requirements
- Ensure compliance with regulatory agencies
- Ensure compliance with contract requirements
- Ensure compliance with published methodologies
- Establish minimum standards consistent with industry practices

The procedures in this manual were developed to achieve these objectives and are binding on all LRI employees.

QUALITY ASSURANCE POLICY

Prepared by: _____
President

Reviewed and
implemented by: _____
Quality Assurance Director

The quality assurance policy of Laboratory Resources, Inc., is expressed in the following extract from the corporate Mission Statement.

> **Laboratory Resources will be known for its ability to consistently meet customer demands and for the high quality of analysis which becomes part of every analytical report it generates. Customers will be assured their expectations will be met on time, every time.**

INSTRUMENT SPECIFICATIONS

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

Prepurchase Requirements for All Instruments

1. The Technical Director shall review all proposed instrument purchases to ensure the following requirements are met:

   a. The instrument must meet all requirements of the analytical procedure(s) for which it will be used.
   b. The instrument must meet all requirements of this section of the Quality Assurance Manual.
   c. The proposed purchase shall be reviewed for compatibility with existing and proposed hardware and software, operator training requirements, and fit into the overall LRI business plan.

2. If the purchase includes software or involves interfacing with software, the proposal must be reviewed by the information systems analyst for compatibility and stability.

Analytical Balances

Analytical balances must have a minimum sensitivity of 0.1 mg (0.0001 g).

General Purpose Balances

General purpose balances must have a minimum sensitivity less than 1% of the target weight or 0.1 g, whichever is less.

Visual/Ultraviolet Spectrophotometers

Spectrophotometers must have a bandwidth of no more than 20 nm and a wavelength accuracy of ±2.5 nm.

pH Meters

pH meters must have an accuracy and readability of at least ±0.05 pH units within the pH range of 2.0 to 10.0.

Specific Ion Meters

Specific ion meters must have an accuracy and readability of at least ±5 mV.

Conductivity Meters

Electrodes for conductivity meters should have platinum electrodes; nonplatinum electrodes must be calibrated against a platinum electrode every six months.

Thermometers

1. All thermometers must be of the appropriate immersion type for the intended use.

2. Thermometers used for measurement of water sample temperature must be graduated in 0.1 °C increments.

3. Thermometers used for temperature monitoring of incubators must be graduated in 0.2 °C increments.

3. Thermometers used for temperature monitoring of refrigerators, and ovens must be graduated in 0.5 °C increments.

Temperature Control Equipment

1. Freezers used for storing organic standards or extracts must maintain a temperature not exceeding -10 °C.

2. Refrigerators used for storing standards or sample must maintain a temperature between 1 °C and 4.5 °C.

3. BOD incubators must maintain a temperature of 20.0 °C ±1.0 °C.

4. Total coliform incubators must maintain a temperature of 35.0 °C ±0.5 °C.

5. Fecal coliform incubators must maintain a temperature of 44.5 °C ±0.2 °C and a relative humidity of at least 90%.

INSTRUMENT MAINTENANCE

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

The chart on the following page lists minimum maintenance requirements for gas chromatography (GC), gas chromatography/mass spectrometry (GC/MS), inductively coupled argon plasma (ICP), graphite furnace atomic absorption (GFAA), and direct aspiration flame atomic absorption (FLAA) instruments. The maintenance requirements listed are general and minimal; any additional maintenance requirements listed in the manufacturers' manuals are also required and shall be included with these minimum requirements in the LRI instrument operation manual.

All scheduled and unscheduled maintenance activities shall be recorded in the instrument maintenance logbook. A separate instrument logbook is required for each instrument. The maintenance logbook must conform to the requirements of the Laboratory Notebook Procedures section of this manual and must be maintained in the same room as the instrument. The following information shall be recorded for each maintenance event:

Date and time maintenance was initiated
Triggering event
Description of maintenance performed
Date and time maintenance was completed
Initials of person who performed maintenance
Initials of supervisor if maintenance was not performed by supervisor

Minimum Maintenance Requirements

Instrument	Procedure	Frequency
GC/MS	Change pump oil	Annually or when oil becomes dark
	Change alumina beads	Annually or when beads become dark
	Change VOA packed columns	When ketone peaks broaden
	Change BNA capillary columns	When the column becomes too short to resolve N-nitrosodimethylamine or when response for acids can't be restored
	Change BNA glass wool liner	Daily or after analysis of "dirty" extract
	Change VOA trap	When gases and ketones lose sensitivity
	Clean VOA source	When BFB m/z 75 is too high
	Clean BNA source	When DFTPP m/z's 219 and 502 are too low or ion focus is greater than 30 V
GC	Change septa	Daily or every sequence, whichever occurs first
	Change injection liners	At the beginning of each sequence
	Clip column	Every two months; sooner if indicated by chromatography
	Change pesticide column	Every six months; sooner if indicated chromatography
	Change volatiles column	Annually; sooner if indicated by chromatography
	Change oxygen and moisture filters	Annually; sooner if indicated
	Change volatiles trap	Annually; sooner if indicated
	Clean ECD detector	Annually
	Change PID lamp	Every six months
ICP	Clean torch	Weekly
	Clean nebulizer end cap	Weekly
	Replace pump tubing	Weekly
	Clean filters	Weekly
	Clean autosampler	Weekly
	Adjust dark current and light current	Annually
Furnace	Clean contact rings	Daily
	Change contact rings	Monthly
	Clean quartz windows	Daily
	Check cooling water	Weekly
	Align optics	As required
Flame AA	Clean instrument	Weekly
	Align optics	As required

GLASSWARE SPECIFICATIONS

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

1. All glassware used for chemical analysis must be manufactured from borosilicate glass unless specified otherwise by the analytical procedure.

2. All volumetric glassware must be Class A. Volumetric glassware shall not be exposed to temperatures greater than 105 °C.

3. Dangerously broken, chipped, or cracked glassware shall not be used for analysis. This does not apply to broken tips on separatory funnels.

4. Before use, glassware must be cleaned according to the Glassware Cleaning procedure in this manual.

5. Mohr and similar measuring pipettes shall not be used for chemical analysis.

GLASSWARE CLEANING

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

This procedure is to be used for cleaning all glassware used for sample analysis.

ALL GLASSWARE MUST BE THOROUGHLY RINSED WITH TAP WATER BEFORE SUBMITTING TO BE CLEANED.

Glassware cleaning personnel must wear their lab coats, aprons, gloves, and safety glasses as required by laboratory safety policies.

Initial Cleaning of All Glassware

1. Thoroughly wash the glassware in tap water and phosphate-free detergent until the glassware is free of visible material. If this does not adequately clean the glassware, soak the glass in Chromerge™ solution for one hour.

2. Rinse the glassware at least four times with tap water to remove all detergent.

3. INORGANIC ANALYSIS GLASSWARE ONLY.
   a. Rinse the glassware with 20% nitric acid, taking care that all internal surfaces are rinsed.
   b. Rinse the glassware with tap water to remove all traces of the nitric acid.

4. Thoroughly rinse the glassware with reagent water (DI water).

5. Dry the glassware at 105 °C in the drying oven.

6. Return the glassware to the appropriate room.

Pre-analysis Rinsing for Organic Analysis Glassware

This procedure is to be performed by the analyst just prior to using the glassware for extraction analysis.

1. Rinse the glassware with acetone.

2. Rinse the glassware with the solvent to be used in the extraction or analysis procedure.

REAGENT SPECIFICATIONS

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

Reagent Water

Reagent water used for chemical or microbiological analyses must meet the following specifications. If any parameters are outside control limits the reagent water cannot be used until the reagent water supply is serviced. Bottled reagent water may be used if the laboratory reagent water supply is out of specifications provided the bottled water is tested and found to meet the requirements below.

Reagent Water for Chemical Analyses

1. Conductivity must be measured and recorded daily. The control limit for conductivity is 0.5 μmho/cm maximum (2 Megohm/cm minimum) at 25 °C.

2. pH must be measured and recorded daily. The pH must be between 5.5 and 7.5 units.

3. Specific chemical contamination is monitored by the analysis of method blanks. The reagent water supply must meet all method-specific requirements for method blank analysis.

Additional Monitoring for Microbiology Analyses

1. Residual chlorine must be analyzed and recorded monthly, and must be less than 0.1 mg/L.

2. Heterotrophic plate count must be analyzed and recorded monthly, and must be less than 1000 colonies/mL.

3. Cadmium, chromium, copper, lead, nickel, and zinc must be analyzed and recorded annually, and the concentration of each metal must be less than 50 μg/L.

4. All TAL metals must be analyzed and recorded annually, and the total concentration all metals must be less than 1000 μg/L.

5. Bacterial quality must be analyzed and recorded annually, and must be between 0.8 and 3.0.

Reagents

1. All inorganic reagents shall be ACS Reagent Grade or equivalent unless the analytical procedure specifies a different grade.

2. All organic reagents used to prepare standards shall be of the highest quality obtainable. Organic reagents used to prepare general reagent solutions shall be free of detectable interferences as demonstrated by the analysis of acceptable method blanks.

2. All organic solvents shall be free of detectable residue as demonstrated by the analysis of acceptable method blanks. For organic analyses contamination shall not be restricted to target analytes.

Other Supplies

1. Supplies such as filter paper, glass wool, and boiling beads must be free of contamination as demonstrated by the analysis of acceptable method blanks. For organic analyses, contamination shall not be restricted to target analytes.

2. Supplies such as those listed above used for preparation of organic extracts shall be prerinsed with the solvent(s) used in the extraction and concentration procedures.

3. All dessicants must contain moisture indicators.

REAGENT LABELLING, DOCUMENTATION, AND STORAGE

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

Purchased Chemicals and Solutions

1. The labels of all purchased chemicals and solutions must be marked with the date of receipt. If chemicals or solutions are purchased in case quantities, the date of receipt can be marked on the outer case at the time of receipt. As each container is removed from the case the date of receipt must be copied to the label on the container.

2. As new stock is received, rotate the old stock so that the oldest stock is most accessible (in fi or on top) and the newest stock is least accessible (in back or on bottom).

3. If an expiration date is not provided by the manufacturer, the following default dates shall be recorded on the label:

   a. Volatile organic solutions: one (1) month from the date opened
   b. Other solutions with organic solvents: three (3) months from the date opened
   c. Aqueous solutions: six (6) months from the date opened
   b. Neat chemicals: two (2) years from the date opened

4. If the storage requirements are not provided by the manufacturer, the following storage requirements apply:

   a. Aqueous solutions and neat chemicals: store at room temperature
   b. Solutions in organic solvents:
      1) Sealed ampules may be stored at room temperature until opened
      2) All other containers must be stored in a freezer (-15 °C)
      3) Volatile organic solutions shall not be stored with any other solutions

Solutions Prepared in the Laboratory

1. The following information shall be recorded on the storage container label for each standard:

   Name of solute
   Concentration
   Solvent (if other than water)
   Storage conditions
   Expiration date
   Lot number

2. The following information shall be recorded in the laboratory notebook or logbook:

   Date prepared
   Name of solute
   Weight of solute
   Solvent (if other than water)
   Final volume of solution
   Concentration of solute
   Lot number assigned to solution
   Name of preparer

3. The following expiration times apply to all solutions where the expiration time is not provided by the method:

   a. Volatile organic solutions: one (1) month
   b. Other solutions with organic solvents: three (3) months
   c. Aqueous solutions: six (6) months

4. If the storage requirements are not provided by the method, the following storage requirements apply:

   a. Solutions with organic solvents shall be stored in a freezer (-15 °C)
   b. Volatile organic solutions shall not be stored with any other solutions
   c. Aqueous solutions shall be stored at room temperature

STANDARDS LABELLING, DOCUMENTATION, AND STORAGE

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

Labelling

The following information shall be recorded on the storage container label for each standard:

- Name of solute
- Concentration
- Solvent (if other than water)
- Storage conditions
- Expiration date
- Lot number

Documentation

The following information shall be recorded in the standards preparation logbook:

- Date prepared
- Name of solute
- Manufacturer of solute
- Lot number of solute
- Weight of solute
- Purity of solute
- Corrected weight of solute if purity is less than 95%
- Solvent (if other than water)
- Manufacturer of solvent
- Lot number of solvent
- Final volume of solution
- Concentration of solute
- Lot number assigned to standard
- Name of preparer

Purchased Standards

1. All certificates and documentation pertaining to concentrations, purity, traceability, *etc.*, must be retained for a minimum of five (5) years.

2. The concentrations of uncertified standards must be verified using primary standards or secondary standards that can be traced to primary standards. Record verification data in the standards preparation logbook.

Storage

Expiration

The following expiration times apply where the expiration time is not provided by the manufacturer or method:

a. Volatile organic standards: one (1) month
b. Other standards with organic solvents: three (3) months
c. Aqueous standards: six (6) months

Storage Conditions

The following storage conditions apply where the storage conditions are not specified by the manufacturer or method:

a. Standards with organic solvents shall be stored in a freezer (-15 °C)
b. Volatile organic standards shall not be stored with any other standards
c. Aqueous metals standards and stable inorganic standards shall be stored at room temperature
d. Unstable aqueous standards shall be stored in a refrigerator (1 - 4 °C)

PERSONNEL REQUIREMENTS BY FUNCTION

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

The personnel requirements of this section merge the USEPA minimum requirements for certification and contract compliance. The requirements are listed by function; the actual titles will differ in certification and contract documents. If an individual performs more than one function, that individual must satisfy the requirements for all the functions he or she performs. In addition, many contracts require redundancy for most functions.

This is a guidance document and the requirements herein are not mandatory for LRI laboratories. However, all personnel employed by LRI must meet the minimum requirements for the states in whi the laboratory holds or seeks certification, as well as the requirements of any contracts in which th laboratory is engaged.

Industrial Hygiene Laboratory Director

Education

- Bachelor's degree in science

Experience

- Full certification by the American Board of Industrial Hygiene *or*
- Five years combined education beyond the bachelor's degree level and experience in an industrial hygiene laboratory

Industrial Hygiene Laboratory Manager

Education

- Bachelor's degree in science

Experience

- Full certification in chemical aspects by the American Board of Industrial Hygiene *or*
- Five years combined education beyond the bachelor's degree level and experience, at least half of which must be in industrial hygiene chemistry and the remainder in other analytical chemistry procedures

Environmental Laboratory Manager

Education

- Bachelor's degree in science
- If the degree is not in chemistry, chemistry courses equivalent to a minor in chemistry are required

Experience
- Two years of experience in an environmental laboratory

Quality Assurance Officer

Education
- Bachelor's degree in any scientific or engineering discipline

Experience
- Three years of laboratory experience
- One year of applied experience with quality assurance principles and practices in an environmental laboratory

Deliverables/Compliance Screening Supervisor

Experience
- Three years of experience in compliance screening and preparing data deliverables
- One year of supervisory experience in the preparation of data deliverables

Sample Custodian

Experience
- Three years of experience in sample receiving, login, chain-of-custody documentation, and internal transfer
- One year of related supervisory experience

GC/MS Supervisor

Education
- Bachelor's degree in any scientific or engineering discipline
- If the degree is not in chemistry, chemistry courses equivalent to a minor in chemistry are required
- A formal training course in GC/MS operation

Experience
- Three years of experience in interpretation of GC/MS data, and operation and maintenance of GC/MS systems
- One year of supervisory experience

Mass Spectral Interpretation Specialist

Education
- Bachelor's degree in any scientific or engineering discipline
- A formal training course in mass spectral interpretation

Experience
- Two years of experience in mass spectral interpretation

GC/MS Operator

Education
- Bachelor's degree in any scientific or engineering discipline *or* increase the experience requirement to three years
- A formal training course in GC/MS operation

Experience
- One year of experience in operation and maintenance of GC/MS systems

GC Supervisor

Education
- Bachelor's degree in any scientific or engineering discipline
- If the degree is not in chemistry, chemistry courses equivalent to a minor in chemistry are required

Experience
- Three years of experience in interpretation of GC data, and operation and maintenance of GC systems
- One year of supervisory experience

Pesticide Residue Specialist

Education
- Bachelor's degree in any scientific or engineering discipline

Experience
- Two years of experience in interpretation of GC data, and operation and maintenance of GC systems

GC Operator

Education
- Bachelor's degree in any scientific or engineering discipline *or* increase the experience requirement to three years
- If the degree is not in chemistry, chemistry courses equivalent to a minor in chemistry are required

Experience
- One year of experience in operation and maintenance of GC systems

Organic Extraction Supervisor

Education
- Bachelor's degree in any scientific or engineering discipline

Experience
- Three years of experience in organic sample preparation
- One year of supervisory experience

Extraction/Concentration Specialist

Education
- High school diploma
- A college level course in general chemistry

Experience
- One year of experience in extraction and concentration

Inorganic Chemistry Supervisor

Education
- Bachelor's degree in any scientific or engineering discipline

Experience
- Three years of laboratory experience
- One year of supervisory experience

ICP Spectroscopist

Education
- Bachelor's degree in any scientific or engineering discipline
- Specialized training in ICP spectroscopy

Experience
- Two years of experience with ICP analysis of environmental samples

ICP Operator

Education
- Bachelor's degree in any scientific or engineering discipline *or* increase the experience requirement to four years
- A short course in ICP

Experience
- One year of experience in operation and maintenance of ICP systems

AA Operator

Education
- Bachelor's degree in any scientific or engineering discipline *or* increase the experience requirement to four years

Experience
- One year of experience in operation and maintenance of ICP systems

Inorganic Sample Preparation Specialist

Education
- High school diploma
- A college level course in general chemistry

Experience
- Six months of experience in an analytical laboratory
- If microwave digestion is used, six months of experience in sample dissolution using microwave digestion techniques is required

Classical Chemistry Specialist

Education
- Bachelor's degree in any scientific or engineering discipline *or* increase the experience requirement to three years

Experience
- One year of experience in classical procedures

Microbiology Supervisor

Education

- Bachelor's degree in science
- A minimum of three credits in microbiology
- A minimum of two weeks formal training in microbiological analysis of drinking water

Experience

- One year of experience in microbiology

Microbiology Specialist

Education

- High school diploma or equivalent

Experience

- One year of experience in sanitary, water, milk, or food microbiology

Industrial Hygiene Analyst

Same as the requirements for the corresponding specialist above

Systems Manager

Education

- Bachelor's degree with four or more intermediate courses in programming, informati management, database systems management, or systems requirements analysis

Experience

- Three years of experience in data systems management or programming
- One year of experience with the software being used for data management and generation of laboratory reports

Programmer Analyst

Education

- Bachelor's degree with four or more intermediate courses in programming, information management, database systems management, or systems requirements analysis

Experience

- Two years of experience in systems or applications programming
- One year of experience with the software being used for data management and generation of laboratory reports

EMPLOYEE TRAINING

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

1. The manager of administration shall orient all new employees and provide each new employee with an Employee Packet. The new employee shall verify that he or she has reviewed the materials provided in the Employee Packet by signing the form provided at the end of the Employee Handbook.

2. Safety training is the responsibility of the laboratory safety officer.

   a. Each employee whose duties involve work in the laboratory or sample management areas shall receive a copy of the laboratory contingency plan, chemical hygiene plan, and chemical waste plan. This must be read and a statement signed by the employee indicating the plans were understood.

   b. The employee shall be given a tour of the laboratory, and all safety equipment and exit locations shall be pointed out.

   c. The employee shall receive the laboratory safety training course and then must complete the safety training examination and obtain a passing grade for each section of the test.

   d. In addition to the above, employees whose duties require access to the hazardous waste storage room shall receive respirator training and a respirator fit test.

3. Each new analyst shall receive orientation from his or her immediate supervisor. This orientation shall include location of the Quality Assurance Manual, SOPs, notebooks, and physical layout of the department. The new analyst shall be briefed on quality assurance practices, use of SOPs, and laboratory etiquette.

4. Each analyst must be qualified in each analysis he or she is to perform.

   a. The analyst will be provided with a copy of the LRI SOP for the procedure in which he or she is to be qualified. The analyst will be provided an opportunity to discuss the procedure with the department manager or a lead technician designated by the department

manager. When it is determined that the analyst understands the procedure and its quality control requirements, the analyst and department manager shall enter the analysis name and LRI SOP number in the Laboratory Training Log, and both the analyst and department manager shall sign and date the entry LRI SOP READ AND UNDERSTOOD.

b. The analyst will perform the analysis on blanks and laboratory control samples under the direct supervision of the department manager or lead technician. The analyst must demonstrate proficiency in the analysis of QC samples by obtaining results within the method specified laboratory control sample recovery limits. When acceptable proficiency has been demonstrated, the analyst and department manager shall sign and date the Laboratory Training Log entry PROFICIENCY DEMONSTRATED.

NOTE: Some analyses, such as ignitability, cannot be spiked. In these cases a standard reference material or previously analyzed sample must be analyzed.

APPROVED ANALYTICAL METHODS

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

Most environmental regulations stipulate the methods which must be used to perform analyses. This stipulation may take the form of a specific procedure, or a list of procedures or references from which an appropriate method may be chosen. In general, these procedures must be performed without modification. There are two exceptions:

1. If a regulatory agency modifies a published procedure, the modified procedure must be used for analyses performed within the agency's jurisdiction.

2. The stipulated procedure may not be appropriate for analysis of some samples. (This most often happens when a water method is specified for a nonaqueous sample.) When this occurs, the laboratory must, with the client's permission, work with the regulatory agency to determine a course of action. Possible actions are, in order of preference, to (1) use a different procedure, (2) use an agency modification, (3) use a laboratory modification, or (4) delete the analysis for the affected samples. When contacting the regulatory agency, the laboratory should be prepared to suggest appropriate alternate or modified procedures. The section in this manual on Alternate Methods should be consulted.

   NOTE: Any agreement reached between the laboratory, client, and regulatory agency must be confirmed in writing, and the written document must include the scope of the agreement. (The scope of the agreement may be specific samples only, a specific project, any project for this agency, *etc.*) The written confirmation must be included in all applicable hardcopy data packages.

Divisions of Laboratory Resources, Inc., (LRI) are restricted to methods from the following list. When selecting methods from this list, the laboratory must ensure that the method is appropriate for the regulation and the sample to be analyzed. Methods with an asterisk (*) appended are LRI modifications that must be approved before use.

Leachate Procedures

EP Toxicity Extraction by Federal Register/SW-846 method 1310
TCLP Bulk Extraction by Federal Register/SW-846 method 1311
TCLP Zero Headspace Extraction by Federal Register/SW-846 method 1311

Organic Extractions

Extraction Procedures

Herbicides by SM14 method 509B
Herbicides by EPA method 515.1
Herbicides by SW-846 method 8150
Pesticides and PCBs by ASP 12/91
Pesticides and PCBs by OLM02 (CLP)
Pesticides and PCBs by EPA method 505
Pesticides and PCBs by EPA method 508
Pesticides and PCBs by EPA method 608
Pesticides and PCBs by SW-846 method 3510
Pesticides and PCBs by SW-846 method 3520
Pesticides and PCBs by SW-846 method 3550
Pesticides and PCBs by SW-846 method 3580
Petroleum Hydrocarbons Fingerprint by SW-846 method 8015*
Phthalates by EPA method 606
Phthalates by SW-846 method 3510
Phthalates by SW-846 method 3520
Phthalates by SW-846 method 3550
Phthalates by SW-846 method 3580
Semivolatiles (BNA) by ASP 12/91
Semivolatiles (BNA) by OLM02 (CLP)
Semivolatiles (BNA) by EPA method 625
Semivolatiles (BNA) by SW-846 method 3510
Semivolatiles (BNA) by SW-846 method 3520
Semivolatiles (BNA) by SW-846 method 3550
Semivolatiles (BNA) by SW-846 method 3580

Cleanup Procedures

Acid/Base Partition Cleanup by 3650
Alumina Cleanup by 3611
Fluorisil Cleanup by EPA method 608/SW-846 method 3660
Gel Permeation Cleanup by SW-846 method 3640
Sulfur Cleanup by EPA method 608/SW-846 method 3660

Organic Analyses

Gas Chromatography Methods

Alcohols by SW-846 method 8015*
Herbicides by SM14 method 509B
Herbicides by EPA method 515.1
Herbicides by SW-846 method 8150
Pesticides and PCBs by ASP 12/91
Pesticides and PCBs by OLM02 (CLP)
Pesticides and PCBs by EPA method 505
Pesticides and PCBs by EPA method 508
Pesticides and PCBs by EPA method 608
Pesticides and PCBs by SW-846 method 8080
Petroleum Hydrocarbons Fingerprint by SW-846 method 8015*
Petroleum Hydrocarbons by ASTM method D3328
Phthalates by EPA method 606
Phthalates by SW-846 method 8060
Volatiles by EPA method 501.1
Volatiles by EPA method 502.2
Volatiles by EPA method 503.1
Volatiles by EPA method 504
Volatiles by EPA method 601
Volatiles by EPA methods 601 + 602
Volatiles by EPA method 602
Volatiles by EPA method 603
Volatiles by SW-846 method 8010
Volatiles by SW-846 methods 8010 + 8020
Volatiles by SW-846 method 8020
Volatiles by SW-846 method 8021

Gas Chromatography/Mass Spectrometry Methods

Semivolatiles (BNA) by ASP 12/91
Semivolatiles (BNA) by OLM02 (CLP)
Semivolatiles (BNA) by EPA method 625
Semivolatiles (BNA) by SW-846 method 8270
Volatiles by ASP 12/91
Volatiles by OLM02 (CLP)
Volatiles by EPA method 524.2
Volatiles by EPA method 624
Volatiles by SW-846 method 8240
Volatiles by SW-846 method 8260

Metals Preparation and Analyses

ICP Methods

General Metals by ICP, ASP 12/91
General Metals by ILM03 (CLP)
General Metals by EPA method 200.7
General Metals by SW-846 method 6010
General Metals in Sludge by NJDEPE method DEP 100

Furnace Methods

Aluminum by EPA method 202.2
Antimony by EPA method 204.2
Arsenic by EPA method 206.2
Arsenic by SW-846 method 7060
Arsenic by ASP 12/91
Arsenic by ILM03 (CLP)
Arsenic in Sludge by NJDEPE method DEP 100
Antimony by SW-846 method 7041
Barium by EPA method 208.2
Beryllium by EPA method 210.2
Beryllium by SW-846 method 7091
Cadmium by ASP 12/91
Cadmium by ILM03 (CLP)
Cadmium by EPA method 213.2
Cadmium by SW-846 method 7131
Chromium by EPA method 218.2
Chromium by SW-846 method 7191
Copper by EPA method 220.2
Iron by EPA method 236.2
Lead by ASP 12/91
Lead by ILM03 (CLP)
Lead by EPA method 239.2
Lead by SW-846 method 7421
Manganese by EPA method 243.2
Molybdenum by EPA method 246.2
Molybdenum by SW-846 method 7481
Nickel by EPA method 249.2
Selenium by ASP 12/91
Selenium by ILM03 (CLP)
Selenium by EPA method 270.2
Selenium by SW-846 method 7740
Silver by EPA method 272.2
Thallium by ASP 12/91
Thallium by ILM03 (CLP)

Thallium by EPA method 279.2
Thallium by SW-846 method 7841
Tin by EPA method 282.2
Titanium by EPA method 283.2
Vanadium by EPA method 286.2
Vanadium by SW-846 method 7911
Zinc by EPA method 289.2

Flame Methods

Aluminum by SW-846 method 7020
Barium by EPA method 208.1
Barium by SW-846 method 7080
Beryllium by EPA method 210.1
Beryllium by SW-846 method 7090
Cadmium by EPA method 213.1
Cadmium by SW-846 method 7130
Calcium by EPA method 215.1
Calcium by SW-846 method 7140
Chromium by EPA method 218.1
Chromium by SW-846 method 7190
Copper by EPA method 220.1
Copper by SW-846 method 7210
Iron by EPA method 236.1
Iron by SW-846 method 7380
Lead by EPA method 239.1
Lead by SW-846 method 7420
Iron by EPA method 236.1
Iron by SW-846 method 7380
Lead by EPA method 239.1
Lead by SW-846 method 7420
Magnesium by EPA method 242.1
Magnesium by SW-846 method 7450
Manganese by EPA method 243.1
Manganese by SW-846 method 7460
Nickel by EPA method 249.1
Nickel by SW-846 method 7520
Potassium by EPA method 258.1
Potassium by SW-846 method 7610
Silver by EPA method 272.1
Silver by SW-846 method 7760
Sodium by EPA method 273.1
Sodium by SW-846 method 7770
Thallium by EPA method 279.1
Thallium by SW-846 method 7840

Zinc by EPA method 289.1
Zinc by SW-846 method 7950

Cold Vapor Methods

Mercury by ASP 12/91
Mercury by ILM03 (CLP)
Mercury by EPA method 245.1
Mercury by SW-846 method 7470
Mercury by SW-846 method 7471

General Chemistry

Methods for Water and Aqueous Preparations

Acidity by EPA method 305.1
Alkalinity by EPA method 310.1
Alkalinity, Bicarbonate, by SM16 method 403
Alkalinity, Phenolphthalein Endpoint, by EPA method 310.1
Ammonia Nitrogen by EPA method 350.1
Ammonia Nitrogen by EPA method 350.3
Ammonia Nitrogen with Distillation by EPA method 350.2
Biochemical Oxygen Demand (BOD), 5-Day, by SM16 method 507
Biochemical Oxygen Demand (BOD), 20-Day, by SM16 method 507
Biochemical Oxygen Demand, Carbonaceous (CBOD), 5-Day, by SM16 method 507
Biochemical Oxygen Demand, Carbonaceous (CBOD), 20-Day, by SM16 method 507
Biochemical Oxygen Demand, Nitrogenous (NBOD), 5-Day, by SM16 method 507
Biochemical Oxygen Demand, Nitrogenous (NBOD), 20-Day, by SM16 method 507
Bromide by EPA method 300.0
Carbon, Total Organic (TOC) by SW-846 method 9060
Chemical Oxygen Demand (COD) by HACH method 8000
Chloride by EPA method 325.3
Chlorine Demand by SM16 method 409A
Chlorine, Residual, by EPA method 330.5
Chromium, Hexavalent, by SM16 method 312B
Chromium, Hexavalent, by SW-846 method 7196
Color by EPA method 110.2
Conductance, Specific, by EPA method 120.1/SW-846 method 9050
Cyanide by ASP 12/91
Cyanide by ILM03 (CLP)
Cyanide, Amenable, by EPA method 335.1/SW-846 method 9010
Cyanide, Free, by EPA method 335.2
Cyanide, Total by EPA method 335.2/SW-846 method 9010
Fluoride by EPA method 340.2
Formaldehyde by AOAC method 20.062
Halides, Total Organic (TOX) by SW-846 method 9020

Hardness by SM16 method 314A
Hardness by SM16 method 314B
Kjeldahl Nitrogen, Total (TKN) by EPA method 351.3
Langelier Index by SM16 method 203
Nitrate Nitrogen by EPA method 352.1
Nitrate Nitrogen by Calculation (nitrate-nitrite *minus* nitrite)
Nitrate-Nitrite Nitrogen by EPA method 353.1
Nitrite Nitrogen by EPA method 354.1
Odor (TON) by EPA method 140.1
Oil & Grease by EPA method 413.1/SW-846 method 9070
Oil & Grease by EPA method 413.2
Organic Nitrogen by Calculation (TKN *minus* Ammonia-N)
Orthophosphate Phosphorus by EPA method 365.2
Oxygen, Dissolved (DO) by SM16 method 421B
Oxygen, Dissolved (DO) by EPA method 360.2
Petroleum Hydrocarbons by EPA method 418.1
pH by EPA method 150.1/SW-846 method 9040
Phenolics by EPA method 420.1
Phosphorus by EPA method 365.2
Salinity by SM16 method 210
Solids, Settleable by EPA method 160.5
Solids, Total (TS) by EPA method 160.3
Solids, Total Dissolved (TDS) by EPA method 160.1
Solids, Total Fixed or Mineral (TFS or TMS) or by EPA method 160.4
Solids, Total Fixed or Mineral Suspended (TFSS or TMSS) by EPA methods 160.2 and 160.4
Solids, Total Suspended (TSS) by EPA method 160.2
Solids, Total Volatile (TVS) by EPA method 160.4
Solids, Total Volatile Suspended (TVSS) by EPA methods 160.2 and 160.4
Sulfate by EPA method 375.4/SW-846 method 9038
Sulfide by EPA method 376.1
Sulfide by EPA method 376.2
Sulfide by SW-846 method 9030
Sulfite by EPA method 377.1
Surfactants (mbas) by SM16 method 512B
Tannin by SM16 method 513
Turbidity by EPA method 180.1

Methods for Sludge

NOTE: The methods in this category are specific to sludge analysis. Most of the methods listed for soils and sediments can also be used to analyze sludges.

Ash Content by NJDEPE method DEP 013

Oil & Grease by NJDEPE method DEP 036
pH by NJDEPE method DEP 010
Phenols by NJDEPE method DEP 032
Residue, Total by NJDEPE method DEP 012
Residue, Total Volatile by NJDEPE method DEP 013
Solids, Total (TS) by 209F
Solids, Total Fixed (TFS) by 209F
Solids, Total Volatile (TVS) by 209F
Specific Gravity by SM16 method 213E

Methods for Soil, Sediment, and Other Fine Particulates

CAUTION: Care must be exercised when analyzing powdered chemicals or suspected powdered chemicals using these methods. Consult your supervisor before proceding.

Acidity by EPA method 305.1*
Alkalinity by EPA method 310.1*
Ammonia Nitrogen with Distillation by EPA method 350.2*
Biochemical Oxygen Demand (BOD) 5-Day by SM16 method 507*
Chemical Oxygen Demand (COD) by HACH method 8000*
Chloride by SW-846 method 9252*
Chromium, Hexavalent, Digestion by SW-846 method 3060 (2^{ND} edition)
Chromium, Hexavalent, Digestion by SW-846 method 3060, NJDEPE modification
Cyanide by ASP 12/91
Cyanide by ILM03 (CLP)
Cyanide by SW-846 method 9010*
Formaldehyde by AOAC method 20.062*
Moisture for Dry Weight Adjustment
Nitrate (as N) by SW-846 method 9200*
Nitrate-Nitrite Nitrogen by EPA method 353.1*
Nitrite Nitrogen by EPA method 354.1*
Oil & Grease by SW-846 method 9071
Orthophosphate by EPA method 365.2*
Petroleum Hydrocarbons by EPA method 418.1, NJDEPE modification
pH in Soil by SW-846 method 9045
Phosphorus by EPA method 365.2*
Sulfite by EPA method 377.1*
Surfactants (MBAS) by SM16 method 512B*
Water by Dean Stark (ASTM D95)

Methods for General Nonaqueous Matrices

Ash by ASTM D482
Chlorine by ASTM method D808
Heat of Combustion by ASTM D240

Ignitability by SW-846 method 1010/ASTM method D93
Paint Filter Liquids Test by SW-846 method 9095
Sulfur by ASTM D129

Methods for Waste Characterization

CAUTION: Care must be exercised when analyzing samples for waste characterization. Wear appropriate safety gear and perform all analyses in an approved fume hood.

NOTE: The methods in this category are specific to waste characterization analyses. Methods in other categories may also be required for complete characterization.

Bulk Density
Cyanide Spot Test
Flammability
Hexane Solubility
Odor
Oxidizer Spot Test
Peroxide Spot Test
pH
Physical State
Redox Potential Spot Test
Sulfide Spot Test
Viscosity
Water Solubility/Reactivity

Microbiology

Bacteriological Suitability by SM18 method 9020B
Coliforms, Fecal (MF) by EPA p. 124
Coliforms, Fecal (MPN) by EPA p.132
Coliforms, Presence or Absence
Coliforms, Total (MF) by SM18 method 9132
Coliforms, Total (MF) by EPA p. 108
Coliforms, Total (MF) Chlorine Present EPA p. 111
Coliforms, Total (MPN) by EPA p.114
Fecal Streptococci by EPA p.136
Heterotrophic Plate Count by SM16 method 907
Microscopic Identification (Algae Scan)

Industrial Hygiene

General

Acetic Acid by NIOSH method 1603
Alkaline Dusts by NIOSH method 7401
Ammonia by NIOSH method S205
Ammonia by NIOSH method 5347
Carbon Black by NIOSH method 5000
Chromic Acid by NIOSH method 7600
Nuisance Dust by NIOSH method 0500
Fluoride by NIOSH method 7902
Formaldehyde by NIOSH method 3500
Hydrogen Sulfide by NIOSH method S4
MDI by NIOSH method 142
NO/NO_2 Profile by NIOSH method S321
Ozone by NIOSH method S8
Phenol by NIOSH method 3502
Respirator Dust by NIOSH method 0600
Sulfur Dioxide by NIOSH method S308
Sulfuric Acid by NIOSH method S174
TDI by NIOSH method 141

Asbestos

Asbestos, Bulk by EPA method 40 CFR 763, Appendix A
Asbestos, Fiber in Air by NIOSH method 7400A

Metals

Aluminum by NIOSH method 7013
Arsenic by NIOSH method 7900
Barium by NIOSH method 7055
Beryllium by NIOSH method 7102
Cadmium by NIOSH method 7048
Chromium by NIOSH method 7024
Chromium, Hexavalent by NIOSH method 7600
Cobalt by NIOSH method 7027
Copper by NIOSH method 7029
Lead by NIOSH method 7082
Lead in Paint Chips by ASTM ZAP method
Mercury by NIOSH method 6009
Metals by NIOSH method 173
Metals by NIOSH method 7300
Metals by OSHA method ID-121
Selenium by NIOSH method 190
Tin, Organic by Elf Atochem AA-64

Vanadium by NIOSH method S388
Zinc by NIOSH method 7030

Organics

Acetate Solvents by NIOSH method 1450
Acrolein by NIOSH P&CAM method 118
Alcohols by NIOSH method 1400
Aliphatic Solvents by NIOSH method 1500
Aromatic Solvents by NIOSH method 1501
Cellosolve Solvents by NIOSH method 1403:
Chlorinated Solvents by NIOSH method 1003:
Ethyl Acetate by NIOSH method S49
Ethylene Glycol by NIOSH method 5500
Heptachlor by NIOSH method S287
Isobutanol by NIOSH method 1401
Isopropyl Acetate by NIOSH method S50
Ketones by NIOSH method 1300
Ketones by NIOSH method 2500
Methanol by NIOSH method 2000
Methylene Chloride by NIOSH method 1005
PCBs by NIOSH method 5503
Pesticides by NIOSH method 5510
Petroleum-based Products by NIOSH method 1550
Pesticides by NIOSH method 5510
Pesticides by OSHA method 57
Polyaromatic Hydrocarbons (PAH) by NIOSH method 5515
Solvent Profile by OSHA method 7
Tetrachloroethene by NIOSH method 5335
Trichloroethene by NIOSH method 1022
Turpentine by NIOSH method 1551

Air Toxics

Volatile Organic Compounds by EPA TO-1
Volatile Organic Compounds by EPA TO-2
Chlorinated Pesticides and PCBs by EPA TO-4
Polynuclear Aromatic Hydrocarbons by EPA TO-13

Field Services

Explosivity by Field meter
Temperature, Water by SM16 method 212

QUANTITATION LIMITS

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

The quantitation limit for a procedure is the smallest concentration of analyte that can be measured with known confidence. The following procedure for calculating method detection limits and quantitation limits is derived from 40 CFR 136 Appendix B.

Method Detection Limit (MDL)

The MDL procedure that follows is taken from 40 CFR 136 Appendix B. This procedure is define "the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero." The results obtained are specific to the sample matrix and analytical system.

1. If the approximate MDL is known, or an accurate estimate can be made, proceed to step 2. Otherwise, obtain an initial estimate of the method detection limit as follows.

   Prepare a synthetic sample (see step 2) with target analyte concentration equivalent to the lowest standard used for calibration. For procedures that do not use a calibration curve, such as gravimetric or titrimetric procedures, prepare the synthetic samples at a concentration equivalent to 5 times the lowest theoretical result obtainable. Analyze 3 aliquots of the synthetic sample and calculate the standard deviation. The initial estimate of the method detection limit is 3 times the standard deviation.

2. Prepare a synthetic sample with the target analyte concentration at 3 times the estimated method detection limit. The sample must be large enough to provide at least the number of aliquots required in step 3. Alternatively, individual samples may be prepared, but this will introduce an extra variable into the procedure.

   Prepare the synthetic sample by adding an appropriate amount of target analyte to reagent water and mixing thoroughly. Retain a portion of the reagent water used to be analyzed as method blanks.

3. Analyze 7 aliquots of the synthetic sample. The 7 aliquots should be processed on separate occasions and each analyst certified in the analysis should analyze a proportionate share of the

aliquots. If more than one instrument is used for analysis, all 7 samples must be analyzed on each instrument. Each sample aliquot must be carried through the entire analytical procedure exactly as required by the LRI SOP or other procedural reference.

4. Calculate the analyte concentration for each sample using the formula(s) in the calculations section of the procedure. If the procedure requires that the reagent blank be subtracted, a separate reagent blank must be analyzed with each sample aliquot, and the average blank measurement subtracted from each sample measurement.

5. Calculate the standard deviation and method detection limit as described below. If the concentration of the synthetic sample used is more than 5 times the calculated method detection limit, repeat this procedure using a reduced concentration.

6. Use the equations from Appendix A of this manual to calculate the standard deviation, then calculate the MDL as follows:

$$MDL = 3.143s$$

where MDL = method detection limit in the same units as sample concentrations
s = standard deviation of 7 analyte concentration measurements

Report results to the same number of significant digits as used to report sample concentrations.

7. Calculate the upper control limit at 95% confidence from two or more studies as follows:

$$UCL_{pooled} = k\sqrt{\frac{\Sigma s_i^2}{n}}$$

where UCL_{pooled} = upper control limit calculated from pooled MDL study data
k = factor from Table 7B-1 corresponding to the number of studies
s_i = standard deviation of 7 analyte concentration measurements from study i
n = number of studies

Report results to the same number of significant digits as used to report sample concentrations.

8. The UCL_{pooled} shall be the lowest value reported as a quantitation limit by LRI laboratories.

Table 7B-1
Values of *k* for pooled MDL data

Number of Studies	Total Number of Sample Analyses	*k*
1	7	6.920
2	14	4.426
3	21	3.775
4	28	3.467
5	35	3.285
6	42	3.162
7	49	3.074
8	56	3.007
9	63	2.953
10	70	2.910
11	77	2.874
12	84	2.843
13	91	2.817
14	98	2.79
15	105	2.77
16	112	2.755
17	119	2.739
18	126	2.724
19	133	2.711
20	140	2.699

The values of *k* for this table were calculated as the Student's t value at 99% confidence times the chi square over degrees of freedom at 95% confidence in QuattroPro as follows:

@TINV(0.02,f)* @SQRT(f/@CHIINV(0.975,f))

where f = degrees of freedom.

PREPARATION, REVIEW, REVISION, AND DISTRIBUTION OF SOPs

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

The procedures in this section provide the means by which standard operating procedures (SOPs) are prepared, reviewed, revised, approved, distributed, maintained, and archived. In the text that follows, "SOP" refers to a document describing a single procedure, such as this procedure, and "SOP manual" or "manual" refers to a collection of related procedures within a single binding, such as the Quality Assurance Manual.

Preparation

1. The following three items must be included as the first pages to appear in each SOP manual.

   a. The title page shall contain the title of the SOP manual and the signature of the person(s) responsible for overview of the activities addressed in the manual.

   b. The Distribution Control Page shall contain a brief description of the document control policy and a statement declaring whether the copy is controlled. For controlled copies, the following additional information shall be entered in blue ink:

      1) Controlled copy number
      2) Name and affiliation of person to whom the manual is issued
      3) Signature of the corporate document control officer
      4) Expiration date

   c. The table of contents shall contain the SOP number, title, and latest revision date for each SOP included in the manual. The table of contents serves as the revision control document and therefore must be revised for every revision of the manual.

2. Each page of the SOP must have a document control header in the upper right corner of each page with the following four lines.

   Title of SOP manual — Revision Date
   SOP number — Page *n* of *total pages*

3. The following items must appear immediately following the document control header on the first page of each SOP:

   a. Title of the SOP.
   b. Signature of the person with primary responsibility for writing the SOP ("Prepared by").
   c. Signature of the person with primary responsibility for overview of the activities addressed by the SOP, if different from the writer (Reviewed and approved by).
   d. Signature of the person directly responsible for implementing the procedure, if different from the those above (Reviewed and implemented by).

4. The remainder of each SOP will vary depending on its function. The following subsections present minimum standards for each type of SOP.

Analytical Procedures

   a. References: Include the full name, volume, edition, publication date, and method number for each reference.
   b. Applicability: List the target analytes, matrices, and regulations for which the method is applicable.
   c. Important Notes: Information, warnings, and cautions that should be known to anyone performing the procedure.
   d. Procedure: Step-by-step instructions for performing the procedure.
   e. Quality Control: List all quality control requirements for method validation, instrument performance check, initial and continuing calibration, method blanks, duplicate analyses, matrix spike analyses, laboratory control sample analyses, and all method-specific quality control, including control limits and corrective action.
   f. Calculations: Formulae for all calculations required to obtain reported values, including quality control results, in the correct units. Include the number of significant digits for each result.
   g. Reagents: List all neat chemicals with specifications; list solutions with detailed and specific preparation instructions. Include storage conditions and expiration times for all solutions.

Sample Management Procedures

   a. Include the title of the person(s) responsible for performing each procedure.

Review, Revision, and Approval

1. Each SOP should also be submitted in draft for comment to those who are familiar with its content and/or those who will use it. The request for comment must be accompanied by a memo

indicating a cutoff date, which should not be less than 14 days nor more than 30 days. After review of the comments and modification of the procedure where necessary, the SOP must be reviewed and approved by the person responsible for overview of the activities addressed by the SOP.

2. Revisions of an SOP must go through all the review and approval procedures required for the initial version.

Distribution and Maintenance

1. SOP manuals are distributed as controlled or uncontrolled documents. The distribution of controlled documents must be recorded to ensure that they are updated when new or revised SOPs are released. All SOP manuals for use within Laboratory Resources, Inc., must be controlled documents. In addition, SOP manuals submitted to regulatory agencies in support of certification or submitted to clients for contract compliance must be controlled for the duration of the certification or contract.

2. The corporate document control officer (CDCO) shall be responsible for maintaining updated masters for all controlled documents.

   a. The CDCO shall maintain a distribution log for all controlled documents in which the following information shall be recorded for each controlled copy:

      Document name
      Controlled copy number
      Name of recipient
      Date of issue
      Date control expires (for copies with contract duration)

   b. New and/or revised SOPs must be submitted with a revised table of contents to the CDCO for distribution. The CDCO shall add the revised table of contents and the new and/or revised SOPs to the master document, removing the obsolete table of contents and SOPs to archival storage.

   c. The CDCO shall provide an update instruction sheet along with the revised table of contents and SOPs to every current controlled copy recipient listed in the distribution log. The instruction sheet will indicate which pages are to be added, which pages are to be deleted, and which pages are to be replaced.

   d. Obsolete SOPs must be archived for at least ten years from the date they are removed from circulation.

LABORATORY NOTEBOOK PROCEDURES

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

Laboratory Notebooks

1. Laboratory notebooks shall be permanently bound with each page sequentially prenumbered.

2. All notebook entries must be in black ink.

3. Correct errors by drawing a single line through the incorrect data. Initial and date the error, and continue with the correct data. **No other means of correcting errors is permitted.**

4. Record the analytical method number at the top of each page. Do not include more than one method per page.

5. Record all information needed to reconstruct the analyses and recalculate results.

6. Do not record confidential information such as client names, project names, *etc.*, in the laboratory notebook.

7. Each page must be signed and dated by the analyst and his or her supervisor when analyses are completed. Any unused portion of the page must be lined out.

Laboratory Notebook Control

1. The quality assurance manager shall maintain a log of issued and returned laboratory notebooks. This log shall be maintained in a bound, prenumbered notebook meeting all the requirements of a laboratory notebook.

2. The following information shall be recorded in the logbook when each notebook is issued:

   notebook number
   number of previous notebook
   signature of person receiving the notebook
   notebook use (instrument log, solids analysis, *etc.*)

date of issue

3. The following information shall be recorded in the laboratory notebook when it is issued:

   notebook number
   signature of person receiving the notebook
   date of issue

4. When the notebook is completed it shall be returned to the document control officer. The document control officer shall record the date returned in the notebook log and place the notebook in archival storage. Laboratory notebooks must be archived for at least ten years following the date of the last entry.

METHOD VALIDATION

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

A method validation study must be performed before any new procedure can be used for sample analysis. This section delineates the minimum requirements for a method validation study. Most analytical procedures have specific requirements with respect to method validation. If the method-specific requirements are more restrictive than these requirements, they supersede these requirements; otherwise, they are in addition to these requirements.

1. Perform a method detection limit (MDL) study following the procedures in the Quantitation Limits section of this manual. The following acceptance criteria must be met:

   a. The MDL determined must be less than the concentration used for the study but not less than 20% of the concentration used for the study.

   b. The MDL study must demonstrate the ability to achieve the detection limits published in the reference within the experimental variance of the method. If the experimental variance is not given in the reference, the MDL determined by the study can not be more than 50% greater than the published detection limit. If the detection limit is not given in the reference, contact the LRI Technical Director or Quality Assurance Director for appropriate action.

2. Follow the procedures in the Employee Training section of this manual to qualify each analyst who is to perform the new procedure.

INSTRUMENT PERFORMANCE CHECK

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

General

Instrument performance checks ensure the proper functioning of an analytical instrument prior to analysis. Specific performance check procedures are included in the instrument operation manuals and are frequently incorporated into analytical procedures. When an instrument has passed the required performance checks, no adjustment of operating parameters is permitted that will alter instrument performance. In addition to the frequency requirements of the instrument operation manuals and analytical methods, an instrument performance check must be performed whenever the operating parameters have been changed.

An instrument has failed the performance check requirements and corrective action must be initiated if it does not meet the requirements of the operation manuals and the analytical method. If the manual and method have conflicting requirements, the requirements of the method shall have precedence over the operation manual requirements.

Corrective action will vary from instrument to instrument. The following general procedure should be followed to find and correct the problem.

1. Review the instrument adjustment procedure and ascertain that the instrument is properly adjusted.

2. If adjustment fails to solve the problem, review the trouble-shooting procedures to determine the cause of the problem.

3. If the problem cannot be solved by adjustment and trouble-shooting, the instrument must be adjusted or repaired by a qualified professional service representative.

After adjustment and/or repair is completed, the instrument performance check must be repeated. The instrument may not be used for analysis until the performance check has passed.

Analytical Balances

Perform the following checks each day the analytical balance is used, and just prior to preparing calibration standards.

1. Ascertain that the balance is level and adjust if necessary.

2. Check the balance with at least two Class S weights bracketing the range normally used or, if the check is performed just prior to calibration standard preparation, use one Class S weight as near the target weight as possible. The maximum permissible error is 0.2 mg (0.0002 g). Record the results of all balance weight checks in the balance logbook.

General Purpose Balances

Perform the following checks each day the balance is used.

1. Ascertain that the balance is level and adjust if necessary.

2. Check the balance with at least two Class S weights bracketing the range normally used or, if the check is performed just prior to using the balance, use one Class S weight as near the target weight as possible. The maximum permissible error is 1% or 0.1 g, whichever is less. Record the results of all balance weight checks in the balance logbook.

Ultraviolet/Visual Wavelength Spectrophotometers

Perform the following check annually.

1. Prepare a potassium chromate test solution: Dissolve 2.80 g of potassium hydroxide (KOH) in 900 mL of reagent water in a 1000-mL volumetric flask. Add 0.400 g of potassium chromate (K_2CrO_4) and dissolve completely; then adjust the volume to 1000 mL with reagent water. Adjust temperature of solution to 25 ±1 °C.

2. Using a 1.00-cm cell, measure the absorbance or transmittance at each of the following wavelengths. The measured absorbance or transmittance must fall within the range specified. Record the results in the spectrophotometer maintenance logbook.

Wavelength (nm)	Transmittance*	Absorbance*
220	0.347 - 0.367	0.433 - 0.456
275	0.170 - 0.180	0.744 - 0.770
325	0.780 - 0.828	0.082 - 0.108
375	0.099 - 0.105	0.979 - 1.005
420	0.728 - 0.774	0.112 - 0.138

*Acceptance limits are based on ±3% of theoretical transmittance.

Conductivity Meters

Perform the daily electrode performance test and annual linearity test as directed in the Conductivity procedure. Record the results in the conductivity meter logbook.

Thermometers

Calibrate thermometers annually as follows.

1. Immerse an NBS-certified thermometer and the thermometer to be calibrated in a circulated ice-water bath. Take care to immerse both thermometers correctly according to immersion type. Record the temperature readings of both thermometers after the readings have stabilized for at least one minute.

2. Immerse an NBS-certified thermometer and the thermometer to be calibrated in a circulated warm or hot water bath. If possible, adjust the temperature of the water bath to be near the temperature to be monitored by the thermometer being calibrated; otherwise, adjust the temperature of the water bath as near boiling as possible. Take care to immerse both thermometers correctly according to immersion type. Record the temperature readings of both thermometers after the readings have stabilized for at least one minute.

3. Tag the thermometer with an identifying label and the temperature error.

Temperature Control Equipment

The temperature of all freezers, refrigerators, incubators, and ovens shall be monitored by means of a calibrated thermometer properly immersed in water, mineral oil, or sand, and the temperature shall be recorded daily. Temperature control equipment that is out of specification must be adjusted immediately or removed from service.

INITIAL CALIBRATION

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

An initial calibration must be performed before any other analyses may be performed. The initial calibration establishes the relationship between instrument response and sample concentration, and the working concentration range of the analytical system. This section delineates the minimum requirements for initial calibration analysis. Most analytical procedures have specific requirements with respect to calibration. If the method-specific requirements are more restrictive than these requirements, they supersede these requirements; otherwise, they are in addition to these requirements.

1. Levels: A minimum of five (5) nonzero concentrations must be used unless the method specifies less. The lowest concentration must be greater than the quantitation limit but should be no greater than four times (4×) the quantitation limit. The highest concentration should be near but below the upper linear range of the instrument. The remaining three concentrations must be evenly spaced between the lowest and highest concentrations.

2. Calibration: The instrument is calibrated by calculating the linear regression for each analyte of interest (see Appendix A). The resulting equation is used to calculate sample concentrations.

3. Frequency: The initial calibration must be performed whenever (1) a continuing calibration fails to meet quality control limits or (2) every 90 days, whichever occurs first.

4. Quality Control Limit: The correlation coefficient for each target analyte must be greater than 0.995. An initial calibration has failed quality control requirements and corrective action must be initiated if the correlation coefficient for any target analyte is less than 0.995.

5. Verification: The initial calibration must be verified by analyzing an independently prepared standard with target analyte concentrations within the calibration range. This standard must pass all the continuing calibration check requirements.

6. Corrective Action: If an initial calibration fails quality control requirements, the analytical system must be investigated to determine the cause of the problem and an acceptable initial calibration must be obtained.

CONTINUING CALIBRATION CHECK

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

A continuing calibration check must be performed before any quality control or sample analyses may be performed. The continuing calibration check determines whether the initial calibration is still valid. This section delineates the minimum requirements for continuing calibration check analysis. Most analytical procedures have specific requirements with respect to calibration. If the method-specific requirements are more restrictive than these requirements, they supersede these requirements; otherwise, they are in addition to these requirements.

1. Level: The concentration of the continuing calibration check standard should be the same as the midlevel initial calibration standard.

2. Procedure: Calculate the concentration of each analyte of interest in the continuing calibration check standard from the linear regression equations derived from the initial calibration.

3. Frequency: The continuing calibration check must be performed before sample analyses (except immediately following an initial calibration), again at the end of the analytical sequence, and every 24 hours during the sequence. Additional continuing calibration checks throughout the sequence are recommended to bracket groups of sample analyses (usually after every 10 sample analyses).

   NOTE: An analytical sequence begins with the initial calibration or continuing calibration check and continues without interruption until the final continuing calibration check. No changes in analytical conditions are permitted during an analytical sequence.

4. Quality Control Limits: The calculated analyte concentrations must fall within 15% of their theoretical (or true) values. A continuing calibration check has failed quality control requirements and corrective action must be initiated if the concentration of any target analyte is greater than 115% of its theoretical value or less than 85% of its theoretical value.

5. Corrective Action:

   a. If the continuing calibration check that starts an analytical sequence fails quality control requirements, the continuing calibration check may be repeated once. All target analytes

must pass quality control requirements in the second continuing calibration check in order for samples to be analyzed; otherwise, a new initial calibration must be performed.

b. If any continuing calibration check during or at the end of an analytical sequence fails quality control requirements, analyses must be terminated, the problem resolved, and all analyses performed since the last acceptable continuing calibration check or initial calibration must be repeated.

METHOD BLANK ANALYSIS

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

Analytical systems must be demonstrated to be free of contamination by the successful analysis of method blanks. This section delineates the minimum requirements for method blank analysis. Many analytical procedures have specific requirements with respect to method blank analysis. If the method-specific requirements are more restrictive than these requirements, they supersede these requirements; otherwise, they are in addition to these requirements.

NOTE: Method blanks are not to be used to correct analytical results.

1. Preparation: Method blanks must be prepared and analyzed in the same manner as the samples with which they are prepared and analyzed, except that sample is omitted or, for analysis of water samples, replaced with deionized water. The final concentration of all reagents used is the same in the method blank and the samples.

2. Frequency: A method blank shall be prepared and analyzed with each batch of samples analyzed or one method blank per 20 samples, whichever is more frequent. The maximum time span for a valid sample batch is thirty days. These frequencies are for a single matrix and method; quality control samples cannot be shared by matrices or methods.

3. Quality Control Limits:

   a. Method blanks must be free of contamination by nonexempted target analytes at or above the reported quantitation limit. The maximum allowable concentration for exempted target analytes three times (3×) the reported quantitation limit. A method blank has failed quality control requirements and corrective action must be initiated if (1) any nonexempted target analyte is detected at or above the reported quantitation limit or (2) the concentration of any exempted target analyte is greater than 2.5 times the reported quantitation limit.

   b. The exempted target analytes are:

      methylene chloride
      acetone

2-butanone
toluene
bis(2-ethylhexyl) phthalate

4. Corrective Action: If a contaminated method blank is encountered, sample analysis must be terminated and the analytical system must be investigated to determine the cause of the problem. The method blank and all associated samples (including quality control samples) must be reprepared and reanalyzed.

SAMPLE DUPLICATE ANALYSIS

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

Sample duplicates are analyzed to demonstrate the precision of an analytical system. This section delineates the minimum requirements for sample duplicate analysis. Many analytical procedures have specific requirements with respect to sample duplicate analysis. If the method-specific requirements are more restrictive than these requirements, they supersede these requirements; otherwise, they are in addition to these requirements.

1. Preparation: For inorganic analyses, two equivalent aliquots of the sample selected for duplicate analysis are prepared and carried through the preparation and analysis procedures together. For organic analyses that do not specify a duplicate analysis, a second matrix spike is prepared and carried through the preparation and analysis. All references to sample duplicates in this document apply equally to matrix spike duplicates.

2. Frequency: A sample duplicate shall be prepared and analyzed with each batch of 20 samples. The maximum time span for a valid sample batch is thirty days. This frequency is for a single matrix and method; quality control samples can not be shared by matrices or methods.

3. Relative Percent Difference (RPD): The relative percent difference is used to evaluate precision for analyses that measure concentration of an analyte directly.

$$RPD = \frac{200|C_1 - C_2|}{C_1 + C_2}$$

where RPD = relative percent difference
C_1 = original sample concentration
C_2 = sample duplicate concentration

NOTE: The relative percent difference cannot be calculated if either or both analyses are below the quantitation limit.

4. Difference: The absolute value of the difference of two measurements is used to evaluate precision for analyses that do not measure analyte concentrations directly (*e.g.*, temperature, pH, ignitability).

$$D = |M_1 - M_2|$$

where D = absolute value of the difference between two measurements
M_1 = original sample measurement
M_2 = duplicate sample measurement

5. Control Limits: The equations for calculating the mean and standard deviation are included in Appendix A of this manual. Use the data from at least 20 sample and sample duplicate analyses to calculate warning and control limits. Eliminate outliers using the method in Appendix A.

   a. RPD: The warning limit is the mean RPD plus two times (2×) the standard deviation, and the control limit is the mean plus three times (3×) the standard deviation. A sample duplicate analysis has failed quality control requirements and corrective action must be initiated if (1) the RPD is greater than the control limit or (2) the concentration for one analysis is less than the quantitation limit and the concentration for the other analysis is greater than two times (2×) the quantitation limit.

   b. Difference: The warning limit is the mean difference plus two times (2×) the standard deviation, and the control limit is the mean plus three times (3×) the standard deviation. A sample duplicate analysis has failed quality control requirements and corrective action must be initiated if the difference is greater than the upper control limit.

6. The relative percent difference or absolute difference, as appropriate, must be plotted on control charts showing the mean, warning limits, and control limits.

7. Corrective Action: If a sample duplicate analysis fails quality control requirements, the failure must be included in the nonconformance summary. No further action is required.

MATRIX SPIKE ANALYSIS

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

Matrix spikes are analyzed to demonstrate the accuracy of an analytical system. This section delineates the minimum requirements for matrix spike analysis. Many analytical procedures have specific requirements with respect to matrix spike analysis. If the method-specific requirements are more restrictive than these requirements, they supersede these requirements; otherwise, they are in addition to these requirements.

1. Preparation: Matrix spikes are prepared with the same sample size that is used for the samples with which they are analyzed. The spiking solution is added immediately after the sample aliquot is measured, and is mixed as thoroughly as practical with the sample. Subsequent treatment and analysis of the spiked sample is the same as that for the unspiked samples.

2. Level: The amount of spike added to the sample must give a concentration that will fall between the lowest and highest calibration standards when carried through the analysis procedure without dilution. The preferred concentration is 25% of the highest calibration standard; this concentration yields usable recovery data without dilution at low to moderate sample concentrations.

3. Frequency: A matrix spike shall be prepared and analyzed with each batch of 20 samples. The maximum time span for a valid sample batch is thirty days. For organic analyses that do not specify a duplicate analysis, a matrix spike duplicate shall be prepared and analyzed with each matrix spike and shall serve the same function as a duplicate analysis. This frequency is for a single matrix and method; quality control samples cannot be shared by matrices or methods.

4. Recovery (Accuracy):

$$C_t = \frac{A_s}{S_s}$$

$$R = \frac{100(C_s - C_u)}{C_t}$$

where C_t = theoretical concentration of spiked sample

A_s = amount of analyte added to spiked sample
S_s = size of sample aliquot spiked
R = recovery, %
C_s = measured concentration of spiked sample
C_u = measured concentration of unspiked sample

5. Relative Percent Difference (Precision): See the section on Sample Duplicate Analyses.

6. Control Limits: The equations for calculating the mean and standard deviation are included in Appendix A of this manual.

   a. Recovery: Use the data from at least 20 matrix spike analyses to calculate warning and control limits for recovery. Do not include data from matrix spike duplicate analyses. Eliminate outliers using the method in Appendix A.

      The upper warning limit is the mean recovery plus two times (2×) the standard deviation, and the upper control limit is the mean plus three times (3×) the standard deviation. The lower warning limit is the mean recovery minus two times (2×) the standard deviation, and the lower control limit is the mean minus three times (3×) the standard deviation. A matrix spike analysis has failed quality control requirements and corrective action must be initiated if the recovery is greater than the upper control limit or less than the lower control limit.

   b. RPD: See the section on Sample Duplicate Analyses.

7. The percent recovery must be plotted on control charts showing the mean, warning limits, and control limits.

8. Corrective Action: If the procedure utilizes surrogate spikes in every sample analyzed, all samples for which the surrogate spikes meet quality control requirements shall be considered acceptable regardless of the associated matrix spike recoveries. Samples for which surrogate spikes do not meet quality control requirements must be reprepared and reanalyzed.

   If the procedure does not utilize surrogate spikes, the following corrective action protocol applies.

   a. If a matrix spike recovery is outside control limits and the RPD is within control limits, the problem is attributed to matrix interference and no further action is required.

   b. If the matrix spike is outside control limits and the laboratory control sample is acceptable, the problem is attributed to matrix interference and no further action is required.

   c. If the matrix spike recovery is outside control limits and the concentration of the same

analyte in the unspiked sample is more than four times (4×) the concentration of spike analyte added, the problem is attributed to sample analyte concentration and must be noted in the nonconformance summary. No further action is required.

d. If the matrix spike recovery is positive and outside control limits and the RPD is outside control limits, the problem must be noted in the nonconformance summary. No further action is required.

e. If the matrix spike has zero or negative recovery, report the problem to the quality assurance officer for a specific corrective action procedure.

LABORATORY CONTROL SAMPLE ANALYSIS

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

Laboratory control samples are analyzed to demonstrate the accuracy of an analytical system. They are supplemental to matrix spikes and, because environmental matrices are not involved, provide useful information when matrix interference is encountered. Laboratory control sample (LCS) analyses are optional unless specifically required by the analytical procedure.

This section delineates the general requirements for LCS analysis. If the analytical procedure requires LCS analysis, the method-specific requirements supersede these requirements.

1. Preparation: Laboratory control samples are prepared in the same manner as matrix spikes except that spiking solution is added to laboratory reagent water (DI water) instead of sample. Subsequent treatment and analysis of the LCS is the same as that for environmental samples.

2. Level: The amount of spike added must be the same as that used for matrix spikes unless specified otherwise by the analytical method.

3. Frequency: A LCS shall be prepared and analyzed with each batch of 20 samples. The maximum time span for a valid sample batch is thirty days. This frequency is for a single matrix and method; quality control samples cannot be shared by matrices or methods.

4. Recovery (Accuracy):

$$C_t = \frac{A_s}{S_s}$$

$$R = \frac{100(C_s - C_u)}{C_t}$$

where C_t = theoretical concentration of spiked sample
A_s = amount of analyte added to spiked sample
S_s = size of sample aliquot spiked
R = recovery, %
C_s = measured concentration of spiked sample

C_u = measured concentration of unspiked sample

5. Control Limits: The equations for calculating the mean and standard deviation are included in Appendix A of this manual.

   Use the data from at least 20 LCS analyses to calculate warning and control limits for recovery. Eliminate outliers using the method in Appendix A.

   The upper warning limit is the mean recovery plus two times (2×) the standard deviation, and the upper control limit is the mean plus three times (3×) the standard deviation. The lower warning limit is the mean recovery minus two times (2×) the standard deviation, and the lower control limit is the mean minus three times (3×) the standard deviation. An LCS analysis has failed quality control requirements and corrective action must be initiated if the recovery is greater than the upper control limit or less than the lower control limit.

6. The percent recovery must be plotted on control charts showing the mean, warning limits, and control limits.

7. Corrective Action: If the procedure utilizes surrogate spikes in every sample analyzed, all samples for which the surrogate spikes meet quality control requirements shall be considered acceptable regardless of the associated LCS recoveries. Otherwise, if the LCS recovery is outside control limits, sample analysis must be terminated and the analytical system must be investigated to determine the cause of the problem. The LCS and all associated samples (including quality control samples) must be reprepared and reanalyzed.

QUALITY ASSURANCE ASSESSMENT

Prepared by: _____
Quality Assurance Director

Reviewed and implemented by: _____
General Manager

The previous sections in this manual addressed specific quality assurance requirements and their implementation. This section addresses audits, which are the primary procedures for assessing compliance with these requirements and the requirements of other LRI procedural manuals. Appropriate forms for use with each of the audits described are included in Appendix B of this manual.

Each audit is based on a single LRI procedural manual. The auditor shall conduct the audit as directed in the *Instructions to the auditor* near the top of the audit form. Immediately following the audit, the auditor shall meet with the General Manager or his/her designee and determine appropriate measures to correct any deficiencies found. If a condition is found that affects the accuracy or defensibility of reported data, the deficient practice must be suspended until the condition is corrected. Otherwise, a maximum of 30 days may be allowed to correct deficiencies. The corrective actions to be taken shall be recorded in the audit logbook. The audit logbook must be signed by the auditor and the General Manager. A follow-up audit shall be performed within 45 days to determine whether the corrective actions were properly completed.

The Quality Assurance Program Compliance Audit is based on the Corporate Quality Assurance Manual and determines the degree to which a laboratory is in compliance with general quality assurance program requirements. This audit is performed annually.

The Qualifications Audit is based on the Statement of Qualifications and determines whether quality assurance information is accurate and updated. This audit is performed quarterly.

The Sample Management Audit is based on the Sample Management Manual and determines the degree of compliance with sample management procedures. This audit is performed annually.

The Analytical Method Audit is based on the standard operating procedures for analyses and determines whether analytical procedures are being performed properly. This audit is performed annually for each analyst.

MATH AND STATISTICS

The following topics are included in this appendix.

Significant Digits
Rounding
Arithmetic Mean (Average)
Standard Deviation
Linear Regression
Test for Outliers

Significant Digits

The *n* most significant digits of a value are the leftmost nonzero digit and the *n-1* digits to its immediate right.

Examples: In the following numbers, the two most significant digits are underlined: 12678, 507, 8.033, 0.0003927.

Rounding

1. Carry at least one digit beyond the last significant digit throughout all calculations.

2. Round the final result by changing all digits beyond the last significant digit to zeroes; drop these zeroes if they are to the right of the decimal point.

   a. If the value dropped is greater than half the last significant digit, increase the last significant digit by one.

      Example: 12873 rounds to 13000

   b. If the value dropped is less than half the last significant digit, the last significant digit remains unchanged.

      Example: 12173 rounds to 12000

   c. If the value dropped is *exactly* half the last significant digit, the last significant digit remains unchanged if it is even (or zero) and is increased by one if it is odd.

      Examples: 12500 rounds to 12000 and 13500 rounds to 14000

Arithmetic Mean (Average)

$$\overline{X} = \frac{\sum X_i}{n}$$

where $\overline{X}$ = the arithmetic mean
X_i = the value of observation i
n = total number of observations

Standard Deviation

$$s = \sqrt{\frac{\sum (X_i - \overline{X})}{(n-1)}}$$

where s = the standard deviation
X_i = the value of observation i
$\overline{X}$ = the arithmetic mean
n = total number of observations

Linear Regression

$$m = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{n\sum x_i^2 - (\sum x_i)^2}$$

$$b = \frac{\sum y_i - m\sum x_i}{n}$$

$$r = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{(n\sum x_i^2 - (\sum x_i)^2)(n\sum y_i^2 - (\sum y_i)^2)}}$$

where x_i = independent measurement
y_i = dependent measurement corresponding to x_i
n = total number of observations
m = the slope
b = the y-intercept
r = the correlation coefficient

Test for Outliers

The highest or lowest value in a group for which the mean and standard deviation have been calculated shall be considered an outlier if the statistic T is greater than the critical value from the table below.

$$T = \frac{\overline{X} - X_i}{s}$$

where $\overline{X}$ = the arithmetic mean for the group with X_i included
X_i = the value to be tested
s = the standard deviation for the group with X_i included

Critical Values for 1% Tests of Discordancy for a Single Outlier in a Normal Distribution

Number of Measurements	Critical Value	Number of Measurements	Critical Value
3	1.15	15	2.71
4	1.49	16	2.75
5	1.75	18	2.82
6	1.94	20	2.88
7	2.10	30	3.10
8	2.22	40	3.24
9	2.32	50	3.34
10	2.41	60	3.41
12	2.55	100	3.60
14	2.66	120	3.66

AUDIT FORMS

The following audit forms are included in this appendix.

Quality Assurance Program Compliance Audit
Qualifications Audit
Sample Management Audit
Analytical Method Audit

Facility Audited _____ Date _____

Auditor's Signature _____ Number of Attached Pages _____

This audit is based on the LRI Corporate Quality Assurance Manual (CQAM).

Instructions to the auditor: Check the box labelled "YES" if the audit item is in compliance. Check the box labelled "NO" if the audit item is not in compliance. Enter a description of each noncompliant item in the facility's Audit Logbook with a corrective action plan and completion date. Attach copies of the Audit Logbook pages to this audit form and distribute copies to the General Manager of the facility audited, the Technical Director, and the President of LRI.

YES	NO	
☐	☐	A copy of the most recent release of the CQAM is available in each room where samples are logged in, stored, prepared, or analyzed and in each room where data is processed.
☐	☐	The facilities, instrumentation, organization, and key personnel are in agreement with the Statement of Qualifications.
☐	☐	Analytical balances have a minimum sensitivity of 0.1 mg and are clean, level, and checked with Class S weights daily or before use.
☐	☐	General purpose balances have sufficient sensitivity for their intended use and are clean, level, and checked with Class S weights daily or before use.
☐	☐	Spectrophotometers are checked annually with potassium chromate solution and spectrophotometer cells are properly maintained.
☐	☐	Conductivity meters have platinum electrodes, or nonplatinum electrodes that have been calibrated against platinum electrodes within the past year. Daily and annual checks are performed.
☐	☐	pH meters have a readability of at least ±0.05 pH units, are calibrated at pH 7.00 and 4.00, and are checked at pH 10.00.
☐	☐	Specific ion meters have a readability of at least ±5 mV.
☐	☐	Thermometers have appropriate graduations, are properly immersed, and are calibrated annually against an NBS-certified thermometer.
☐	☐	The temperature of freezers, refrigerators, incubators, and ovens is monitored and recorded daily.
☐	☐	Instrument maintenance logbooks are available for all instruments and required instrument maintenance procedures are performed and recorded.
☐	☐	Volumetric glassware is Class A and is not exposed to temperatures exceeding 105 °C. Mohr and similar measuring pipettes are not used.
☐	☐	Glassware is rinsed by analysts before it is submitted for cleaning, and the correct cleaning protocols are followed.

YES	NO	
☐	☐	The conductivity and pH of reagent water is checked and recorded daily.
☐	☐	Residual chlorine and heterotrophic plate count are performed and recorded monthly on the reagen water source used for microbiology analyses.
☐	☐	Heavy metals and bacterial quality are analyzed and recorded annually on the reagent water source used for microbiology analyses.
☐	☐	Reagents, standards, and solvents are of the correct grades and are properly labelled, documented and stored. Expired reagents and solutions are not used.
☐	☐	Employees are trained according to LRI protocol and training is properly documented.
☐	☐	The laboratory uses only methods listed as approved in the CQAM.
☐	☐	SOPs and manuals are in compliance with the CQAM policy for preparation, review, revision, and distribution.
☐	☐	Laboratory notebooks are in compliance with CQAM laboratory notebook procedures, correction. are made properly, and the pages are signed by the analyst and supervisor.
☐	☐	Method validation studies are available for all procedures.
☐	☐	Instrument performance checks, initial calibrations, and continuing calibration checks are performed at the required frequencies.
☐	☐	Method blanks are free of contamination from other than exempted compounds, and the latter do no exceed 2.5 times the quantitation limit.
☐	☐	Sample duplicates, matrix spikes, matrix spike duplicates, and laboratory control samples ar performed at the required frequencies and the data is plotted on control charts.

Auditor's Signature _____ Date _____

This audit is based on the LRI Statement of Qualifications (SOQ).

Instructions to the auditor: Check the box labelled "YES" if the audit item is in compliance. Check the box labelled "NO" if the audit item is not in compliance. Enter a description of each noncompliant item in the space provided and distribute copies to the Manager of Communications, the Director of Sales and Marketing, and the President of LRI.

YES	NO	
☐	☐	Information describing LRI facilities is complete and up to date.
☐	☐	Information describing LRI instrumentation is complete and up to date.
☐	☐	Information describing the organization of LRI is complete and up to date.
☐	☐	Resumes for key LRI personnel are up to date and all key personnel are included.

Facility Audited _____ Date _____

Auditor's Signature _____ Number of Attached Pages _____

This audit is based on the LRI Sample Management Manual.

Instructions to the auditor: Check the box labelled "YES" if the audit item is in compliance. Check the box labelled "NO" if the audit item is not in compliance. Enter a description of each noncompliant item in the facility's Audit Logbook with a corrective action plan and completion date. Attach copies of the Audit Logbook pages to this audit form and distribute copies to the General Manager of the facility audited, the Technical Director, and the President of LRI.

YES	NO	
☐	☐	A copy of the Corporate Quality Assurance Manual is available in the sample management area.
☐	☐	A copy of the Sample Management Manual is available in the sample management area.
☐	☐	Chain of custody forms are properly signed and dated with no breaks in the chain of custody.
☐	☐	The sample management personnel verify the pH of acid- and base-preserved samples and records the information in a notebook.
☐	☐	The pH of samples submitted for volatile organics analysis is determined by the analyst at the ti of analysis and recorded in the appropriate logbook.
☐	☐	The sample management personnel check sample volume against the volume required for the requested analyses.
☐	☐	A temperature control bottle is shipped with all coolers, and the temperature of the water in this bottle is measured and recorded when the cooler is received at the laboratory.
☐	☐	Internal chain of custody forms are properly completed when required.
☐	☐	Analyses are put on hold until instructions are received from the client when any of the following situations is encountered: samples are received physically damaged or improperly preserved, the cooler temperature is above 4.5 °C, insufficient sample quantity is received for the analyses requested, or the chain of custody form is not properly completed.
☐	☐	The sample containers provided by the laboratory are of the correct size and type and contain appropriate preservatives.
☐	☐	Sample containers are securely packed in coolers with shock-absorbent material separating the bottles.
☐	☐	Custody seals are placed on the hinged and opposite sides of the cooler before shipping.
☐	☐	The laboratory does not recycle sample containers.

YES	NO	
☐	☐	Case lots of sample containers are marked with the month and year of receipt, and stock is rotated so that the oldest cases are most accessible and are used first.
☐	☐	Original copies of bottle cleaning certificates are maintained on file.
☐	☐	Access to samples is restricted to authorized personnel only.
☐	☐	Sample storage refrigerators are maintained at 4 °C ±2 °C and the temperature of refrigerators is checked and recorded daily.
☐	☐	The laboratory segregates samples received under contract from regulatory agencies from commercial samples.
☐	☐	The laboratory follows advertised procedures for receipt of samples outside regular business hours.
☐	☐	The laboratory has established and adheres to procedures for handling rush analyses and analyses with short (<48 hours) holding times.
☐	☐	When "TOTAL" and "DISSOLVED" analytes are requested for the same sample, the filtered and unfiltered fractions are assigned different sample numbers.
☐	☐	LRI sample labels are applied to sample containers in such a way as not to obstruct the client's label.

Facility Audited _____ Date _____

Procedure Audited _____ Analyst _____

Auditor's Signature _____ Number of Attached Pages _____

This audit is based on the LRI standard operating procedures for analyses.

Instructions to the auditor: Check the box labelled "YES" if the audit item is in compliance. Check the box labelled "NO" if the audit item is not in compliance. Enter a description of each noncompliant item in the facility's Audit Logbook with a corrective action plan and completion date. Attach copies of the Audit Logbook pages to this audit form and distribute copies to the General Manager of the facility audited, the Technical Director, and the President of LRI.

YES	NO	
☐	☐	The method is approved in the LRI Corporate Quality Assurance Manual (CQAM).
☐	☐	The reagents and standards used meet the requirements of the method and the CQAM.
☐	☐	Preparation of reagents and standards is recorded as required by the CQAM.
☐	☐	Reagents and standards are labelled as required by the CQAM.
☐	☐	Applicable instrument performance checks are performed as required by the method and the CQAM.
☐	☐	Initial calibration is performed as required by the method and the CQAM.
☐	☐	Continuing calibration checks are performed as required by the method and the CQAM.
☐	☐	Method blanks are analyzed and meet the requirements of the method and the CQAM.
☐	☐	Matrix spikes are analyzed at the required frequency and the recoveries are recorded on control charts.
☐	☐	Sample duplicates or matrix spike duplicates are analyzed at the required frequency and the RPDs are recorded on control charts.
☐	☐	Laboratory control samples are analyzed at the required frequency.
☐	☐	Appropriate corrective action is taken and recorded for failed quality control analyses.
☐	☐	No deviations from method protocol were observed.
☐	☐	The analyst demonstrated acceptable analytical skills.

VOLATILE ORGANIC COMPOUNDS ANALYSIS
SW-846 8240

Approval: _____
Laboratory Quality Assurance Officer

_____
Laboratory Manager

Approval: Lee M Cramer
Quality Assurance Director

R. V. Payne
Technical Director

REFERENCE:

Test Methods for Evaluating Solid Waste, SW-846, 3rd Edition, November 1986, method 8240.

APPLICABILITY:

Analyte:	volatile organic compounds listed in Table 2
Matrix:	water, soil, sediment, sludge
Regulation:	RCRA, ECRA

IMPORTANT NOTES:

1. Interferences purged or coextracted from the samples will vary considerably from source to source, depending upon the particular sample or extract being tested. The analytical system, however, must be checked to ensure freedom from interferences, under the analysis conditions, by analyzing reagent blanks.

2. Samples can be contaminated by diffusion of volatile organics (particularly methylene chloride and fluorocarbons) through the septum seal into the sample during shipment and storage. A field blank prepared from reagent water and carried through the sampling and handling protocol can serve as a check on such contamination.

3. Cross-contamination can occur whenever high-level and low-level samples are analyzed sequentially. Whenever an unusually concentrated sample is analyzed, it should be followed by the analysis of reagent water to check for

cross-contamination. The purge-and-trap system may require extensive bake-out and cleaning after a high-level sample.

4. The laboratory where volatile analysis is performed should be completely free of solvents.

5. Impurities in the purge gas and from organic compounds out-gassing from the plumbing ahead of the trap account for the majority of contamination problems. The analytical system must be demonstrated to be free from contamination under the conditions of the analysis by running laboratory reagent blanks. The use of non-TFE plastic coating, non-TFE thread sealants, or flow controllers with rubber components in the purging device shall be avoided.

APPARATUS AND MATERIALS:

1. Microsyringes: 10-µL, 25-µL, 100-µL, 250-µL, 500-µL, and 1,000 µL. These syringes should be equipped with a 20-gauge (0.006-in I.D.) needle having a length sufficient to extend from the sample inlet to within 1 cm of the glass frit in the purging device.

2. Syringe valve: Two-way, with Luer ends (three each), if applicable to the purging device.

3. Syringe: 5-mL, gas-tight with shutoff valve.

4. Balance: Analytical, capable of accurately weighing 0.0001 g, and a top-loading balance capable of weighing 0.1 g.

5. Volumetric flasks: 10-mL and 100-mL, class A with ground-glass stoppers.

6. Spatula: Stainless steel.

7. Disposable Pasteur pipets.

8. Purge-and-trap device with available heated purge chamber. The gaseous headspace between the water column and the trap must have a total volume of less than 15 mL. The purge gas must pass through the water column as finely divided bubbles with a diameter of less than 3-mm at the origin. The purge gas must be introduced no more than 5 mm from the base of the water column.

The trap must be at least 25 cm long and have an inside diameter of at least 0.105 in. Starting from the inlet, the trap must contain the following amounts of adsorbents: ⅓ of 2,6-diphenylene oxide polymer, ⅓ of silica gel, and ⅓ of coconut charcoal. It is recommended that 1.0 cm of methyl silicone-coated packing be inserted at the inlet to extend the life of the trap. If it is not necessary to analyze for dichlorodifluoromethane or other fluorocarbons of similar volatility, the charcoal can be eliminated and the polymer increased to fill ⅔ of the trap. If only compounds boiling above 35 °C are to be analyzed, both the silica gel and charcoal can be eliminated and the polymer increased to fill the entire trap. Before initial use, the trap should be conditioned overnight at 180 °C by backflushing with an inert gas flow of at least 20 mL/minute. Vent the trap effluent to the room, not to the analytical column. Prior to daily use, the trap should be conditioned for 10 minutes at 180 °C with backflushing. The trap may be vented to the analytical column during daily conditioning; however, the column must be run through the temperature program prior to analysis of samples.

The desorber shall be capable of rapidly heating the trap to 180 °C for desorption. The polymer section of the trap should not be heated higher than 180 °C, and the remaining sections should not exceed 220 °C during bake-out mode.

9. Gas chromatograph/mass spectrometer/data system with the most recent version of the EPA/NIH Mass Spectral Library.

10. Column: 6-ft x 0.1-inch I.D. glass, packed with 1% SP-1000 on Carbopack-B (60/80 mesh) or equivalent.

REAGENTS:

1. Stock solutions: Stock solutions shall be obtained from commercial suppliers. If commercial standards are not available, prepare stock standard solutions in methanol, using assayed liquids or gases, as appropriate.

   Place about 9.8 mL of methanol in a 10-mL tared groundglass- stoppered volumetric flask. Allow the flask to stand, unstoppered, for about 10 minutes or until all alcohol-wetted surfaces have dried. Weigh the flask to the nearest 0.1 mg.

   Add the assayed reference material, as described below.

Liquids: Using a 100-µL syringe, immediately add two or more drops o assayed reference material to the flask; then reweigh. The liquid must fall directly into the alcohol without contacting the neck of the flask.

Gases: To prepare standards for any compounds that boil below 30-C (*e.g.*, bromomethane, chloroethane, chloromethane, or vinyl chloride), fill a 5-mL valved gas-tight syringe with the reference standard to the 5.0-mL mark. Lower the needle to 5 mm above the methanol meniscus. Slowly introduce the reference standard above the surface of the liquid. The heavy gas will rapidly dissolve in the methanol. Standards may also be prepared by using a lecture bottle equipped with a Hamilton Lecture Bottle Septum (#86600). Attach Teflon tubing to the side-arm relief valve and direct a gentle stream of gas into the methanol meniscus.

Reweigh, dilute to volume, stopper, and then mix by inverting the flask several times. Calculate the concentration in micrograms per microliter (µg/µL) from the net gain in weight. When compound purity is assayed to be 96% or greater, the weight may be used without correction to calculate the concentration of the stock standard.

Transfer the stock standard solution into a Teflon-sealed screw cap bottle. Store, with minimal headspace, at -10 °C to -20 °C and protect from light.

Prepare fresh standards every two months for gases. Reactive compounds such as 2-chloroethylvinyl ether and styrene may need to be prepared more frequently. All other standards must be replaced after six months, or sooner if comparison with check standards indicates a problem.

2. Secondary dilution standards: Using stock standard solutions, prepare in methanol secondary dilution standards containing the compounds of interest, either singly or mixed together. Secondary dilution standards must be stored with minimal headspace and shall be checked frequently for signs of degradation or evaporation, especially just prior to preparing calibration standards from them.

3. Surrogate standards: The required surrogates are toluene-d_8, 4-bromofluorobenzene, and 1,2-dichloroethane-d_4. A surrogate standard spiking solution shall be prepared from the stock surrogate solution at a concentration of 250 µg/10 mL In methanol. Each sample undergoing GC/MS analysis must be spiked with 10 µL of the surrogate spiking solution prior to analysis.

4. Internal standards: The required internal standards are bromochloromethane, 1,4-difluorobenzene, and chlorobenzene-d_5. The working standard shall be prepared at a concentration of 25 µg/mL of each internal standard compound. Addition of 10 µL of this standard to 5.0 mL of sample or calibration standard would be the equivalent of 50 µg/L.

5. Bromofluorobenzene (BFB) standard: A standard solution containing 25 ng/µL of BFB in methanol shall be prepared.

6. Calibration standards: Calibration standards shall be prepared at five concentration levels (µg/L): 20, 50, 100, 150, and 200. Prepare these solutions in reagent water. Each standard shall contain each analyte for detection by this method. Store for one week only in a vial with no headspace.

7. Matrix spiking standards: Matrix spiking standards shall be prepared from the volatile organic compounds listed in Table 7. The standard shall be prepared in methanol, with each compound present at a concentration of 250 µg/10.0 mL.

8. Great care must be taken to maintain the integrity of all standard solutions. It is recommended that all standards be stored at -10 °C to -20 °C in screw-cap amber bottles with Teflon liners.

9. Methanol: Organic residue grade. Store apart from other solvents.

PROCEDURE:

GC/MS operating conditions

Electron energy:	70 volts (nominal).
Mass range:	35 - 260 amu.
Scan time:	To give 5 scans/peak but not to exceed 7 seconds/scan.
Initial column temperature:	45 °C.
Initial column holding time:	3 minutes.
Column temperature program:	8 °C/minute.
Final column temperature:	220 °C.
Final column holding time:	15 minutes.
Injector temperature:	200 - 225 °C.
Source temperature:	According to manufacturer's specifications. Transfer line temperature: 250 - 300 °C.

Carrier gas: Hydrogen at 50 cm/second or helium at 30 cm/second.

GC/MS Calibration

1. Each GC/MS system must be hardware-tuned to meet the criteria in Table 3 for a 50-ng injection or purging of 4-bromofluorobenzene (2-μL injection of the BFB standard). Analyses must not begin until these criteria are met.

2. Assemble a purge-and-trap device. Condition the trap overnight at 180 °C in the purge mode with an inert gas flow of at least 20 mL/minute. Prior to use, condition the trap daily for 10 minutes while backflushing at 180 °C with the column at 220 °C.

3. Connect the purge-and-trap device to a gas chromatograph.

4. Prepare the final solutions containing the required concentrations of calibration standards, including surrogate standards, directly in the purging device. Add 5.0 mL of reagent water to the purging device. The reagent water is added to the purging device using a 5-mL glass syringe fitted with a 15-cm 20-gauge needle. The needle is inserted through the sample inlet shown in Figure 1. The internal diameter of the 14-gauge needle that forms the sample inlet will permit insertion of the 20-gauge needle. Next, using a 10-μL or 25-μL microsyringe equipped with a long needle, take a volume of the secondary dilution solution containing appropriate concentrations of the calibration standards. Add the aliquot of calibration solution directly to the reagent water in the purging device by inserting the needle through the sample inlet. When discharging the contents of the micro-syringe, be sure-that the end of the syringe needle is well beneath the surface of the reagent water. Similarly, add 10 μL of the internal standard solution. Close the 2-way syringe valve at the sample inlet.

5. Carry out the purge-and-trap analysis procedure.

6. Tabulate the area response of the characteristic ions (see Table 1) against concentration for each compound and each internal standard. Calculate response factors (RF) for each compound relative to one of the appropriate internal standard. The RF is calculated as follows:

$$RF = \frac{A_X \times C_{IS}}{A_{IS} \times C_X}$$

where: A_x = Area of the characteristic ion for the compound being measured.
A_{IS} = Area of the characteristic ion for the specific internal standard.
C_{IS} = Concentration of the specific internal standard.
C_x = Concentration of the compound being measured.

7. The average RF must be calculated for each compound. A system performance check shall be made before this calibration curve is used. Five compounds (the System Performance Check Compounds, or SPCCs) are checked for a minimum average response factor. These compounds are chloromethane, 1,1-dichloroethane, bromoform, 1,1,2,2-tetrachloroethane, and chlorobenzene. The minimum acceptable average RF for these compounds shall be 0.300 (0.250 for bromoform). These compounds typically have RRFs of 0.4 - 0.6 and are used to check compound instability and check for degradation caused by contaminated lines or active sites in the system. Examples of these occurrences are:

Chloromethane: This compound is the most likely compound to be lost if the purge flow is too fast.

Bromoform: This compound is one of the compounds most likely to be purged very poorly if the purge flow is too slow. Cold spots and/or active sites in the transfer lines may adversely affect response. Response of the quantitation ion (m/z 173) is directly affected by the tuning of BFB at ions m/z 174/176. Increasing the m/z 174/176 ratio may improve bromoform response.

Tetrachloroethane and 1,1-dichloroethane: These compounds are degraded by contaminated transfer lines in purge-and-trap systems and/or active sites in trapping materials.

8. Using the RRFs from the initial calibration, calculate the percent relative standard deviation (%RSD) for Calibration Check Compounds (CCCs).

$$\%RSD = \frac{SD}{x} \times 100$$

where: RSD = relative standard deviation.
x = mean of 5 initial Refs for a compound.

SD = standard deviation of average RRFs for a compound.

The %RSD for each individual CCC shall be less than 30 percent. This criterion must be met in order for the individual calibration to be valid. The CCCs are: 1,1-dichloroethene, chloroform, 1,2-dichloropropane, toluene, ethylbenzene, and vinyl chloride.

9. Prior to the analysis of samples, inject or purge 50-ng of the 4-bromofluorobenzene standard. The resultant mass spectra for the BFB must meet all of the criteria given in Table 3 before sample analysis begins. These criteria must be demonstrated each 12-hr shift.

10. The initial calibration curve for each compound of interest must be checked and verified once every 12 hours of analysis time. This is accomplished by analyzing a 50 µg/L calibration standard and checking the SPCCs and CCCs.

System Performance Check Compounds (SPCCs): A system performance check must be made each 12 hours. If the SPCC criteria are met, a comparison of response factors is made for all compounds. This is the same check that is applied during the initial calibration. If the minimum response factors are not met, the system must be evaluated, and corrective action must be taken before sample analysis begins. The minimum response factor for volatile SPCCs is 0.300 (0.250 for Bromoform). Some possible problems are standard mixture degradation, injection port inlet contamination, contamination at the front end of the analytical column, and active sites in the column or chromatographic system.

Calibration Check Compounds (CCCs): After the system performance check is met, the CCCs are used to check the validity of the initial calibration. If the percent difference for any compound is greater than 20, the laboratory should consider this a warning limit. If the percent difference for each CCC is less than 25%, the initial calibration is assumed to be valid. If the criterion is not met for any one CCC, corrective action must be taken. Problems similar to those listed under SPCCs could affect this criterion. If no source of the problem can be determined after corrective action has been taken, a new five-point calibration must be generated. This criterion must be met before quantitative sample analysis begins.

The internal standard responses and retention times in the check calibration standard must be evaluated immediately after or during data acquisition. If the retention time for any internal standard changes by more than 30 seconds from

the last daily check calibration, the chromatographic system must be inspected for malfunctions and corrections must be made, as required. If the EICP area for any of the internal standard changes by a factor of two (-50% to +100%) from the last daily calibration standard check, the mass spectrometer must be inspected for malfunctions and corrections must be made, as appropriate. When corrections are made, reanalysis of samples analyzed while the system was malfunctioning is necessary.

GC/MS analysis of water samples

1. All samples and standard solutions must be allowed to warm to ambient temperature before analyses.

2. Adjust the purge gas (helium) flow rate to 25 - 40 mL/minute on the purge-and-trap device. Optimize the flow rate to provide the best response for chloromethane and bromoform, if these compounds are analytes. Excessive flow rate reduces chloromethane response, whereas insufficient flow reduces bromoform response.

3. Remove the plunger from a 5-mL syringe and attach a closed syringe valve. Open the sample or standard bottle, which has been allowed to come to ambient temperature, and carefully pour the sample into the syringe barrel to just short of overflowing. Replace the syringe plunger and compress the sample. Open the syringe valve and vent any residual air while adjusting the sample volume to 5.0 mL. This process of taking an aliquot destroys the validity of the liquid sample for future analysis; therefore, if there is only one VOA vial, the analyst should fill a second syringe at this time to protect against possible loss of sample integrity. This second sample is maintained only until such time when the analyst has determined that the first sample has been analyzed properly. Filling one 20-mL syringe would allow the use of only one syringe. If a second analysis is needed from a syringe, it must be analyzed within 24 hours. Care must be taken to prevent air from leaking into the syringe.

4. The following procedure is appropriate for diluting purgeable samples. All steps must be performed without delays until the diluted sample is in a gas-tight syringe.

   Dilutions may be made in volumetric flasks (10- to 100-mL). Select the volumetric flask that will allow for the necessary dilution. Intermediate dilutions may be necessary for extremely large dilutions.

Calculate the approximate volume of reagent water to be added to the volumetric flask selected and add slightly less than this quantity of reagent water to the flask.

Inject the proper aliquot of samples from the syringe into the flask. Aliquots of less than 1 mL are not recommended. Dilute the sample to the mark with reagent water. Cap the flask, invert, and shake three times. Repeat above procedure for additional dilutions.

Fill a 5-mL syringe with the diluted sample.

5. Add 10.0 µL of surrogate spiking solution and 10 µL of internal standard spiking solution (Paragraph 5.4) through the valve bore of the syringe; then close the valve. The surrogate and internal standards may be mixed and added as a single spiking solution. The addition of 10 µL of the surrogate spiking solution to 5 mL of sample is equivalent to a concentration of 50 µg/L of each surrogate standard.

6. Attach the syringe-syringe valve assembly to the syringe valve on the purging device. Open the syringe valves and inject the sample into the purging chamber.

7. Close both valves and purge the sample for 11.0 ± 0.1 minutes at ambient temperature.

8. At the conclusion of the purge time, attach the trap to the chromatograph, adjust the device to the desorb mode, and begin the gas chromatographic temperature program and GC/MS data acquisition. Concurrently, introduce the trapped materials to the gas chromatographic column by rapidly heating the trap to 180-C while backflushing the trap with inert gas between 20 and 60 mL/minute for 4 minutes. If this rapid heating requirement cannot be met, the gas chromatographic column must be used as a secondary trap by cooling it to 30 °C (or subambient, if problems persist) instead of the recommended initial program temperature of 45 °C.

9. While the trap is being desorbed into the gas chromatograph, empty the purging chamber. Wash the chamber with a minimum of two 5-mL flushes of reagent water (or methanol followed by reagent water) to avoid carryover of pollutant compounds into subsequent analyses.

10. After desorbing the sample for 4 minutes, recondition the trap by returning the purge-and-trap device to the purge mode. Wait 15 seconds; then close the syringe valve on the purging device to begin gas flow through the trap. The trap temperature should be maintained at 180 °C. Trap temperatures up to 220 °C may be employed; however, the higher temperature will shorten the useful life of the trap. After approximately 7 minutes, turn off the trap heater and open the syringe valve to stop the gas flow through the trap. When cool, the trap is ready for the next sample.

11. If the initial analysis of a sample or a dilution of the sample has a concentration of analytes that exceeds the initial calibration range, the sample must be reanalyzed at a higher dilution. Secondary ion quantitation is allowed only when there are sample interferences with the primary ion. When a sample is analyzed that has saturated ions from a compound, this analysis must be followed by a blank reagent water analysis. If the blank analysis is not free of interferences, the system must be decontaminated. Sample analysis may not resume until a blank can be analyzed that is free of interferences.

12. For matrix spike analysis, add 10 µL of the matrix spike solution to the 5 mL of sample purged. Disregarding any dilutions, this is equivalent to a concentration of 50 µg/L of each matrix spike standard.

13. All dilutions shall keep the response of the major constituents (previously saturated peaks) in the upper half of the linear range of the curve.

GC/MS analysis of water-miscible liquids

1. Water-miscible liquids are analyzed as water samples after first diluting them at least 50-fold with reagent water.

2. Initial and serial dilutions can be prepared by pipetting 2 mL of the sample to a 100-mL volumetric flask and diluting to volume with reagent water. Transfer immediately to a 5-mL gas-tight syringe.

3. Alternatively, prepare dilutions directly in a 5-mL syringe filled with reagent water by adding at least 20 µL, but not more than 100-µL of liquid sample. The sample is ready for addition of internal and surrogate standards.

Low level GC/MS analysis of soil, sediment, and waste samples

1. The low level procedure is designed for samples containing individual purgeable compounds of <1 mg/kg. It is limited to soil/sediment samples and waste that is of a similar consistency (granular and porous). The low-level method is based on purging a heated sediment/soil sample mixed with reagent water containing the surrogate and internal standards. Analyze all reagent blanks and standards under the same conditions as the samples.

2. Use a 5-g sample if the expected concentration is <0.1 mg/kg or a 1-g sample for expected concentrations between 0.1 and 1 mg/kg.

3. A heated purge calibration curve must be prepared and used for the quantitation of all samples analyzed with the low level method. Follow the initial and daily calibration instructions, except for the addition of a 40 °C purge temperature.

4. Remove the plunger from a 5-mL Luerlock type syringe equipped with a syringe valve and fill until overflowing with reagent water. Replace the plunger and compress the water to vent trapped air. Adjust the volume to 5.0 mL. Add 10 µL each of surrogate spiking solution and internal standard solution to the syringe through the valve. (Surrogate spiking solution and internal standard solution may be mixed together.) The addition of 10 µL of the surrogate spiking solution to 5 g of sediment/soil is equivalent to 50 µg/kg of each surrogate standard.

5. The sample consists of the entire contents of the sample container. Do not discard any supernatant liquids. Mix the contents of the sample container with a narrow metal spatula. Weigh the sample aliquot into a tared purge device. Note and record the actual weight to the nearest 0.1 g.

6. Determine the percent moisture of the soil/sediment sample. This includes waste samples that are amenable to moisture determination. Other wastes shall be reported on a wet weight basis. Immediately after weighing the sample, weigh (to 0.1 g) 5 - 10 g of additional sediment/soil into a tared crucible. Dry the contents of the crucibles overnight at 105 °C. Allow to cool in a desiccator and reweigh the dried contents. Concentrations of individual analytes will be reported relative to the dry weight of sediment.

7. Add the spiked reagent water to the purge device, which contains the weighed amount of sample, and connect the device to the purge-and-trap system.

8. Heat the sample to 40 °C ± 1 °C and purge the sample for 11.0 ± 0.1 minutes.

9. Proceed with the analysis as for water samples. Use 5 mL of the same reagent water as in the reagent blank. If saturated peaks occurred or would occur if a 1-g sample were analyzed, the medium level procedure must be followed.

10. For low level soil/sediment spikes, add 10 µL of the matrix spike solution to the 5 mL of water. The concentration for a 5-g sample would be equivalent to 50 µg/kg (wet weight) of each matrix spike standard.

<u>High level GC/MS analysis of soil, sediment, and waste samples</u>

1. This procedure is based on extracting the soil/sediment with methanol. A waste sample is either extracted or diluted, depending on its solubility in methanol. An aliquot of the extract is added to reagent water containing surrogate and internal standards. This is purged at ambient temperature. All samples with an expected concentration of > 1.0 mg/kg should be analyzed by this procedure.

2. The sample consists of the entire contents of the sample container. Do not discard any supernatant liquids. Mix the contents of the sample container with a narrow metal spatula. For soil/sediments and wastes that are insoluble in methanol weigh 4 g (wet weight) of sample into a tared 20-mL vial. Use a top-loading balance. Note and record the actual weight to 0.1 gram and determine the percent moisture of the sample in the same manner as for the low level procedure. For waste that is soluble in methanol, weigh 1 g (wet weight) into a tared scintillation vial or culture tube or a 10-mL volumetric flask. (If a vial or tube is used, it must be calibrated prior to use. Pipet 10.0 mL of methanol into the vial and mark the bottom of the meniscus. Discard this solvent.)

3. Quickly add 9.0 mL of methanol then add 1.0 mL of the surrogate spiking solution to the vial. Cap and shake for 2 minutes.

4. Pipet approximately 1 mL of the extract to a GC vial for storage, using a disposable pipet. The remainder may be disposed of. Transfer approximately 1 mL of reagent methanol to a separate GC vial for use as the method blank for each set of samples. These extracts may be stored at 4 °C in the dark, prior to analysis. The addition of a 100-µL aliquot of each of these extracts will give

a concentration equivalent to 6,200 µg/kg (wet weight) of each surrogate standard.

5. Table 4 can be used to determine the volume of methanol extract to add to the 5 mL of reagent water for analysis. If a screening procedure was followed, use the estimated concentration to determine the appropriate volume. Otherwise, estimate the concentration range of the sample from the low level analysis to determine the appropriate volume. If the sample was submitted as a medium level sample, start with 100 µL. All dilutions must keep the response of the major constituents (previously saturated peaks) in the upper half of the linear range of the curve.

6. Remove the plunger from a 5.0-mL Luerlock type syringe equipped with a syringe valve and fill until overflowing with reagent water. Replace the plunger and compress the water to vent trapped air. Adjust the volume to 4.9 mL. Pull the plunger back to 5.0 mL to allow volume for the addition of the sample extract and of standards. Add 10 µL of internal standard solution. Also add the volume of methanol extract and a volume of methanol solvent to total 100 µL (excluding methanol in standards).

7. Attach the syringe-syringe valve assembly to the syringe valve on the purging device. Open the syringe valve and inject the water/methanol sample into the purging chamber.

8. 7.4.3.2.8 Proceed with the analysis. Analyze all reagent blanks on the same instrument as that use for the samples. The standards and blanks shall also contain 100 µL of methanol to simulate the sample conditions.

9. For a matrix spike in the medium-level soil/sediment samples, add 8.0 mL of methanol, 1.0 mL of surrogate spike solution, and 1.0 mL of matrix spike solution. This results in a 6,200 µg/kg (wet weight) concentration of each matrix spike standard when added to a 4-g sample. Add a 100-µL aliquot of this extract to 5 mL of water for purging.

Qualitative analysis

1. An analyte (*e.g.*, those listed in Table 1) is identified by comparison of the sample mass spectrum with the mass spectrum of a standard of the suspected compound (standard reference spectrum). Mass spectra for standard reference shall be obtained on the user's GC/MS within the same 12 hours as the sample analysis. These standard reference spectra may be obtained through analysis of the calibration standards. Two criteria must be satisfied to verify

identification: (1) elution of sample component at the same GC relative retention time (RRT) as those of the standard component; and (2) correspondence of the sample component and the standard component mass spectrum.

2. The sample component RRT must compare within ± 0.06 RRT units of the RRT of the standard component. For reference, the standard must be run within the same 12 hours as the sample. If coelution of interfering components prohibits accurate assignment of the sample component RRT from the total ion chromatogram, the RRT shall be assigned by using extracted ion current profiles for ions unique to the component of interest.

3. (1) All ions present in the standard mass spectra at a relative intensity greater than 10% (most abundant ion in the spectrum equals 100%) must be present in the sample spectrum.

   (2) The relative intensities of ions specified in (1) must agree within ±20% between the standard and sample spectra. (Example: For an ion with an abundance of 50% In the standard spectra, the correspond~ng sample abundance must be between 30 and 70 percent).

4. For samples containing components not associated with the calibration standards, a library search may be made for the purpose of tentative identification. The necessity to perform this type of identification will be determined by the type of analyses being conducted. Guidelines for making tentative identification are:

   (1) Relative intensities of major ions in the reference spectrum (ions > 10% of the most abundant ion) should be present in the sample spectrum.

   (2) The relative intensities of the major ions should agree within ±20%. (Example: For an ion with an abundance of 50% in the standard spectrum, the corresponding sample ion abundance must be between 30 and 70%).
   (3) Molecular ions present in the reference spectrum should be present in the sample spectrum.

   (4) Ions present in the sample spectrum but not in the reference spectrum should be reviewed for possible background contamination or presence of coeluting compounds.

(5) Ions present in the reference spectrum but not in the sample spectrum should be reviewed for possible subtraction from the sample spectrum because of background contamination or coeluting peaks. Data system library reduction programs can sometimes create these discrepancies.

Computer generated library search routines must not use normalization routines that would misrepresent the library or unknown spectra when compared to each other. Only after visual comparison of sample with the nearest library searches will the mass spectral interpretation specialist assign a tentative identification.

Quantitative analysis

1. When a compound has been identified, the quantitation of that compound will be based on the integrated abundance from the EICP of the primary characteristic ion. Quantification will take place using the internal standard technique. The internal standard used shall be the one nearest the retention time of that of a given analyte (*e.g.*, see Table 5).

2. Calculate the concentration of each identified analyte in the sample as follows:

Water and Water-Miscible Waste:

$$\text{concentration } (\mu g/L) = \frac{A_X \times I_s}{A_{IS} \times RF \times V_o}$$

where: A_X = Area of characteristic ion for compound being measured.
I_s = Amount of internal standard injected (ng).
A_{IS} = Area of characteristic ion for the internal standard.
RF = Response factor for compound being measured.
V_o = Volume of water purged (mL), taking into consideration any dilutions made.

High Level Soil/Sediment, Sludge, and Waste:

$$\text{concentration } (\mu g/L) = \frac{A_X \times I_s \times V_T}{A_{IS} \times RF \times V_I \times W_s}$$

where: A_X = Area of characteristic ion for compound being measured.

I_S = Amount of internal standard injected (ng).
V_T = volume of total extract (μL) (use 10,000 μL or a factor of this when dilutions are made).
A_{IS} = Area of characteristic ion for the internal standard.
RF = Response factor for compound being measured.
V_I = volume of extract added (μL) for purging.
W_S = weight of sample extracted or purged. The wet weight or dry weight may be used, depending upon the specific applications of the data.

Low Level Soil/Sediment, Sludge, and Waste:

$$\text{concentration } (\mu g/L) = \frac{A_X \times I_S}{A_{IS} \times RF \times W_S}$$

where:
A_X = Area of characteristic ion for compound being measured.
I_S = Amount of internal standard injected (ng).
A_{IS} = Area of characteristic ion for the internal standard.
RF = Response factor for compound being measured.
W_S = weight of sample extracted or purged. The wet weight or dry weight may be used, depending upon the specific applications of the data.

3. Soil/sediment samples are reported on a dry weight basis, while sludges and wastes are reported on a wet weight basis. The % moisture of the sample shall be reported along with the data in either instance.

4. Where applicable, an estimate of concentration for noncalibrated components in the sample shall be made. The formulas given above shall be used with the following modifications: The areas A_X and A_{IS} shall be from the total ion chromatograms, and the RF for the compound shall be assumed to be 1. The concentration obtained shall be reported indicating (1) that the value is an estimate and (2) which internal standard was used to determine concentration. Use the nearest internal standard free of interferences.

5. Report results without correction for recovery data. When duplicates and spiked samples are analyzed, report all data obtained with the sample results.

QUALITY ASSURANCE:

1. This method must be validated by the successful analysis of a blind quality control sample before samples can be analyzed.

2. A method detection limit (MDL) study (procedure AP0001) must be completed before samples can be analyzed. The MDL study must be repeated whenever a significant change in the procedure is made.

3. The required quantitation limits are listed in Table 2.

4. A new calibration curve must be run when the continuing calibration check fails quality control criteria or once each 30 days, whichever occurs first.

5. Analyze a reagent blank with each batch of samples analyzed or one per 20 samples, whichever is more frequent. The concentration of each target compound detected in the reagent blank must be less than the required quantitation limit. Exception: methylene chloride, acetone, and toluene may not exceed 5 × the quantitation limit.

6. Analyze a matrix spike and matrix spike duplicate at a minimum frequency of one per 20 samples or one per month, whichever is more frequent. The control limits for recovery and RPD are listed in Table 7.

Table 1. CHARACTERISTIC IONS FOR VOLATILE COMPOUNDS

Compound	Primary Ion	Secondary Ion(s)
Acetone	43	58
Acrolein	56	55, 58
Acrylonitrile	53	52, 51
Benzene	78	52, 77
Bromochloromethane (I.S.)	128	49, 130, 51
Bromodichloromethane	83	85, 129
4-Bromofluorobenzene (surr.)	95	174, 176
Bromoform	173	171, 175, 252
Bromomethane	94	96, 79
2-Butanone	72	57, 43
Carbon disulfide	76	78
Carbon tetrachloride	117	119, 121
Chlorobenzene	112	114, 77
Chlorobenzene-d_5 (I.S.)	117	82, 119
Chlorodlbromomethane	129	208, 206
Chloroethane	64	66, 49
2-Chloroethyl vinyl ether	63	65, 106
Chloroform	83	85, 47
Chloromethane	50	52, 49
Dibromomethane	93	174, 95
1,4-Dichloro-2-butane	75	53, 89
Dichlorodifluoromethane	85	87, 50, 101
1,1-Dichloroethane	63	65, 83
1,2-Dichloroethane	62	64, 98
1,2-Dichloroethane-d_4 (surr.)	65	102
1,1-Dichloroethene	96	61, 98
trans-1,2-Dichloroethene	96	61, 98
1,2-Dichloropropane	63	62, 41
cis-1,3-Dichloropropene	75	77, 39
trans-1,3-Dichloropropene	75	77, 39
1,4-Difluorobenzene (I.S.)	114	63, 88
Ethanol	31	45, 27, 46
Ethylbenzene	106	91
Ethyl methacrylate	69	41, 39, 99
2-Hexanone	43	58, 57, 100
Iodomethane	142	127, 141
Methylene chloride	84	49, 51, 86
4-Methyl-2-pentanone	43	58, 100
Styrene	104	78, 103
1,1,2,2-Tetrachloroethane	83	85, 131, 133
Tetrachloroethene	164	129, 131, 166
Toluene	92	91, 65
Toluene-d_8 (surr.)	98	70, 100
1,1,1-Trichloroethane	97	99, 117
1,1,2-Trichloroethane	97	83, 85, 99
Trichloroethene	130	95, 97, 132
Trichlorofluoromethane	101	103, 66
1,2,3-Trichloropropane	75	110, 77, 61
Vinyl acetate	43	86
Vinyl chloride	62	64, 61
Xylene	106	91

Table 2. PRACTICAL QUANTITATION LIMITS (PQL) FOR VOLATILE ORGANICS

	Volatiles	CAS Number	Practical Quantitation Limits^ Ground water µg/L	Low Soil/ Sediment µg/Kg
1.	Chloromethane	74-87-3	10	10
2.	Bromomethane	74-83-9	10	10
3.	Vinyl Chloride	75-01-4	10	10
4.	Chloroethane	75-00-3	10	10
5.	Methylene Chloride	75-09-2	5	5
6.	Acetone	67-64-1	100	100
7.	Carbon Disulfide	75-15-0	5	5
8.	1,1-Dichloroethene	75-35-4	5	5
9.	1,1-Dichloroethane	75-35-3	5	5
10.	trans-1,2-Dichloroethene	156-60-5	5	5
11.	Chloroform	67-66-3	5	5
12.	1,2-Dichloroethane	107-06-2	5	5
13.	2-Butanone	78-93-3	100	100
14.	1,1,1-Trichloroethane	71-55-6	5	5
15.	Carbon Tetrachloride	56-23-5	5	5
16.	Vinyl Acetate	108-05-4	50	50
17.	Bromodichloromethane	75-27-4	5	5
18.	1,1,2,2-Tetrachloroethane	79-34-5	5	5
19.	1,2-Dichloropropane	78-87-5	5	5
20.	trans-1,3-Dichloropropene	10061-02-6	5	5
21.	Trichloroethene	79-01-6	5	5
22.	Dibromochloromethane	124-48-1	5	5
23.	1,1,2-Trichloroethane	79-00-5	5	5
24.	Benzene	71-43-2	5	5
25.	cis-1,3-Dichloropropene	10061-01-5	5	5
26.	2-Chloroethyl Vinyl Ether	110-75-8	10	10
27.	Bromoform	75-25-2	5	5
28.	2-Hexanone	591-78-6	50	50
29.	4-Methyl-2-pentanone	108-10-1	50	50
30.	Tetrachloroethene	127-18-4	5	5
31.	Toluene	108-88-3	5	5
32.	Chlorobenzene	108-90-7	5	5
33.	Ethyl Benzene	100-41-4	5	5
34.	Styrene	100-42-5	5	5
35.	Total Xylenes	1330-20-7	5	5

^PQLs listed for soil/sediment are based on wet weight.

Other Matrices	Factor[1]
Water miscible liquid waste	50
High-level soil & sludges	125
Non-water miscible waste	500

[1]PQL = PQL for ground water (Table 2) × Factor. For nonaqueous samples, the factor is on a wet weight basis.

Table 3. BFB KEY ION ABUNDANCE CRITERIA

Mass	Ion Abundance Criteria
50	15 to 40% of mass 95
75	30 to 60% of mass 95
95	base peak, 100% relative abundance
96	5 to 9% of mass 95
173	less than 2% of mass 174
174	greater than 50% of mass 95
175	5 to 9% of mass 174
176	greater than 95% but less than 101% of mass 174
177	5 to 9% of mass 176

Table 4. QUANTITY OF METHANOL EXTRACT REQUIRED FOR ANALYSIS OF MEDIUM-LEVEL SOILS/SEDIMENTS

Approximate Concentration Range	Volume of Methanol Extract[A]
500- 10,000 µg/kg	100 µL
1,000- 20,000 µg/kg	50 µL
5,000-100,000 µg/kg	10 µL
25,000-500,000 µg/kg	100 µL of 1/50 dilution[B]

Calculate appropriate dilution factor for concentrations exceeding this table.

[A]The volume of methanol added to 5 mL of water being purged must be kept constant. Therefore, add to the 5-mL syringe whatever volume of methanol is necessary to maintain a volume of 100 µL added to the syringe.
[B]Dilute an aliquot of the methanol extract and then take 100 µL for analysis.

Table 5. VOLATILE INTERNAL STANDARDS WITH CORRESPONDING ANALYTES ASSIGNED FOR QUANTITATION

Bromochloromethane	1,4-Difluorobenzene
Acetone	Benzene
Acrolein	Bromodichloromethane
Acrylonitrile	Bromoform
Bromomethane	2-Butanone
Carbon disulfide	Carbon tetrachloride
Chloroethane	Chlorodibromomethane
Chloroform	2-Chloroethyl vinyl ether
Chloromethane	Dibromomethane
Dichlorodifluoromethane	1,4-Dichloro-2-butene
1,1-Dichloroethane	1,2-Dichloropropane
1,2-Dichloroethane	cis-1,3-Dichloropropene
1,2-Dichloroethane-d_4 (surrogate)	trans-1,3-Dichloropropene
1,1-Dichloroethene	1,1,1-Trichloroethane
trans-1,2-Dichloroethene	1,1,2-Trichloroethane
Iodomethane	Trichloroethene
Methylene chloride	Vinyl acetate
Trichlorofluoromethane	
Vinyl chloride	

Chlorobenzene-d_5
Bromofluorobenzene (surrogate)
Chlorobenzene
Ethylbenzene
Ethyl methacrylate
2-Hexanone
4-Methyl-2-pentanone
Styrene
1,1,2,2-Tetrachloroethane
Tetrachloroethene
Toluene
Toluene-d_8 (surrogate)
1,2,3-Trichloropropane
Xylene

Table 6. SURROGATE SPIKE RECOVERY LIMITS FOR WATER AND SOIL/SEDIMENT SAMPLES

Surrogate Compound	Low/Medium Water	Low/Medium Soil/Sediment
4-Bromofluorobenzene	86-115	74-121
1,2-Dichloroethane-d_4	76-114	70-121
Toluene-d_8	88-110	81-117

Table 7. MATRIX SPIKE/MATRIX SPIKE DUPLICATE QUALITY CONTROL LIMITS

	Water		Soil	
	Recovery	RPD	Recovery	RPD
1,1-Dicloroethane	61 - 145	14	59 - 172	22
Trichloroethene	71 - 120	14	62 - 137	24
Chlorobenzene	75 - 130	13	60 - 133	21
Toluene	76 - 125	13	59 - 139	21
Benzene	76 - 127	11	66 - 142	21

APPENDIX C
ENVIRONMENTAL LABORATORIES, INC. QAPP

APPENDIX C

QAPP FOR INORGANIC ANALYSIS
ENVIRONMENTAL LABORATORIES, INC.

Environmental Laboratories, Inc.
Quality Assurance Program Plan
(QAPP)

Revision 1.1
November 1993

ANALYTICAL TESTING-ENVIRONMENTAL SERVICES

ENVIRONMENTAL LABORATORIES, INC.

A Subsidiary of EICON • New Haven • Hartford • Bridgeport
142 Temple Street, New Haven, CT 06510 (203)789-1260

Environmental Laboratories, Inc.
Quality Assurance Program Plan
(QAPP)

Revision 1.1
November 1993

Approval:

Robert Wasp, President

Robert J. Schock, Laboratory Director

Deborah A. Loring, Loring Environmental Associates
Acting Quality Assurance Officer

Table of Contents

List of Figures

List of Tables

1. Introduction

Environmental Laboratories Inc. (ELI) was established in 1974 and is a consulting environmental engineering firm and analytical laboratory uniquely organized to provide the diverse technical resources required to address complex environmental projects from within a single organization.

This Quality Assurance Program Plan (QAPP) addresses the analytical laboratory's approach to all aspects of data production ranging from sampling procedures to data reporting.

The address of the laboratory is:

Environmental Laboratories, Inc.
A Subsidiary of EICON
142 Temple Street
New Haven, Connecticut 06510
(203) 789-1260

2. Quality Assurance Policy

Environmental Laboratories, Inc. (ELI) is committed to providing scientifically and legally defensible data regardless of the project size or the regulatory program under which the analyses are conducted.

It is the policy of ELI to meet the quality control and methodology requirements for each of the regulatory programs under which it performs environmentally related measurement activities. Because many of these programs require different applications of the methodology, and varying levels of quality control procedures and documentation, a tiered approach is used in the laboratory.

In many regulatory programs, such as RCRA, a well-defined project planning procedure is required prior to the initiation of sampling and analysis. This procedure can include submission of sampling plans, establishment of data quality objectives (DQOs), documentation of method detection limits and standard operating procedures, outlining data deliverables, and incorporation of these project specific requirements into a Quality Assurance Project Plan (QAPjP). ELI strongly supports the use of this approach with all clients prior to project initiation regardless of the regulatory program requirements.

3. Purpose and Scope of Document

The purpose of this document is to describe the specific elements of the Quality Assurance (QA) program in operation at ELI during all sample analyses. The purpose of a well-defined QA program at ELI is to ensure that all data is both technically valid and legally defensible, and that all appropriate documentation is accessible for future data inquiries.

The scope of this document includes the procedures which ELI uses to ensure that all data is of known and documented quality. These procedures are outlined as follows:

- Well established chain of custody procedures that start from bottle and cooler preparation and continue through sample disposal.
- Analysis of QC samples to document laboratory precision and accuracy, and the effect of the matrix on the method performed.
- Laboratory and data auditing procedures.
- Corrective action procedures and documentation.
- Data management through Laboratory Information Management System (LIMS) and data archival.

In addition, ELI's laboratory staff consists of organic and inorganic analysts with extensive experience in analytical testing.

3. Purpose and Scope of Document (con't)

This QAPP, used alone or in conjunction with specific QAPjPs, describes the various procedures used in the laboratory which are designed to meet the regulatory requirements of various state and federal programs under which ELI performs sample analysis. In the case of any specific discrepancy between this document and approved QAPjPs, the QAPjP is considered to supersede this document for that particular project.

4. Definitions of Terms

Data Quality Objectives *(DQO)*

Describes the level of uncertainty that the decision maker is willing to accept in analytical data results.

Precision, Accuracy, Representativeness, Completeness, and Comparability (PARCC)

Precision: The agreement in a set of replicate measurements.

Accuracy: The closeness of agreement between a measured value and a true or accepted reference value.

Representativeness: The degree to which a measurement accurately and precisely represents true conditions.

Completeness: Measured as the number of valid data points obtained/number of data points attempted. When listed numerically as an objective, the calculation of this variable can be somewhat subjective.

Comparability: The degree to which one set of data can be compared to another set of data.

Laboratory Control Sample **(LCS)**

A known matrix spiked with target analyte(s). Used to assess laboratory accuracy independent of the sample matrix.

Matrix Duplicate **(MD)**

A duplicate sample which is used to document precision of the method in a particular matrix.

Matrix Spike **(MS)**

A field sample to which target analyte(s) have been added at a known quantity to determine the effect of the matrix on accuracy.

Matrix Spike Duplicate **(MSD)**

An additional matrix spike for determination of the effect of the matrix on precision.

4. Definitions of Terms (con't.)

Method Blank **(MB)**

A blank matrix to which all reagents are added in the same volume or proportion as used in sample processing. Used to document contamination resulting from the analytical process.

Method Detection Limit **(MDL)**

The minimum concentration of a compound that can be measured at a 99% confidence interval. Calculated as prescribed in 40 CFR Part 139 Appendix B.

National Pollution Discharge and Elimination System **(NPDES)**

Resource Conservation and Recovery Act **(RCRA)**

Safe Drinking Water Act **(SDWA)**

Quality Assurance **(QA)**

The total integrated program for assuring reliability of monitoring and measurement data.

Quality Assurance Program Plan **(QAPP)**

A plan designed to describe a laboratory's overall program to ensure measurement of data with known and documented quality.

Quality Assurance Project Plan **(QAPjP)**

A plan designed to describe QA/QC goals and operating procedures for a specific data collection activity.

Quality Control **(QC)**

The routine application of procedures for obtaining prescribed standards of performance in the monitoring and measurement process.

Standard Operating Procedure **(SOP)**

A written procedure describing each step in a process or task in specific detail.

5. Responsibilities and Authorities

5.1 Laboratory Organization

An organization chart appears as Figure 5.1 which outlines the structure of ELI.

5.1 QA Officer

The QA Officer of ELI is directly responsible for monitoring compliance with the specific quality control requirements presented in this document and in the methodology quoted herein. This monitoring is accomplished using both laboratory and data audits as described in Section 12. The resulting audit reports are distributed to the Laboratory Director and President of ELI. The QA Officer is also responsible, in conjunction with laboratory management, for the organization, tracking, and responses to performance evaluation samples and external laboratory and data audits.

Other responsibilities of the QA Officer are revising the QA program to meet changing regulatory guidelines; approval, distribution, and archival of all Standard Operating Procedures (SOPs); and reviewing QAPjPs in conjunction with program and laboratory management.

The authority of the QA Officer comes directly from the President of the laboratory.

5. Responsibilities and Authorities (con't.)

5.2 President

It is the responsibility of the President to assign a QA Officer with sufficient responsibility and authority to carry out the auditing programs and to make recommendations for changes in methodology and QC procedures in the laboratory. It is also the responsibility and authority of the President to maintain a working environment that actively supports the importance of scientifically sound and legally defensible data.

5.3 Laboratory Director

It is the responsibility of the Laboratory Director to emphasize the importance of data quality with the laboratory staff. It is also the responsibility of the Laboratory Director to maintain updated, accurate SOPs and method manuals for use in the laboratory, and to respond to the internal laboratory and data audits.

In routine daily applications, the Laboratory Director must review and/or designate authorized personnel to review the data reports that are produced by the laboratory. In this final review, the QC procedures as described in this document must be verified, and any anomalies found must be investigated and corrected. The Laboratory Director has the discretion to report anomalous data, provided that any problems (i.e. missed holding times, QC samples out of control) are fully documented and explained in the project narrative, and their effect on the data explained.

The Laboratory Director has the responsibility and authority, along with the QA Officer to review and approve QAPjPs under which the laboratory will be reporting data.

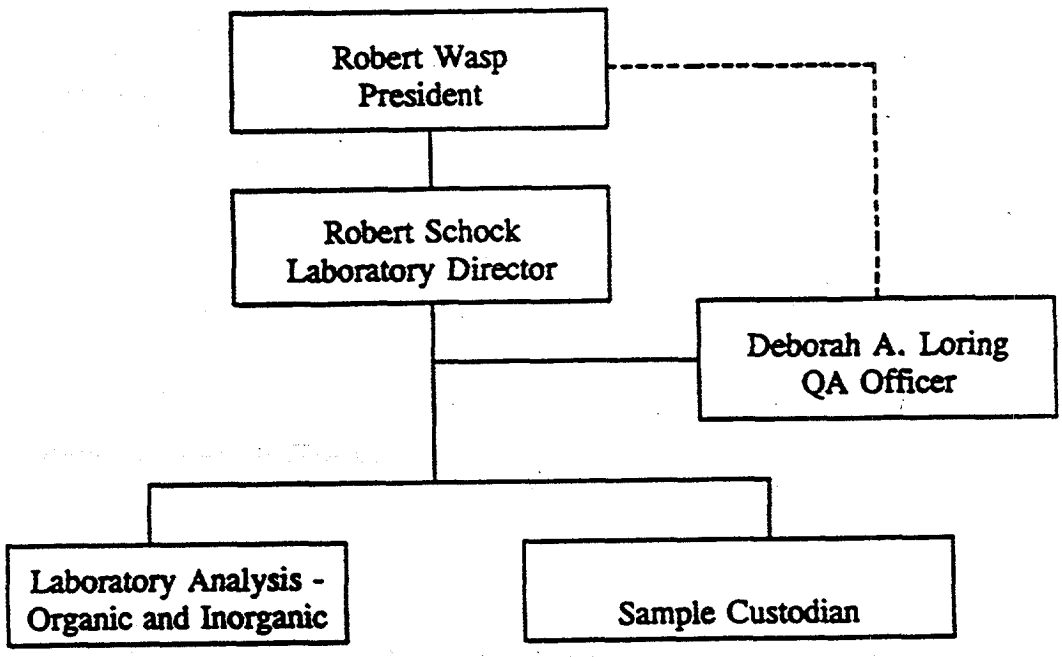
5. Responsibilities and Authorities (con't.)

The Laboratory Director has the authority to change and update any procedures in the laboratory as long as the SOPs are updated to reflect these changes.

5.4 Laboratory Staff

Control of data quality begins at the bench level. The laboratory staff, and their training in data quality matters is essential in maintaining a laboratory with consistent high quality output. It is the responsibility of each individual to ensure that his/her analytical work meets with the requirements of the methodology, the SOPs, and the QAPP.

Each employee has the authority to accept or reject data based on these criteria. If any data is to be accepted which does not meet established QC guidelines, it must be with the written approval of the manager.



ELI Laboratory Organization Chart
Figure 5.1

6. Sampling Procedures

Quality Assurance in field sampling procedures is of vital importance in achieving accurate and representative analytical results. This document addresses sampling procedures only so far as to outline how sample containers are provided to field personnel, proper preservation techniques, and holding times in use at the laboratory. The responsibility for implementing a proper sampling program, including sample collection procedures, the use of appropriate containers, preservation techniques, proper transport of samples to the laboratory, and ensuring that the samples are shipped in a timely fashion to allow the laboratory to meet the holding times, is the responsibility of the field personnel.

Chain of custody procedures and documentation, which are a key part of this process, are discussed in Section 7.0.

6.1 Bottles

Bottles can be supplied to the client on request. Both clear glass, brown glass, and polyethylene bottles are available depending on the test requests associated with the sampling event. Glass bottles are supplied with teflon-lined caps to prevent contamination from the caps. Upon arrangement with the client, preservatives are included in the bottle. In some cases, upon arrangement with the client, preservatives may be supplied in a separate container with instructions for their use.

A complete listing of sizes, bottle types, and preservatives used are found in Table 6.1 for aqueous samples and Table 6.2 for solid samples.

6. Sampling Procedures (con't.)

6.2 Holding Times

Holding times applied are listed in Table 6.1 for aqueous samples and Table 6.2 for solid samples. Holding times are calculated from the date of sample collection.

Clients of the laboratory are urged to return samples to the laboratory as soon as possible to allow the laboratory to meet the specified holding times. In the case where a holding time is missed, due to either being held in the field or due to laboratory error or problems, the client will be notified immediately for instructions. If analytical data is generated from samples which have exceeded their holding time, this will be clearly stated in the project narrative.

Table 6.1
Container, Preservative, and Holding Time Requirements
Aqueous Samples

Parameter	Minimum Volume Required[1] (ml)	Container[2]	Preservative	Maximum Holding Time[3]
Acidity	100	P, G	4°C	14 days
Alkalinity	100	P, G	4°C	14 days
Ammonia	500	P, G	H_2SO_4 to pH < 2, 4°C	28 days
BOD, 5 day	500	P	4°C	48 hours
Chloride	100	P, G	4°C	28 days
Chlorine, Residual	500	P, G	4°C	ASAP
COD	250	P, G	H_2SO_4 to pH < 2, 4°C	28 days
Cyanides, Total	500	P, G	4°C, NaOH to pH > 12	14 days
Fluoride	500	P	4°C	28 days
Hardness, Total	100	P	4°C	6 months
Kjeldahl Nitrogen, Total	1000	P, G	H_2SO_4 to pH < 2, 4°C	28 days
Metals, Total and Dissolved[4] except:	100	P	HNO_3 to pH < 2	6 months
Mercury, Total and Dissolved[4]	100	P	HNO_3 to pH < 2	28 days

Table 6.1
Container, Preservative, and Holding Time Requirements
Aqueous Samples

Parameter	Minimum Volume Required[1] (ml)	Container[2]	Preservative	Maximum Holding Time[3]
Hexavalent Chromium	100	P	4°C	24 hours
Nitrate	100	P, G	4°C	48 hours
Nitrate/Nitrite	100	P,G	4°C	28 days
Nitrite	100	P,G	H_2SO_4 to pH < 2	48 hours
Oil & Grease	1000	G	H_2SO_4 to pH < 2, 4°C	28 days
pH	100	P, G	4°C	ASAP
Phenols	100	G	H_2SO_4 to pH < 2 4°C	28 days
Solids, Total	100	P, G	4°C	7 days
Solids, Total Dissolved	100	P, G	4°C	7 days
Solids, Total Suspended	100	P, G	4°C	7 days
Solids, Total Volatile	100	P, G	4°C	7 days
Solids, Settleable	100	P, G	4°C	7 days
Surfactants	100	P	4°C	48 hours
Sulfate	100	P,G	4°C	28 days

Table 6.1
Container, Preservative, and Holding Time Requirements
Aqueous Samples

Parameter	Minimum Volume Required[1] (ml)	Container[2]	Preservative	Maximum Holding Time[3]
Sulfides, Total	500	P,G	4°C, NaOH to pH> 9 Zn acetate	7 days
Turbidity	100	P, G	4°C	48 hours
Organochlorine Pesticides & PCBs	1000	G, teflon lined cap	4°C	7 days to extn 40 days from extn. to analysis
Purgeable Aromatics	40 (x 2)	G, teflon lined cap	HCl to pH < 2 4°C	14 days
Purgeable Halocarbons	40 (x 2)	G, teflon lined cap	4°C	14 days
Semivolatile Organics	1000	G, teflon lined cap	4°C	7 days to extn 40 days from extn. to analysis
Volatile Organics	40 (x 2)	G, teflon lined cap	HCl to pH < 2 4°C	14 days

1 Represents the minimum volume for one analysis. It is recommended that double the volume be collected for possible reextractions/reanalyses. For MS and MSD or MD, triple the volume must be collected.
2 P = Polyethylene, G = Glass
3 Holding times are calculated from date of sample collection unless otherwise specified.
4 Dissolved metals should be field filtered.

Table 6.2
Container, Preservative, and Holding Time Requirements
Solid Samples

Parameter	Minimum Weight Required[1]	Container[2]	Preservative	Holding Time[3]
Cyanides, Total	2 oz.	G, Amber, teflon lined cap	4°C	14 days
Metals, Total except:	15 g	G, teflon lined cap	4°C	6 months
Hexavalent Chromium	50 g	G, teflon lined cap	4°C	24 hours to extn
Mercury, Total	15 g	G, teflon lined cap	4°C	28 days
Sulfides, Total	2 oz.	G, Amber	4°C	7 days
Volatile Organics	10 g (x 2)	G, teflon lined cap	4°C	14 days
Organochlorine Pesticides & PCBs	4 oz.	G, teflon lined cap	4°C	14 days to extn. 40 days from extn. to analysis
Purgeable Halocarbons	10 g (x 2)	G, teflon lined cap	4°C	14 days
Purgeable Aromatics	10 g (x 2)	G, teflon lined cap	4°C	14 days
Semivolatile Organics	4 oz.	G, teflon lined cap	4°C	14 days to extn. 40 days from extn to analysis

Table 6.2 (con't.)
Container, Preservative, and Holding Time Requirements
Solid Samples

Parameter	Minimum Weight Required[1]	Container[2]	Preservative	Maximum Holding Time[3]
Total Petroleum Hydrocarbons	4 oz.	G, teflon lined cap	4°C	14 days
TCLP	4 oz.	G, teflon lined cap	4°C	Days to TCLP extn Volatiles: 14 Semivolatiles: 14 Metals: 180 except Hg: 28 Days to Preparation Semivolatiles: 7 Days to Analysis Volatiles: 14 Semivolatiles: 40 Metals: 180 except Hg: 28

1 Represents the minimum volume for one analysis. It is recommended that double the volume be collected for possible reextractions/reanalyses. For MS and MSD or MD, triple the volume must be collected.
2 P = Polyethylene, G = Glass
3 Holding times are calculated from date of sample collection unless otherwise specified.

Section 7. Sample Custody

The purpose of the chain of custody procedure is to document the movement and custody of the sample from the time of collection through analysis in a legally defensible manner The samples received at ELI are received by the Sample Custodian.

The chain of custody record should contain, at a minimum, the following information:

- Field Identification Number
- Signature of Sampler
- Date and Time of Collection
- Sample Matrix
- Sample Preservative
- Number of Containers
- Parameters Requested for Analysis
- Signatures of All Persons Involved in the Sampling and Transport to the Laboratory

When samples arrive at the laboratory, the Sample Custodian documents the condition of the cooler on the custody form. The labels are checked against the chain of custody for any discrepancies and the sample conditions are checked. Use of the proper containers and preservatives is verified. The sample custodian then assigns unique laboratory numbers to each sample.

7. Sample Custody (con't.)

The samples are then transferred to a refrigerator in the secured laboratory area. The refrigerator is maintained at approximately 4^{o} + 2^{o} C prior to preparation and analysis and checked daily. Analysts will maintain the samples in their possession or in view at all times when the samples are outside of the secured storage area.

Figure 7.1 shows the sample labels supplied to the samplers on request. Figure 7.2 shows the sample custody record used by ELI.

ENVIRONMENTAL LABS, INC.
CLIENT:_____
COLLECTED BY:_____
PROJ. #:_____I.D.:_____
DATE:_____TIME:_____

Figure 7.1
Sample Label

ENVIRONMENTAL LABORATORIES, INC.
analytical testing and environmental sciences

CHAIN - OF - CUSTODY RECORD

142 Temple Street New Haven, CT 06…
Phone: (203) 789-1260 Fax: (203)789-…

PROJECT NAME: PROJECT LOCATION: PROJECT NUMBER:

SOURCE CODES: W = Well, S = Soil, O = Outfall, R = River/Stream, WO = Waste Oil, LF = Landfill, RO = Run Off, WW = Wastewater, B = Bottom Sediment, L = Lake/Ocean, SW = Sewage, X = Other:Specify______, SG = Sludge

ITEM NO.	SAMPLE I.D.	SOURCE CODE	CONTAINER				ANALYSIS REQUIRED	COMMENTS	TRANSFER NO. AND CHECK				ELI SAMPLE #
			NO.	TYPE	SIZE	PRESERVE			1	2	3	4	

Container Codes: P = Plastic, E = EPA Vial, G = Glass, A = Amber Glass, S = [Sterile Bottle?]
Preservation Codes: I = Iced, F = Filtered, N = Nitric Acid (HNO_3), H = Hydrochloric Acid (HCl), S = [Sodium Hydroxide (NaOH)?], T = Sodium Thiosulfate, [illegible] = [Sulfuric Acid?]
O = Other Specify______

SAMPLER'S SIGNATURE	AFFILIATION	DATE	TIME

ADDITIONAL COMMENTS:

TRANSF NO.	ITEM NO.	TRANSFERS RELINQUISHED BY	ACCEPTED BY	DATE	TIME
1					
2					
3					
4					

Figure 7.2
Chain of Custody

Section 8. Calibration Procedures and Frequency

8.1 Regulatory Influence on Calibration Procedures

Calibration procedures vary greatly depending on the methodology, instrument type, regulatory program, and project specific data quality objectives and detection limits. ELI works under various federal regulatory programs including RCRA, NPDES, and SDWA, as well as under state programs with various requirements.

The standard operating procedures applied for calibration reflect the different requirements found in the methodology prescribed under the various regulatory programs. They are described in general in this document.

8.2 Calibration Standards

Primary standards from which calibration standards are made are purchased either neat, or in solution or solvent. The calibration standards are purchased from reliable commercial vendors. They are of the highest purity obtainable. Standard receipt is recorded in a logbook so that all standards are traceable to their original source. Each standard is assigned a unique identifier, and labeled with the receipt date and the expiration date.

The use of Initial Calibration Verification in metals analysis and Laboratory Control Samples in all analyses serves to verify the accuracy of all calibration standards by checking the standard against a second compound or element source.

Section 8. Calibration Procedures and Frequency (con't.)

8.3 Gas Chromatograph (GC) Calibration

For RCRA analyses (8000 series), the SW-846 methodology requires a five point calibration for GC analyses. For NPDES analyses (600 series), a three point calibration is required. In some of the GC methodology, internal standard calibration is used. In others, external calibration is used. For SDWA analyses (500 series), a five point low level calibration is performed.

In both cases, either the Response Factor (RF) or the Calibration Factor (CF) is calculated for each of the analytes, and the Percent Relative Standard Deviation (%RSD) is calculated and compared to the limits as defined in the methods.

Continuing calibration is performed on a routine basis (in most cases every 10 samples), and the RF or CF is calculated, and compared with the average RF or CF. The percent difference is then calculated and compared to the limits as specified in the methods. If the percent difference does not meet the listed criteria, the initial calibration must be rerun.

8.4 Gas Chromatograph/Mass Spectrometer (GC/MS) Calibration

For semivolatile analysis, Decafluorotriphenylphosphine (DFTPP) is used to tune the mass spectrometer. The DFTPP must meet the criteria listed in the methodology. For volatiles analysis, Bromofluorobenzene (BFB) is used to tune the mass spectrometer, and it must also meet the criteria listed in the methodology. In most methods, the instrument tuning criteria is required to be met every twelve hours. In the 600 series methods, the tuning criteria is required to be met daily.

Section 8. Calibration Procedures and Frequency (con't.)

For RCRA analyses (8000 series), the SW-846 methodology requires a five point calibration for GC/MS analyses. For NPDES analyses (600 series), a three point calibration is required. For SDWA analyses (500 series), a five point low level calibration is performed. In all cases, internal standard calibration is used.

The RF is calculated for each analyte in the curve, and the average RF and %RSD is calculated for each analyte and compared to the criteria listed in the methodology. In most methodology, the RF must be verified either each working day or for each twelve hour period in which samples are run. The percent difference of the continuing calibration response factors are compared to those of the intial calibration and if they do not meet the requirements, the initial calibration must be rerun.

8.5 ICP Calibration

ICPs must be calibrated according to the manufacturer's instruction. A daily run sequences starts with a calibration and is followed by Initial Calibration Verification (ICV) from a separate source. The ICV warning limits are 90-110% of the true value of each element in the ICV. The ICB is then analyzed and must contain $\leq$ 2 times the Quantitation Limit of each element to be analyzed. A low level standard is run to determine the accuracy at the low end of the calibration range. The run then proceeds with an ICSA and ICSAB (Interference Check Standards). The analytes in the ICSAB must be between 80-120% to be considered valid.

Continuing Calibration Verifications (CCVs) and Continuing Calibration Blanks (CCBs) are analyzed at a frequency of 10% and must meet the same criteria as that for the ICV and ICB. The sequence is ended with a CCV.

Section 8. Calibration Procedures and Frequency (con't.)

8.6 Graphite Furnace Atomic Absorption (GFAA) Spectrophotometer Calibration

The GFAA is calibrated using a minimum of three standards and a blank. Subsequent to the initial calibration, CCVs and CCBs are analyzed at a frequency of 10% and the control limits are 80-120% of the true value for the CCV, and $\leq$ 2 times the Quantitation Limit for the CCB. The sequence is ended with a CCV.

8.7 Wet Chemistry

The various wet chemistry procedures have calibration protocols in each of the methods quoted. Often, the calibration procedure calls for a 5 point calibration curve to meet a correlation coefficient of $\geq$ 0.995. Other instruments (such as the microwave digestor) are calibrated according to the manufacturer's specifications.

Section 9. Analytical Procedures

Methodologies applied are driven by the regulatory program under which the analytical measurement is performed. ELI analyzes samples under the NPDES program, the RCRA program, and the SDWA program. Each of these requires various methodologies to be applied.

Methodologies are available to the laboratory staff in the form of either standard operating procedures (SOPs), actual copies of the methods in a central place in the laboratory accessible to all analysts, or both.

The applications of NPDES methodologies is outlined in the Federal Register, and consists of methods listed in 40 CFR Part 136, (e.g. Method 624, 625, 200.7, etc.), Wet Chemistry and some metals methods for NPDES are contained in "Standard Methods for the Examination of Water and Wastewater", 17th edition, and Methods for Chemical Analysis of Water and Wastes," EPA-600/4-79-020 (revised March 1983).

Recommended RCRA methodologies are contained in "Test Methods for Evaluating Solid Waste" (SW-846), 3rd edition, 1986, and Update I, 1989. RCRA methodologies are applied to both solids and ground and surface water, and are most commonly used in a multi-media site assessment type project. As SW-846 is a recommended guidance document, many of these methods are available to the laboratory analysts in the form of Laboratory SOPs as well as in the methods manual, in order to properly define ELI's approach to the SW-846 methods.

ELI uses appropriate drinking water methods as required in the Safe Drinking Water Act (SDWA). These methods are particularly stringent to achieve the objectives of low level detection limits and a high level of confidence in the accuracy and precision of the data. These methods are available in the laboratory.

Section 9. Analytical Procedures (con't.)

An SOP index is kept at ELI to reference each SOP, and its revision and date. SOPs are available to the laboratory analysts and are updated when the methodology is changed.

ELI can also develop methodology to meet project specific criteria. In this way, the laboratory can design a method to meet specific DQOs which are defined by the client on a project specific basis. When methodology is developed, the method detection limit is documented using the procedure listed in 40 CFR Part 136 Appendix B. The method is also documented in the form of a laboratory SOP.

Section 10. Data Reduction, Validation, and Reporting

10.1 Data Reduction

Data reduction can take various forms. It can include anything from recording an electronic reading from an instrument (i.e. pH Meter) to reducing and reviewing computer generated data from an autosampler run (i.e. GC/MS). The analyst at the bench level who performs the analysis also does the initial data reduction and calculations. The organics analysts are experienced in chromatography and mas spectrometry and are able to determine the absence or presence of a compound based on its retention time and/or pattern in the case of multicomponent analytes, and based on the mass spectrum in the case of GC/MS. The metals chemists are experienced in the operation and review of ICP and AA data and are trained to recognize matrix effects and spectral interferences. The analysts involved in wet chemistry and sample preparation are well trained in the operation of the various types of equipment which are used in these methods.

Benchsheets, analytical run logs, and SOPs, all of which are discussed in detail in Sections 9 and 17, prompt the analyst to follow appropriate calibration, calculation and acceptance or rejection of analytical data, and to document this on the benchsheets and instrument run logs.

Section 10. Data Reduction, Validation, and Reporting (con't.)

10.2 Data Review

ELI believes that the trained analyst at the bench level is most capable of making decisions about acceptability of the data that is generated. The method blanks and LCS are used as indicators of data quality (as described in Section 11 and 14) and after calibration and other method criteria have been met, these QC samples are used as the basis on which data is defined as acceptable.

Due to the various complex matrices involved in generating environmental data, anomalous results often are encountered. In these cases, the experience of the analysts is heavily weighed. For example, surrogate spikes, matrix spikes, matrix spike duplicates, matrix duplicates, and analytical spikes can often show that there is a matrix effect which can result in data which is biased high or low due to interferences or suppression of response.

In these cases, it may be necessary to rerun samples to show the consistency of the matrix effect. In other cases, it may be apparent that the laboratory analysis is valid even though a matrix effect is indicated. In this case, it is necessary for the analyst to obtain the approval of the Laboratory Director or his/her designate prior to reporting anomalous data. All anomalies in analytical data must be outlined in the project narrative.

Section 10. Data Reduction, Validation, and Reporting (con't.)

Once the data is reviewed and reduced, it is entered into the LIMS system. Prior to report generation, a second level review is performed by the Laboratory Director or his/her designate. The Laboratory Director or designate checks the data and either approves the data in the computer system and on the project report. The Laboratory Director checks not only the validity of the analytical data, but also does a general review to determine if the client's objectives have been met. At this stage, a project narrative is generated and any comments or anomalous findings are documented in the narrative.

A third review is performed on Five percent of the project reports. This review is performed by the QA Officer and is described in Section 12.

10.3 Data Validation

ELI considers the data which is reported by the laboratory to have been "validated" by laboratory staff and management. However, data validation also refers to the systematic process by which an outside firm is hired to perform a data review and flag data according to specified EPA data validation protocols. ELI is always willing to work with validators and provide information as agreed upon with the client and validators, upon authorization of the client.

10.4 Data Reporting

Data reports can be customized to meet the needs of the client and the specific regulatory agency. At a minimum, ELI reports include the project number, a cross reference between the ELI Sample Number and the Client Identification Number, a copy of the chain of custody, project narrative, dates of sampling, receipt, preparation, and analysis, analytical results, and quantitation limits. All projects include the authorization signature of the Laboratory Director or his/her designate.

Section 10. Data Reduction, Validation, and Reporting (con't.)

Additional levels of project reports are available. ELI can also include results of all QC samples including LCS, matrix specific QC samples, and method blanks.

Full "CLP-type" project reports can also be issued when requested by the clients. These include reporting on CLP-like forms (the term CLP-like is used as CLP report forms are specific to CLP analytes and methodology, a CLP-like form is meant to represent a reasonable counterpart containing information as found in the CLP format), and providing supporting raw data and copies of logbooks as necessary. In addition, calibration and other summary forms are provided, along with the raw data such as chromatograms, mass spectra, quantitation reports, instrument printouts.

ELI is also capable of meeting client needs in providing both disk deliverables and customized spreadsheet reporting formats. Arrangements for any custom data reporting must be made with ELI in advance.

Section 11. Internal Quality Control Checks

11.1 Introduction

A well-defined internal quality control program (QC), is in use at ELI. The laboratory uses a number of different types of QC samples to document the validity of the generated data. The types of QC samples, their frequency, and their use, is outlined below.

11.2 Laboratory Blank Samples

a. Preparation Blanks - (Reagant blank, Method Blank) - A sample of laboratory water (or in some cases, for solids, a blank matrix such as Ottawa Sand or sodium sulfate) that is carried through the entire analytical procedure (digested or extracted, and then analyzed). These blanks are prepared in the same manner, using the same reagants and process as the samples in order to assess contamination during the analytical process. Preparation blanks are prepared once per batch or once per twenty samples, whichever is more frequent.

b. Holding Blank - A sample of laboratory water which is stored in the volatile organics refrigerator and analyzed for volatile organics, to assess contamination which may be introduced during sample storage. Holding blanks are analyzed once per week.

c. Calibration Blanks - A sample of laboratory water or solvent containing the same reagants at the same concentration as the calibration standards. Initial and Continuing Calibration Blanks (ICBs and CCBs) may be used to detect any instrument drift or contamination. Calibration blanks may be used as a calibration point in the curve for some methods.

11. Internal Quality Control Checks (con't.)

11.3 Field Blank Samples

a. Trip Blank - A sample of laboratory water which is handled in the same manner as field samples and analyzed for volatile organics to assess volatile contamination which may be introduced in transport. Field blank sample frequency is the responsibility of the field sampling crew, however, ELI recommends a frequency of one per cooler.

b. Equipment Blanks - A sample of laboratory water which is passed through the sampling device to assess contamination which may be introduced from the sampling equipment. Field blank sample is determined by the field sampling crew, however, ELI recommends a frequency of one per sampling event.

11.4 Laboratory Control Samples

a. Laboratory Control Sample (LCS) - A control sample of known composition spiked with representative target analytes appropriate for the analytical method. Aqueous and solid laboratory control samples are analyzed using the same process as that of the samples, in order to verify the accuracy of the laboratory analysis and that the laboratory is in control during generation of analytical data. The frequency of LCS analysis is once per batch.

11.5 Matrix QC Samples

a. Analytical Spike or Post-Digest Spike - An aliquot of digested sample into which a known amount of element is added. The post-digest spike is routinely used in graphite furnace analysis only. The analytical spike analysis immediately follows the sample analysis and the percent recovery is calculated in order to assess the effect of the matrix on the method. Matrix-specific QC frequency varies with the regulatory program and with project specific Data Quality Objectives (DQO's), however is generally analyzed at a frequency of 1/20 samples.

11. Internal Quality Control Checks (con't.)

b. Matrix Spike (MS) - An aliquot of sample (water, soil, sludge) into which a known amount of representative target analytes are added. The MS is subjected to the entire analytical procedure and the percent recovery of the spiked analytes are measured order to assess the effect of the matrix on the performance of the method. Matrix-specific QC frequency varies with the regulatory program and with project specific DQO's, however is generally analyzed at a frequency of 1/20 samples.

c. Matrix Spike Duplicate (MSD) - A second aliquot of the same sample as the matrix spike to which a known amount of representative target analytes are added and taken through the entire procedure. MSD's are generally used for organics analyses. The Relative Percent Difference of the spike recoveries are calculated using the MS and MSD are in order to assess the precision of the method for that matrix. Matrix-specific QC frequency varies with the regulatory program and with project specific DQO's, however the MSD is generally analyzed at a frequency of 1/20 samples for organics analyses.

d. Matrix Duplicate (MD) - A second aliquot of a sample carried through the same process as the sample aliquot. The MD is used to measure the precision of the analytical method for a specific sample matrix. Matrix duplicates are generally analyzed in lieu of matrix spike duplicates for inorganic analyses. For metals analysis this precision measurement is considered valid if the analyte is detected at a certain level above the IDL (e.g. for Metals, the analyte must be at 10 times the IDL for the precision measurement to be considered representative). Matrix-specific QC varies with the regulatory program and with project specific DQO's, however the MD is generally analyzed at a frequency of 1/20 samples for inorganic analyses.

11. Internal Quality Control Checks (con't.)

11.6 Other Sample Spikes

a. Surrogate Spike (SS) - Compounds which are added to each blank, sample, matrix spike, matrix spike duplicate and standard (in appropriate GC/MS and GC methods) which are chemically similar to the target analytes. The surrogate spikes provide information about the accuracy of the analysis in individual sample matrices.

b. Internal Standard (IS) - Compounds added to every standard, blank, matrix spike, matrix spike duplicate, sample (for volatile), and sample extract (for semivolatile) at a know concentration prior to analysis in appropriate GC and GC/MS methods. Internal Standards are used as the basis for quantitation of the target analytes in GC/MS and some GC analyses and reflect the accuracy of the injection.

Section 12. Performance and Systems Audits

12.1 Systems Audits

The QA Officer of ELI is directly responsible for monitoring compliance with the specific quality control requirements in this document and in the methodology quoted herein. This monitoring is accomplished using two programs. The first program is a laboratory auditing program which utilizes detailed checklists. The QA Officer is responsible for auditing each of the areas as outlined in Figure 12.1. An example of one of these checklists is found in Figure 12.2. The laboratory audits are conducted once every six months, or more frequently upon the judgment of the QA Officer or at request of program management or laboratory management.

The audits are conducted with the Laboratory Director or his/her designate. The QA Officer must use the checklist and may also include comments in a narrative format. It is imperative that the QA Officer note not only deficiencies, but any significant improvements made in the laboratory operation. The audit report, consisting of an introductory narrative, a copy of the audit checklist, a summary of deficiencies found and improvements noted, must be submitted to the Laboratory Director and President of the laboratory within two weeks.

The audit report is reviewed by the Laboratory Director and an audit response plan, noting dates when deficiencies are to be corrected by, must be submitted to the QA Officer and President within a month from the date of receipt of the audit report. All documentation of these audits must be archived with the QA records. In subsequent audits, the corrections in the audit response plan should be monitored.

Section 12. Performance and Systems Audits (con't.)

12.2 Data Audits

The second part of the auditing program consists of random data audits performed on client projects. The outline for the data audits is found in Figure 12.1. These data audits are required to be performed on a monthly basis. The results of these data audits are documented and distributed to the laboratory manager and the President. Although these audits may be performed either prior to or after delivery of the project report to the client, any significant errors detected in these audits must be corrected in the final report, and the client must be notified if the results have already been reported. Approximately five percent of the projects reported are selected for data auditing.

Laboratory Audit Areas

1. Sample Login and Chain of Custody in the Laboratory
2. Organic Sample Preparation
3. Wet Chemistry
4. Organic Sample Analysis by GC
5. Organic Sample Analysis by GC/MS
6. Metals Analysis
7. Data Reporting and Review
8. Data Archives

Data Audit Areas

1. Standard Calibration Curve
2. QC samples including method and field blanks, duplicates, laboratory control spikes, matrix spikes, matrix spike duplicates, and matrix duplicates.
3. Sample results
4. Method compliance (including SOP, QAPP, QAPjP if applicable)
5. Project Report
6. Turnaround time

Data and Laboratory Audits Areas
Figure 12.1

QA Systems Audit - ELI
GC/MS - Volatile Organics

		YES	NO
1.	Are SOP's available to the personnel?	___	___
2.	What is the source of the reagant water?	___	___
3.	Are daily method blanks meeting criteria (all volatile compounds < quantitation limit except ketones and methylene chloride < 5 times the quantitation limit)? Verify.	___	___
4.	Are LCS being analyzed with every batch?	___	___
5.	Are recent LCS within control limits? Verify.	___	___
6.	Describe procedure in use if LCS is outside of control limits.		
6.	Are samples above calibration range diluted and rerun?	___	___
7.	Are the standards stored properly and prepared with the appropriate frequency? (minimum every two weeks)	___	___
8.	Are the standards labeled with the expiration date?	___	___
9.	If holding times are exceeded, is the lab director notified?	___	___
10.	Is the balance in use being checked daily? Verify.	___	___
11.	Are Class S weights used?	___	___
12.	Are stock standards solutions traceable to standards receipt log?	___	___

Audited Conducted by:_____ Date:_____

Lab Representative:_____

Example Laboratory Audit Checklist
Figure 12.2

Section 13. Preventative Maintenance

To prevent instrument downtime, the analysts at ELI are skilled in maintenance of the analytical equipment. Spare parts such as filaments for GC/MS, spare traps for the purge and trap, plumbing fittings, lamps and electronic components are kept on hand.

Preventative maintenance, such as clipping capillary columns, changing pump oil and injection port liners, and cleaning of cells are performed on a regular basis and documented in the maintenance logs which are kept for all major pieces of equipment. Instrument run logs are also in use and can be used to detect degrading instrumental conditions.

In addition, ELI maintains service contracts on all major pieces of equipment including the GC/MS, ICP, Graphite Furnace AA, and the GC.

Section 14. Calculation of Data Quality Indicators

14.1 Data Quality Indicators

Data Quality Indicators can be expressed in terms of precision, accuracy, representativeness, completeness, and comparability. In addition, sensitivity can also be used to assess whether project specific data quality objectives (DQO's) have been met. DQO's are generally determined on a project specific basis and are often outlined in numeric form in a site specific Quality Assurance Project Plan. The lab operates under defined DQO's at all times.

14.2 Precision

Precision is the agreement in a set of replicate measurements, and is indicative of the reproducibility between measurements. Reproducibility in a specific matrix is measured using the Relative Percent Difference (RPD) of the Matrix Spike and Matrix Spike Duplicate pair, or using the RPD of the results of a sample and its Matrix Duplicate. The RPD is measured as follows:

$$RPD = \frac{|D1 - D2|}{(D1 + D2)/2} \times 100\%$$

where,

RPD = Relative Percent Difference
D1 = First Value
D2 = Second Value

14. Calculation of Data Quality Indicators (con't.)

14.3 Accuracy

Accuracy is a measurement of agreement between an analyzed value and the true value. Laboratory accuracy is evaluated by comparing the percent recovery of the target analytes in the LCS against their true value. The recovery is calculated as follows:

$$\text{Percent recovery} = \frac{X}{T} \times 100\%$$

where,
X = The measured value
T = true or spiked value

Accuracy in a specific sample matrix is measured by the percent recovery of the matrix spike compounds. The matrix specific percent recovery is defined as:

$$\text{Percent Recovery} = \frac{X(m) - X(s)}{S} \times 100\%$$

where,
X (m) = quantity determined in spiked sample
X (s) = quantity determined in unspiked sample
S = quantity spiked

14.4 Representativeness

Representativeness is the degree to which data is indicative of environmental conditions. The data is considered representative if appropriate field procedures and techniques are followed and analytical laboratory techniques are followed. Special attention must be paid to complex sample matrices in order to achieve representative results. Care can be taken in the sample preparation step to achieve a homogenous sample aliquot. In some cases, with multi-phasic samples, the phases must be analyzed separately.

14. Calculation of Data Quality Indicators (con't.)

14.5 Completeness

Completeness is a measure of the amount of valid data obtained from the analytical measurement system compared with the amount of data expected to be obtained. It is calculated as the total amount of acceptable data divided by the total number of data attempted, multiplied by 100%.

$$C = \frac{V}{T} \times 100\%$$

where,
C = Percent Completeness
V = Number of measurements judged as usable
T = Total Number of Measurements

14.6 Comparability

Comparability is the degree to which one set of data can be compared to another set of data. Comparability of data sets can be ensured by using established analytical methodology and checking the validity of analytical standards by performing calibration verifications, laboratory control sample analysis, and performance in proficiency sample testing.

Section 15. Corrective Action

An important part of any quality assurance program is a well-defined effective policy for correcting quality problems. The various systematic procedures defined in this QAPP are intended to allow problem solving and decision making at the bench level inasmuch as routine problems may be solved and documented by the analyst at the time they occur.

Specific quality control procedures such as the laboratory control sample program and well defined standard operating procedures are designed to help analysts detect the need for corrective action. The experience of and analyst can be most valuable in identifying anomalous data or unstable equipment, and immediate corrective action must then be taken. The actions are documented in maintenance logs, analytical run logs, and analyst notebooks.

The need for more formal action may be identified by both internal and external performance audits and system audits (including data validation reports), through client and/or regulatory agency inquiries, or through identification by staff including management, the analysts, or the QA Officer. These types of actions are followed by a more formal corrective action process which includes documenting the problem, the examination into the cause of the problem, and finally, correcting the problem and documentation of the corrective action.

The documentation format for these type of corrective actions is kept informal to urge reporting of these issues. The QA Officer must, however, keep documentation which outlines the date the problem was reported, the examination into the cause of the problem, and the corrective action measures which were taken including the date on which they were implemented.

Section 16. Quality Assurance Reports to Management

Quality Assurance reports to management include the following information:

- Results of All Proficiency Testing.
- Responses to Proficiency Testing for Analytes outside of control windows.
- QA Walkthrough and Data Audits, and Responses to those audits.
- A copy of formal corrective actions.
- A narrative outlining any problems the laboratory is experiencing in general and noting improvements made in the laboratory.

The reports are compiled by the QA Officer in conjunction with the Laboratory Director and are reported to the President of ELI twice annually. Specific QA Reports for project related activity may be included in Quality Assurance Project Plans (QAPjPs).

Section 17. Laboratory Documentation

17.1 General Laboratory Documentation

The laboratory utilizes bound logbooks containing preprinted benchsheets for analytical documentation at the bench level. Instrument run logs, instrument maintenance logs, and various QC forms are also used to record information. In addition, raw data is generated by the various computer systems on the instruments. The laboratory uses a Laboratory Information Management System (LIMS) for project report generation. The following sections outline how these records are kept.

17.1 Bound Logbooks

Bound logbooks with preprinted benchsheets are used to document laboratory analyses. These benchsheets are custom designed to include fields for all of the data which is necessary to record in fully documenting analytical procedures. For wet chemistry analysis, logbooks are organized into analysis type (e.g. colorimetric, titrimetric, etc.).

Logbooks are kept in a consistent, traceable manner. Entries are dated and initialed. Errors are crossed out with one line and dated, and all information and observations are recorded, such as dilutions made to samples as well as stock standards in making secondary working standards, and emulsion formation in extraction procedures.

17.2 QC Records

QC records are kept in the form of bound logbooks and benchsheets. QC Records document various conditions in the laboratory, as well as calibration of universal equipment, such as balance logs. Refrigerator temperature monitoring records are

Section 17. Laboratory Documentation (con't.)

posted to the refrigerator to check maintenance of the temperature at 4°C ± 2°C. Standard receipt logs record the date of standard receipt, vendor, lot number, assigned laboratory ID and standard concentration and components. Login records and chain of custody records as described in Section 7 are also kept as part of the permanent project record.

17.3 Instrument Logbooks

All major pieces of equipment (ICP, GFAA, AA, GC/MS. GC) have associated instrument run logbooks or benchsheets which contain run information in which proper calibration and sequence procedures can be verified. These logbooks contain information such as date of analysis, analyst initials, injection times, instrument computer filenames, dilutions, etc. These also contain commentary information regarding the validity of the run or the need for reanalysis.

17.4 Maintenance Logbooks

Both preventative maintenance and routine and non-routine maintenance records, as described in Section 13, are recorded in logbooks specific to the equipment. The date, person who performed the maintenance, and an outline of the maintenance performed is recorded.

17.5 Computer Records

Computer records from both the LIMS system and the various data systems associated with specific instruments are archived onto magnetic storage media, such as tapes and disks. The tapes and disks are labeled so that the computer information may be reloaded and recovered at a later date if necessary.

Section 17. Laboratory Documentation (con't.)

17.6 Data Archives

All raw data is archived for a period of ten years subsequent to delivery of the data report.

APPENDIX D
STANDARD OPERATING PROCEDURES

APPENDIX D
STANDARD OPERATING PROCEDURES
(Adapted from document ECBSOPQAM, February 1991, EPA Region-IV)

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

SECTION 1
SAMPLE CONTROL, FIELD RECORDS, AND DOCUMENT CONTROL

1.1 Introduction

The objectives of this section are to present SBP standard operating procedures for sample identification, sample control and chain-of-custody, maintenance of field records, and document control.

A sample is defined as physical evidence collected from a facility, site, or the environment. For the purposes of this section, the term "physical evidence" also includes photographs, records, or any other tangible article collected from the environment, facility, or site.

All sample identification, field records, and chain-of-custody records shall be recorded in waterproof, non-erasable ink. If errors are made in any of these documents, SBP personnel will make corrections by simply crossing a single line through the error and entering the correct information. All corrections shall be initialed and dated by the investigator. If possible, all corrections should be made by the individual making the error.

If information is entered onto sample tags, logbooks, or sample containers utilizing stick-on labels, these labels should not be capable of removal later without leaving obvious indications of the attempt. Labels should never be placed over previously recorded information Corrections to information recorded on stick-on labels should be made as stated in the previous paragraph.

1.2 Sample and Evidence Identification

1.2.1 General

The method of sample identification utilized depends on the type of sample collected. Samples collected for in-situ field analyses are those collected for specific field analyses or measurements where the data are recorded directly in bound field logbooks or recorded directly on the Chain-of-Custody Record, with identifying information, while in the custody of the sampling team. Examples of such in-situ field measurements and analyses include pH, temperature, and conductivity. Also included in this category are those field measurements or analyses such as flow measurements, geophysical measurements, surveying measurements, etc. that are made with field instruments or analyzers, where no sample is actually collected.

1.2.2 Sample Identification

Samples, other than those collected for in-situ field measurements or analyses, are identified by using a standard sample tag/label (see next page) which is attached to the sample container. In some cases, particularly with biological samples, the sample tag may have to be included with or wrapped around the sample. The sample tags are sequentially numbered and are accountable documents after they are completed and attached to a sample or other physical evidence. The following information shall be included on the sample tag:

- project number;
- field identification or sample station number;

- date and time of sample collection;
- designation of the sample as a grab or composite;
- type of sample (water, wastewater, leachate, soil, sediment, etc.) and a very brief description of the sampling location;
- the signature(s) of the sampler(s) or of the designated sampling team leader (a team leader is a field investigator assigned by the project leader to be present during the collection of a specific sample and to be responsible and knowledgeable of all activities directly related to the collection of that sample).
- whether the sample is preserved or unpreserved;
- the general types of analyses to be conducted (checked on front of tag); and
- any relevant comments (such as readily detectable or identifiable odor, color, or known toxic properties).

The field sample station number is assigned by the project leader or field investigator. This number is ordinarily an alpha-numeric code, designed for a particular inspection or investigation. For example, if a sample is collected from a monitoring well installed during a site screening investigation conducted at the Abercrombie Widget Company, the alpha-numeric sample number code could be AW-001W. A surface soil sample from this facility might be identified as AW-002S. Each separate monitoring location should have a different numerical designation. Frequently, water and sediment samples are collected from the same sampling station and could have the same numerical designation. For example, water and sediment samples collected from the same location in the Oconee River at Station 001 would be identified as OR-001W and OR-001S, respectively. The project leader or field investigator shall exercise due caution to insure that sample station numbers are not duplicated during studies. The exact description of all sampling stations associated with field identification or sample station numbers shall be documented in the bound field logbooks.

If a sample is split with a facility, state regulatory agency, or other party representative, sample tags or labels with identical information should be attached to each of the sample containers by the party receiving the split sample. Also, all tags for blank or duplicate samples will be marked "blank" or "duplicate," respectively. This identifying information shall also be recorded in the bound field logbooks and on the Chain-Of-Custody Record as outlined in Section 2.4.

FIGURE 1.2.1
SAMPLE TAG

1.3 Chain-of-Custody Procedures

1.3.1 General

The possession of samples or other physical evidence shall be traceable from the time they are obtained until they are introduced as evidence in legal proceedings.

1.3.2 Sample Custody

A sample or other physical evidence is in custody if:

- it is in the field investigator's or the transferee's actual possession; or
- it is in the field investigator's or the transferee's view, after being in his/her physical possession; or
- it was in the field investigator's or the transferee's physical possession and then he/she secured it to prevent tampering; or
- it is placed in a designated secure area.

1.3.3 Chain-of-Custody Record

The field Chain-Of-Custody Record (Figure 1.3.1) is used to record the custody of all samples or other physical evidence collected and maintained by SBP personnel. This form shall not be used to document the collection of split or duplicate samples where there is a legal requirement to provide a receipt for samples (see Section 1.3.4).

The following information must be supplied in the indicated spaces (Figure 1.3.1) in detail to complete the field Chain-Of-Custody Record.

- The project number.
- The project name.
- All samplers and /or sampling team leader must sign in the designated signature block.
- The sampling station number, date, and time of sample collection, grab or composite sample designation, and a brief description of the type of sample and the sampling location must be included on each line (each line shall contain only those samples collected at a specific location).
- The sampling team leader's name should be recorded in the right or left margin of the Chain-Of-Custody Record when samples collected by more than one sampling team are included on the same form. The sampling team leader is an individual designated by the project leader to be responsible for all activities related to the collection of samples by a specific team of sampling personnel.

- The total number of sample containers must be listed in the indicated space for each sample. The total number of individual containers must also be listed for each type of analysis under the indicated media or miscellaneous columns. Note that it is impossible to have more than one media type per sample. The type of container and required analyses should be circled as indicated on the Record.

- The tag numbers for each sample and any needed remarks are to be supplied in the indicated column.

- The field investigator and subsequent transferee(s) must document the transfer of the samples listed on the Record in the spaces provided at the bottom of the Record. One of the samplers documented under the sampler(s) section must be the person that originally relinquished the samples or evidence or a designated field sample custodian who receives secured samples from sampling teams and maintains these samples under secure conditions. Both the person relinquishing the samples and the person receiving them must sign the form; the date and time that this occurred must be documented in the proper space on the Record. Usually, the last person receiving the samples or evidence should be a laboratory sample custodian or other evidence clerk.

- The remarks column at the bottom of the Record is used to record airbill numbers or registered or certified mail serial numbers.

The Chain-Of-Custody Record is a serialized document. Once the Record is completed, it becomes an accountable document and must be maintained in the project file. The suitability of any other form for chain-of-custody should be evaluated based upon its inclusion of all of the above information in a legible format.

1.3.4 Field Custody Procedures

- To simplify the Chain-Of-Custody Record and eliminate potential litigation problems, as few people as possible should handle the sample or physical evidence during the investigation or inspection.

- The field investigator is responsible for the proper handling and custody of the samples collected (Section 1.3.2) until they are properly and formally transferred to another person or facility.

- Sample tags shall be completed for each sample, using waterproof, non-erasable ink as specified in Section 1.3.2.

- All samples shall be sealed immediately upon collection utilizing the custody seal shown in Figure 1.3.2. The field investigator may write the date and his/her signature on the seal. This requirement shall be waived if the field investigator keeps the samples in his/her continuous custody from the time of collection until they are delivered to the laboratory analyzing the samples.

- All samples must be documented in bound field logbooks.

- A Chain-Of-Custody Record will be completed for all samples or physical evidence collected as specified in Section 1.3.3. A separate Chain-Of-Custody Record will be utilized for each final destination or laboratory utilized during the inspection or investigation.

- If chain-of-custody is required for documents received during investigations, they should be placed in large envelopes, and the contents should be noted on the envelope. The envelope shall be sealed and a custody seal placed on the envelope such that it cannot be opened without breaking the seal. A Chain-Of-Custody Record shall be maintained for the envelope. Any time the seal is broken, that fact shall be noted on the Chain-Of-Custody Record and a new seal affixed. The information on the seal shall include the field investigator's signature, as well as the date and time of sealing.

- Other physical evidence such as video tapes or other small items shall be placed in Zip-Loc® type bags or envelopes and a custody seal should be affixed so that they cannot be opened without breaking the seal. A Chain-Of-Custody Record shall be maintained for these items. Any time the seal is broken, a new seal shall be affixed. The information on the seal shall include the field investigator's signature, as well as the date and time of sealing.

- In general, SBP personnel shall not accept samples from other sources unless the sample collection procedures used are known to be acceptable, can be documented, and the sample chain-of-custody can be established. If such samples are accepted by SBP personnel, a standard sample tag containing all relevant information and the Chain-Of-Custody Record, shall be completed for each set of samples.

- The custody seals can be used to maintain custody on other items when necessary by using similar procedures as those outlined previously in this section.

1.3.5 Transfer of Custody and Shipment

- All physical evidence or sample sets shall be accompanied by a Chain-Of-Custody Record. When transferring the possession of samples, the individual receiving the samples shall sign, date, and note the time that he/she received the samples on the Chain-Of-Custody Record. This Chain-Of-Custody Record documents transfer of custody of samples from the field investigator to another person, to other laboratories, or other organizational elements.

- Samples shall be properly packaged for shipment (Section 7) and delivered or shipped to other designated laboratory for analyses. Shipping containers shall be secured by using nylon strapping tape and custody seals. The custody seals shall be placed on the container so that it cannot be opened without breaking the seals. The seal shall be signed and dated by the field investigator.

- When samples are split with a facility, state regulatory agency, or other government agency, the facility, state regulatory agency, or other government agency representative should sign the Chain-Of-Custody Record. The only exception is

that a Receipt For Samples Form will be used for RCRA, TSCA, and CERCLA samples as required by the appropriate regulations (Section 1.3.4).

- All samples shall be accompanied by the Chain-Of-Custody Record. The original and one copy of the Record will be placed in a plastic bag inside the secured shipping container if samples are shipped. One copy of the Record will be retained by the field investigator or project leader. The original Record will be transmitted to the field investigator or project leader after samples are accepted by the laboratory. This copy will become a part of the project file.

- If sent by mail, the package shall be registered with return receipt requested. If sent by common carrier, a Government Bill of Lading (GBL) or Air Bill should be used. Receipts from post offices, copies of GBL's, and Air Bills shall be retained as part of the documentation of the chain-of-custody. The Air Bill number, GBL number, or registered mail serial number shall be recorded in the remarks section of the Chain-Of-Custody Record or in another designated area if using a form other than that shown in Figure 1.3.1.

Figure 1.3.1
Chain of Custody Record

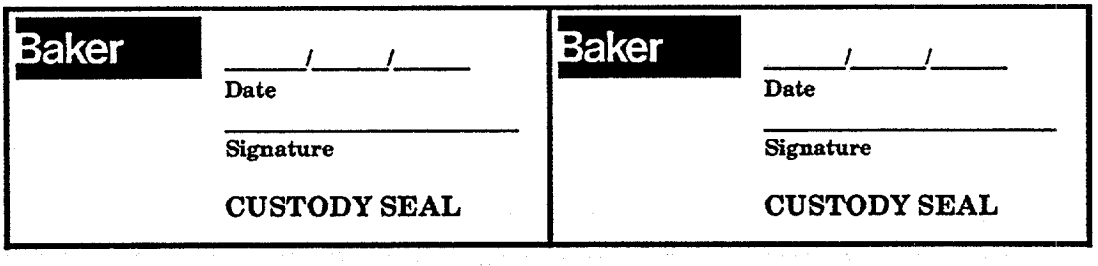
Baker Baker Environmental, Inc.
420 Rouser Road, AOP Building 3, Coraopolis, PA 15108

CHAIN-OF-CUSTODY RECORD

PROJECT NO.:	SITE NAME:					NO. OF CON-TAINERS							REMARKS
SAMPLERS (SIGNATURE):													
STATION NO.	DATE	TIME	COMP	GRAB	STATION LOCATION								

RELINQUISHED BY (SIGNATURE):	DATE/TIME:	RECEIVED BY (SIGNATURE):	RELINQUISHED BY (SIGNATURE):	DATE/TIME:	RECEIVED BY (SIGNATURE):
RELINQUISHED BY (SIGNATURE):	DATE/TIME:	RECEIVED BY (SIGNATURE):	RELINQUISHED BY (SIGNATURE):	DATE/TIME:	RECEIVED BY (SIGNATURE):
RELINQUISHED BY (SIGNATURE):	DATE/TIME:	RECEIVED FOR LABORATORY BY (SIGNATURE):	DATE/TIME:	REMARKS:	

Figure 1.3.2
Custody Seal



1.4 Receipt for Samples

1.4.1 General

Section 3007 of the Resource Conservation and Recovery Act (RCRA) of 1976 and Section 104 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) of 1980 require that a "receipt" for all facility samples collected during inspections and investigations be given to the owner/operator of each facility before the field investigator departs the premises. The Toxic Substances Control Act (TSCA) contains similar provisions.

1.4.2 Receipt for Samples Form

The Receipt For Samples Form (Figure 1.4.1) is to be used to satisfy the receipt for samples provisions of RCRA, CERCLA, and TSCA. The form also documents that split samples were offered and accepted or rejected by the owner/operator of the facility or site being investigated. The following information must be supplied and entered on the Receipt For Samples Form.

- The project number, project name, name of facility or site, and location of the facility or site must be entered at the top of the form in the indicated locations.

- The sampler(s) must sign the form in the indicated location.

- The facility/site owner/operator's acceptance or rejection of split samples must be checked in the appropriate place in the Split Samples Offered section of the form. The owner/operator should be requested to initial his acceptance or rejection by the check mark and to sign his name in this block indicating that he has been offered this choice if the offer is refused.

- Each sample collected from the facility or site must be documented in the sample record portion of the form. The sample station number, date and time of sample collection, composite or grab sample designation, whether or not split samples were collected (yes or no should be entered under the split sample column), the tag numbers of samples collected which will be removed from the site, a brief description of each sampling location, and the total number of sample containers for each sample must be given. If EPA sample tags are used for split samples, these tag numbers should be recorded under the remarks column.

- The bottom portion of the form is used to document the receipt of split samples by the owner/operator of the facility or site. One of the samplers must be requested to sign and complete the information in the "transferred by" section (date and time must be entered). The owner/ operator of the site must sign the "received by" section of the form (the owner/operator must give his title, and telephone number and give the date and time he/she signed the form). If the owner/operator refuses to sign the form, the sampler(s) should note this fact in the owner/operator's signature block and initial this entry.

The copy of the form is to be given to the facility or site owner/operator. The Receipt for Samples Form is serialized and becomes an accountable document after it is completed. The original copy of this form must be maintained in project files.

Figure 1.4.1
Receipt For Samples

SAMPLE RECEIPT CHECKLIST

CLIENT NAME _____ MEDLAB NO._____

PROJECT NAME _____

		COMMENTS
1.	_____ SHIPPED	_____
	_____ AIR BILL #	_____
	_____ HAND-DELIVERED	_____
2.	_____ COC PRESENT ON RECEIPT	_____
	_____ NO COC ON RECEIPT	_____
	_____ COC TAPE ON CONTAINERS/COOLERS	_____
	_____ NO COC TAPE ON CONTAINERS/COOLERS	_____
3.	_____ SAMPLE(S) INTACT ON RECEIPT	_____
	_____ SAMPLE(S) BROKEN/LEAKING	_____
	_____ OTHER (SEE COMMENTS)	_____
4.	_____ PROPER TEMPERATURE W/ICE	_____
	_____ IMPROPER TEMPERATURE W/O ICE	_____
5.	_____ PROPERLY PRESERVED	_____
	_____ IMPROPERLY PRESERVED	_____
	_____ NA	_____
6.	_____ RECEIVED WITHIN HOLDING TIME	_____
	_____ NOT RECEIVED WITHIN HOLDING TIME	_____
	_____ NA	_____
7.	_____ DISCREPANCIES BETWEEN COC AND SAMPLE LABELS	_____
8.	_____ NO DISCREPANCIES NOTED	_____

SAMPLES INSPECTED AND LOGGED BY: _____

DATE/TIME: _____

1.5 Field Records

SBP personnel shall use only bound field logbooks for the maintenance of field records. Other bound logbooks such as bound surveyors logbooks are acceptable so long as pages cannot be removed without tearing them out.

Preferably, a logbook should be dedicated to an individual project. The investigator's name, project name, and project code should be entered on the inside of the front cover of the logbook. All entries should be dated and time of entry recorded. At the end of each day's activity, or entry of a particular event if appropriate, the investigator should draw a diagonal line at the conclusion of the entry and initial indicating the conclusion of the entry or the days activity.

All aspects of sample collection and handling as well as visual observations shall be documented in the field logbooks. All sample collection equipment (where appropriate), field analytical equipment, and equipment utilized to make physical measurements shall be identified in the field logbooks as outlined in Sections 4, 5, 6, and 7 of ECBSOPQAM. All calculations, results, and calibration data for field sampling, field analytical, and field physical measurement equipment shall also be recorded in the field logbooks. All field analyses and measurements must be traceable to the specific piece of field equipment utilized and to the field investigator collecting the sample, making the measurement, or analyses.

All entries in field logbooks shall be dated, shall be legible, and shall contain accurate and inclusive documentation of an individual's project activities. Since field records are the basis for later written reports, language should be objective, factual, and free of personal feelings or other terminology which might prove inappropriate. Once completed, these field logbooks become accountable documents and must be maintained as part of project files.

1.6 Disposal of Samples or Other Physical Evidence

Disposal of samples or other physical evidence obtained during the investigations is conducted on a case-by-case basis. Before any samples analyzed are disposed, a written request to dispose of the samples shall be obtained by the lab. The samples will not be disposed until the SBP field investigator completes the appropriate portions of the lab memo, signs and returns the memo to the lab, specifically giving them permission to dispose of the samples. SBP personnel should check with the EPA Program Office requesting the inspection or investigation before granting permission to dispose of samples or other physical evidence. The following general guidance is offered for the disposal of samples or other physical evidence:

- No samples, physical evidence, or any other document associated with a criminal investigation shall be disposed without written permission from EPA's Office of Criminal Investigation, the Office of Regional Counsel, or the Department of Justice.

- Quality assurance samples are routinely disposed after the analytical results are reported. The lab does not advise SBP on the disposal of these samples.

After samples are disposed, the lab shall send the sample tags to SBP field investigator. These sample tags are accountable and must be placed and maintained in the project files.

1.7 Document Control

The term document control, refers to the maintenance of inspection and investigation project files. All project files shall be maintained by the appropriate manager. All documents as outlined below shall be kept in project files. SBP personnel may keep their own files, however, all official and original documents relating to SBP inspections and investigations shall be placed in the official project files. The following documents shall be placed in the project file:

- a copy of the study plan;
- original Chain-Of-Custody Records and bound field logbooks;
- a copy of the Receipt For Sample Forms;
- all records obtained during the investigation;
- a complete copy of the analytical data and memorandums transmitting analytical data;
- sample tags from samples that have been disposed of by the laboratory;
- all official correspondence received by or issued by SBP relating to the investigation including records of telephone calls;
- one copy of the draft report (without review comments; however, peer review clearance forms shall be included);
- one copy of the final report and transmittal memorandum(s); and
- any other relevant documents related to the original investigation/ inspection or follow-up activities related to the investigation/ inspection.

Under no circumstances are any personal observations or irrelevant information to be filed in the official project files. The project leader or field investigator shall review the file at the conclusion of the project to insure that it is complete.

SECTION 2
SAMPLING PROCEDURES

2.1 Introduction

This section discusses the standard practices and procedures utilized by SBP personnel during field operations to ensure the collection of representative samples. The collection of representative samples depends upon:

- ensuring that the sample taken is representative of the material or medium being sampled;
- using proper sampling, sample handling, preservation, and quality control techniques;
- properly identifying the collected samples and documenting their collection in permanent field records (field log books, Chain-Of-Custody Records); and
- maintaining sample chain-of-custody.

The objectives of this section are to present:

- general considerations that must be incorporated in all sampling operations conducted by SBP
- SBP sampling site selection and collection procedures for an individual medium;
- SBP sampling quality assurance procedures; and
- equipment calibration and maintenance requirements for SBP sampling equipment.

2.2 General Considerations

The following factors and procedures shall be considered and implemented in planning and conducting all sampling operations. All these factors and procedures must be considered in view of specific objectives and scope of each individual field investigation.

2.2.1 Selection of Representative Sampling Sites

Representative sampling sites are dependent on the type of investigation undertaken and are discussed under type of sample procedures for each medium later in this section.

2.2.2 Selection and Proper Preparation of Sampling Equipment

The type of sampling equipment to be used is dictated by the investigation and is discussed for each medium later in this section. Section 6 describes the standard equipment cleaning procedures.

2.2.3 Sampling Equipment Construction Material

The material that sampling equipment is constructed of can affect sample analytical results. Materials used must not contaminate the sample being collected and must be readily cleaned so that samples are not cross-contaminated. The standard materials for sampling equipment used to collect samples for trace organic compounds or metals analyses are, in order of decreasing desirability; Teflon®, glass, stainless steel, and steel.

2.2.4 Selection of Parameters to be Measured

Parameters to be measured are usually dictated by the purpose of an investigation and should be based on required monitoring conditions (NPDES or RCRA permits for example) or on the field investigator's or requestor's knowledge of the problem being investigated.

2.2.5 Required Sample Volumes

The volume of sample obtained should be sufficient to perform all required analyses with an additional amount collected to provide for quality control needs, split samples, or repeat examinations. When using a peristaltic pump, individual aliquots of a composite sample should be at least 100 milliliters in order to minimize sample solids bias.

Although the volume of sample required by contract laboratories depends on the analyses to be performed, the amount of sample required for a complete water or wastewater analysis is normally two gallons (7.6 liters) for each laboratory receiving a sample. The amount of soil/sediment required for a complete analysis is approximately 16 ounces. However, the laboratory receiving the sample should be consulted for any specific volume requirements.

The volumes of samples collected from waste sources at hazardous waste sites or samples from sources which are known to be toxic should be kept to an absolute minimum.

2.2.6 Selection and Proper Preparation of Sample Containers

The type of sample container is dictated by the analyses required. Standard sample containers used by SBP personnel are presented in Section 5.

2.2.7 Sample Preservation

Samples for some analyses must be preserved in order to maintain their integrity. Preservatives required for routine analyses of samples collected are given in Section 5. All chemical preservatives used will be supplied by the analytical lab. All samples requiring preservation should be preserved immediately upon collection in the field. Samples that should not be preserved in the field are:

- Samples collected within a hazardous waste site that are known or thought to be highly contaminated with toxic materials. Barrel, drum, closed container, spillage, or other source samples from hazardous waste sites are not to be preserved with any chemical. These samples may be preserved by placing the sample container on ice, if necessary.

- Samples that have extremely low or high pH or samples that may generate potentially dangerous gases if they were preserved using the procedures given in Section 5.

- Samples for metals analyses which are shipped by air shall not be preserved with nitric acid in excess of the amount specified in Section 7.

- Samples for purgeable organic compounds analyses which are shipped by air shall not be preserved with hydrochloric acid in excess of the amount specified in Section 7.

All samples preserved with chemicals shall be clearly identified by indicating on the sample tag that the sample is preserved. If samples normally requiring preservation were not preserved, field records shall indicate why.

2.2.8 Sample Holding Times

The elapsed time between sample collection and initiation of laboratory analyses must be within a prescribed time frame for each individual analysis to be performed. Sample holding times for all routine samples collected are shown in Section 5.

2.2.9 Special Precautions for Trace Contaminant Sampling

Some contaminants can be detected in the parts per billion and/or parts per trillion range. Extreme care must be taken to prevent cross-contamination of these samples. The following precautions shall be taken when trace contaminants are of concern:

- A clean pair of new, disposable gloves will be worn each time a different location is sampled and gloves should be donned immediately prior to sampling.

- Sample containers for source samples or samples suspected of containing high concentrations of contaminants shall be placed in separate plastic bags immediately after collecting, preserving, tagging, etc.

- If possible, ambient samples and source samples should be collected by different field teams. If different field teams cannot be used, all ambient samples shall be collected first and placed in separate ice chests or shipping containers. Samples of waste or highly contaminated samples shall never be placed in the same ice chest as environmental samples. It is good practice to enclose waste or highly contaminated samples in a plastic bag before placing them in ice chests. Ice chests or shipping containers for source samples or samples suspected to contain high concentrations of contaminants shall be lined with new, clean, plastic bags.

- If possible, one member of the field team should take all the notes, fill out tags, etc., while the other members collect all of the samples.

- When sampling surface waters, the water sample should always be collected before the sediment sample is collected.

- Sample collection activities should proceed progressively from the suspected least contaminated area to the suspected most contaminated area.

- Equipment constructed of Teflon®, stainless steel, or glass that has been properly precleaned for collecting samples for trace metals or organic compounds analyses must be used. Teflon® or glass is preferred for collecting samples where trace metals are of concern. Equipment constructed of plastic or PVC shall not be used to collect samples for trace organic compounds analyses.

2.2.10 Sample Handling and Mixing

After collection, all sample handling should be minimized. Branch personnel should use extreme care to ensure that samples are not contaminated. If samples are placed in an ice chest, personnel should ensure that melted ice cannot cause sample containers to become submerged, as this may result in sample cross-contamination. Plastic bags, such as Zip-Lock® bags, should be used when small sample containers (e.g., VOA's or bacterial samples) are placed in ice chests to prevent cross-contamination.

Once a sample has been collected, it may have to be split into separate containers for different analyses. The best way to split liquid samples is to continually stir the sample contents with a clean pipette or precleaned Teflon® rod and allow the contents to be alternately siphoned into respective sample containers using Teflon® or PVC (Tygon® type) tubing. Teflon® must be used when analyses for organic compounds or trace metals are to be conducted. Any device used for stirring, or tubing used for siphoning, must be cleaned in the same manner as other equipment. However, samples collected for purgeables organic compounds analyses may not be split using this procedure.

A true split of soil, sediment, or sludge samples is almost impossible to accomplish under field conditions. The higher the moisture content, the more difficult it is to split the sample.

It is extremely important that soil samples be mixed as thoroughly as possible to ensure that the sample is as representative as possible of the sample interval. The most common method of mixing is referred to as quartering. The soil in the sample pan is divided into quarters. Each quarter is mixed, then all quarters are mixed into the center of the pan. This procedure is followed several times until the sample is adequately mixed. If round bowls are used for sample mixing, adequate mixing is achieved by stirring the material in a circular fashion and occasionally turning the material over. Soil and sediment samples collected for purgeable organic compounds analyses should not be mixed. The 2-ounce (60-ml) sample container should be filled completely; no head space should remain in the sample containers.

2.2.11 Purgeable Organic Compounds Sampling (VOA)

Water samples to be analyzed for purgeable organic compounds should be stored in 40-ml septum vials with screw cap and Teflon®-silicone disk in the cap to prevent contamination of the sample by the cap. The disks should be placed in the caps (Teflon® side to be in contact with the sample) in the laboratory prior to the beginning of the sampling program.

The vials (40-ml) should be completely filled to prevent volatilization, and extreme caution should be exercised when filling a vial to avoid any turbulence which could also produce volatilization. The sample should be carefully poured down the side of the vial to minimize turbulence. As a rule,

it is best to gently pour the last few drops into the vial so that surface tension holds the water in a "convex meniscus." The cap is then applied and some overflow is lost, but air space in the bottle is eliminated. After capping, turn the bottle over and tap it to check for bubbles. If any bubbles are present, repeat the procedure. Since the VOA vials are pre-preserved, extreme caution should be exercised when the vials are used as the collection device for surface water samples in order to prevent the loss of the preservative. When collecting water samples for purgeable organic compounds, triplicate samples should always be collected from each location. Three 40-ml vials containing four drops of concentrated HCl should be filled with the sample.

2.2.12 Sample Identification

All samples will be fully documented, as outlined in Section 1, in the field records, on the field sample Chain-Of-Custody Record, and on the sample tags.

2.2.13 Procedures for Identifying Potentially Hazardous Samples

Any sample either known or thought to be hazardous should be so identified on both the sample tag and the field sample Chain-Of-Custody Record. Information explaining the hazard, i.e., corrosive, flammable, poison, etc., shall also be listed.

2.2.14 Collection of Auxiliary Data

All auxiliary data such as flow measurements, photographs of sampling sites, meteorological conditions, and other observations shall be entered onto the field records when the auxiliary data are collected. Auxiliary data relative to a particular sampling location should be collected as close to the sample collection time as possible. Specific types of auxiliary data to collect for each medium sampled are discussed later in this section.

2.2.15 Time Records

All records of time shall be kept using local time in the 2400 hour time format and shall be recorded to the nearest minute.

2.2.16 Transporting and Shipping of Samples

Samples may be hand delivered to the laboratory or they may be shipped by common carrier. All personnel must be aware that certain samples are hazardous materials and, as such, are regulated by the U. S. Department of Transportation under the Transportation Safety Act of 1974. These regulations are contained in Title 49, CFR, Parts 110-119. Shipment of dangerous goods by air cargo is also regulated by the United Nations/International Civil Aviation Organization (UN/ICAO). The Dangerous Goods Regulations promulgated by the International Air Transport Association (IATA) meet or exceed DOT and UN/ICAO requirements and should be used for shipment of dangerous goods via air cargo.

2.2.17 Sample Chain-of-Custody

Employees shall maintain sample chain-of-custody during all field investigations for all samples collected. The standard sample chain-of-custody procedures are given in Section 1.3.

2.3 Definitions

2.3.1 Grab Sample

An individual sample collected from a single location at a specific time or period of time generally not exceeding 15 minutes. Grab samples are associated with surface water, groundwater, wastewater, waste, contaminated surfaces, soil, and sediment sampling. Grab samples are typically used to characterize the media at a particular instant in time. See Section 5 for additional guidance concerning parameters requiring a grab sample and for monitoring that indicates that grab samples must be collected.

2.3.2 Composite Samples

A sample collected over time that typically consists of a series of discrete samples which are combined or "composited". Four types of composite samples are listed below:

- Time Composite (TC): A sample comprised of a varying number of discrete samples collected at equal time intervals during the compositing period. The TC sample is typically used to sample wastewater or streams.

- Flow Proportioned Composite (FPC): A sample collected proportional to the flow rate during the compositing period by either a time-varying/constant volume (TVCV) or time-constant/varying volume (TCVV) method. The TVCV method is typically used with automatic samplers that are paced by a flow meter. The TCVV method is a manual method that individually proportions a series of discretely collected samples. The FPC is typically used when sampling wastewater.

- Areal Composite: A sample collected from individual grab samples collected on an areal or cross-sectional basis. Areal composites shall be made up of equal volumes of grab samples. Each grab sample shall be collected in an identical manner. Examples include sediment composites from quarter-point sampling of streams and soil samples from grid points.

- Vertical Composite: A sample collected from individual grab samples collected from a vertical cross section. Vertical composites shall be made up of equal volumes of grab samples. Each grab sample shall be collected in an identical manner. Examples include vertical profiles of soil/sediment columns, lakes and estuaries.

2.3.3 Quality Control Samples

Field studies also require the collection of additional samples for various quality control purposes. These include the isolation of site effects (control samples), define background conditions (background sample), evaluate field/laboratory methodology (spikes and blanks, trip blanks, duplicate samples), or to assess sampling equipment (sampler blanks and equipment rinse blanks). In addition, it may be necessary to provide split or duplicate samples to assess field sampling procedures.

Miscellaneous sampling definitions are listed below:

- Sample Aliquot: A portion of a sample that is representative of the entire sample.
- Split Sample: A sample which has been portioned into two or more containers from a single sample container or sample mixing container.
- Duplicate Sample: Two or more samples collected simultaneously into separate containers from the same source under identical conditions.
- Control Sample: A sample collected upstream or upgradient from a source or site to isolate the effects of the source or site on the particular ambient medium being sampled.
- Background Sample: A sample collected from an area, water body, or site similar to the one being studied, but located in an area known or thought to be free from pollutants of concern.
- Biased Sample: A sample which is known to be non-representative of the entire site being studied. An example is samples collected during Superfund Site Screening Investigations that are intentionally biased towards suspected areas of contamination.
- Trip Blanks: Trip blanks are prepared prior to the sampling event in the actual sample container and are kept with the investigative samples throughout the sampling event. They are then packaged for shipment with the other samples and sent for analysis. At no time after their preparation are the sample containers to be opened before they reach the laboratory. volatile organic trip blanks will be utilized to determine if samples were contaminated during storage and transportation back to the laboratory. If samples are to be shipped, trip blanks are to be provided per shipment but not per cooler.
- Equipment Blanks: Equipment field blanks are defined as samples which are obtained by running organic-free water over/through sample collection equipment after it has been cleaned. These samples will be used to determine if cleaning procedures were adequate. (The equipment could have been cleaned in the field or prior to the field operation.)
- Pre and Post Preservative Blanks: To determine if the preservative used during field operations were contaminated, pre and post preservative blanks are prepared. On small studies, usually only a post preservative sample will be prepared. These samples are prepared by putting analyte-free/organic-free water in the container and then preserving the sample with the appropriate preservative.
- Field Blanks: Organic-free water is taken to the field in sealed containers and poured into the appropriate sample containers at pre-designated locations. This is done to determine if any contaminants present in the area may have an affect on the sample integrity. Field blanks should be collected in dusty environments and/or

from areas where volatile organic contamination is present in the atmosphere and originating from a source other than the source being sampled.

2.4 Data Quality Objectives

As defined in Data Quality Objectives for Remedial Response Activities (29), "Data Quality Objectives (DQO's) are qualitative and quantitative statements which specify the quality of the data required to support decisions during remedial response activities". DQO's should be considered when planning any study. DQO's provide information on the limits of the data, which in turn dictate the proper uses of the data. Data collected in the field include samples and site information. The methods by which samples are collected may limit the uses of the subsequent analytical data. The methods by which site information, such as physical measurements, photographs, field notes, etc., are collected, may reduce their accuracy. The manner in which sampling equipment is cleaned will also affect the DQO level of the data. The various DQO levels are numbered I through V, with I being the lowest and IV the highest quality data. Level V data are collected using special or non-standard methods. Higher quality methods may be substituted for lower level work.

2.4.1 DQO Level I

Sampling equipment and sample containers must be cleaned using soap and tap water, visibly free of contamination, and free of detectable analytes using the analytical screening methods specified for the study. Use of organic vapor survey methods to determine locations or media fractions for higher level analysis is an example of DQO Level I field work. However, this technique is not appropriate for compounds that are not volatile or produce low instrument response. Data produced from such samples may not be used for other than the stated purpose.

2.4.2 DQO Level II

Field methods, decontamination procedures, and sampling equipment construction materials for DQO Level II analyses are as specified elsewhere in this document. The construction materials for sampling equipment may vary if rinse blanks analyzed using the field analytical procedures show that the substituted equipment does not contribute detectable analytes, and the materials would not reasonably be expected to contribute detectable analytes. For example, it may be acceptable to use PVC sampling equipment to collect samples that are only being analyzed for metals, or to use equipment made of chrome plated material for samples being analyzed only for organic compounds. Field cleaning procedures for sampling equipment used to collect samples that will be analyzed at this DQO level may consist of:

- Soap and potable water wash with brush (steam may also be used), followed by potable water rinse.

- Water rinse. The quality of the water is determined by the contaminants of concern and the minimum quantitation limits of the analytical methods used. For example, if an atomic absorption (AA) unit is being used to analyze water samples for lead only, and the minimum quantitation limit is 20 ug/l, water containing up to 10 ug/l lead (one-half the minimum quantitation limit) may be used as decontamination water.

A minimum of five percent of samples collected for DQO Level II analyses should be split for DQO Level IV analysis. These samples must be representative of all samples submitted to the field laboratory.

2.4.3 DQO Level III

Field methods, decontamination procedures, and sampling equipment construction materials for DQO Level III analyses are as specified elsewhere in this document. Some modifications of these specifications are allowable in certain limited instances, as specified below.

If DQO Level III analytical services are being used in support of drilling or excavation operations, the cleaning procedures for the down-hole drilling or excavation equipment only may be cleaned as specified in Section 9.9, with the omission of steps 3, 4, and 5. All other cleaning and decontamination procedures specified in that section apply.

When wells are constructed using materials that are not inert with respect to the contaminants being analyzed, data collected from those wells are DQO Level III or lower for those incompatible analytes, even if DQO Level IV analytical procedures are used.

A minimum of one equipment rinse blank per week for each week sampling equipment is field cleaned is required to be analyzed. If samples are preserved, a preservative blank must be collected and analyzed in the field at the beginning and end of the study. A blank of the rinse water must be collected and analyzed prior to beginning the study and at the end of each week sampling equipment is field cleaned.

A minimum of five percent of samples collected for DQO Level III analysis should be split for DQO Level IV analysis. These samples must be representative of all samples submitted to the field laboratory.

2.4.4 DQO Level IV

Field methods and equipment decontamination procedures described in this document are considered to be level IV methods. These are the standard methods to be used on all studies requiring DQO Level IV quality data. Any deviations from these methods must be documented in the field logbook or the approved study plan. The sampler must be aware that such deviations in the field work may reduce the DQO level of the data, with a subsequent reduction in the data uses.

2.4.5 DQO Level V

Because DQO Level V procedures are by definition non-standard, they are not discussed in detail. The project leader must be aware that special analytical procedures may require specialized field procedures and equipment. These must be specified in the approved study plan prior to beginning the study.

2.5 Investigation Derived Waste

2.5.1 General

Many field investigations generate waste materials. These waste materials are known as investigation derived waste (IDW) (30). Some of these waste materials may be hazardous wastes which must be properly disposed in accordance with EPA regulations. Most, but not all, of these hazardous wastes will be associated with investigations of hazardous waste sites.

2.5.1.1 Types of IDW

Materials which may become IDW requiring proper treatment, storage and disposal are:

- Personnel protective equipment (PPE). This includes disposable coveralls, gloves, booties, respirator canisters, splash suits, etc.
- Disposable equipment (DE). This includes plastic ground and equipment covers, aluminum foil, conduit pipe, coliwasa samplers, Teflon® tubing, broken or unused sample containers, sample container boxes, tape, etc.
- Soil cuttings from drilling or hand auguring.
- Drilling mud or water used for water rotary drilling.
- Groundwater obtained through well development or well purging.
- Cleaning fluids such as spent solvent and washwater.

2.5.1.2 Management of Non-Hazardous IDW

Disposal of non-hazardous IDW from hazardous waste sites should be addressed in the study plan. Non-hazardous IDW such as PPE and DE may be double-bagged and disposed in the trash containers. These materials may also be taken to a permitted landfill local to the site. On larger studies, waste hauling services may be obtained and a dumpster located at the study site. They may also be buried on site near the contamination source, with the burial location noted in the field logbook.

Disposal of non-hazardous IDW such as drill cuttings, purge or development water, decontamination fluids, drilling muds, etc., should be specified in the approved study plan. These materials must not be placed into dumpsters. If the facility at which the study is being conducted is active, permission should be sought to place the liquid IDW into the facilities treatment system. It may be feasible to spread drill cuttings around the borehole, or if the well is temporary, to replace the cuttings back into the borehole. Cuttings, purge water, or development water may also be placed in a pit in or near the source area. Monitoring well purge or development water may also be poured onto the ground downgradient of the monitoring well. Purge water from private potable wells which are in use may be discharged to the ground surface.

2.5.1.3 Management of Hazardous IDW

Disposal of hazardous or suspected hazardous IDW must be specified in the approved study plan. Hazardous IDW must be disposed as specified in USEPA regulations. If appropriate, these wastes may be placed back in an active facility waste treatment system. These wastes may also be disposed of in the source area from which they originated, if doing so does not endanger human health and the environment.

If on-site disposal is not feasible, and if the wastes are suspected to be hazardous, appropriate tests must be conducted to make that determination. If they are determined to be hazardous wastes, they must be properly contained and labeled. They may be stored on the site for a maximum of 90 days before they must be manifested and shipped to a permitted treatment or disposal facility. Generation of hazardous IDW must be anticipated, if possible, to permit arrangements for proper containerization, labelling, transportation, and disposal/treatment in accordance with USEPA regulations.

Hazardous investigation derived waste should be kept to a minimum to conserve resources. Many of the above PPE and DE wastes can be deposited in municipal dumpsters if care is taken to keep them segregated from hazardous waste contaminated materials. Disposable equipment can often be cleaned to render it non-hazardous, as can some PPE, such as splash suits. The volume of spent solvent waste produced during equipment decontamination can be reduced or eliminated by applying only the minimum amount of solvent necessary.

2.6 Ground Water Sampling

2.6.1 General

Ground-water sampling may be required for a variety of reasons, such as examining potable or industrial water supplies, checking for and/or tracking contaminant plume movement in the vicinity of a land disposal or spill site, RCRA compliance monitoring, or examining a site where historical information is minimal or non-existent but where it is thought ground water contamination could have occurred.

Ground water is usually sampled through an in-place well, either temporarily or permanently installed. However, it can also be sampled anywhere ground water is present, as in a pit or a dug or drilled hole.

Occasionally, a well will not be in the ideal location to obtain the sample needed (for example, to track a contaminant plume). In that case, a well will have to be installed, and it may be either a temporary or permanently installed well. An experienced and knowledgeable person will need to locate the well and supervise its installation so that the samples ultimately collected will be representative of the ground water.

Additional guidance is given in the "RCRA Ground Water Monitoring Technical Enforcement Guidance Document" (TEGD) (13).

2.6.2 Site Selection

The relationship of the following factors to potential pollution sources shall be considered and evaluated when selecting ground-water sampling sites:

- the direction of ground-water flow, depth to ground water, thickness of the aquifer (if applicable);
- type of stratigraphy;
- presence of perched water tables;
- types of soils;
- depth to bedrock;
- type of vegetation;
- surface drainage patterns;
- type of topography;
- general land use;
- and surface features such as rock outcrops, seeps, springs, streams, rivers, and wet areas (14).

The area of interest should be located on an aerial photograph, a USGS 7.5 minute quadrangle map, a USDA soils map, and/or any other appropriate map that shows topography and general relationships between surface features. USGS 7.5 minute quadrangle maps can be acquired from the State Geological Survey or from the USGS, and soils maps from the USDA-SCS (Soil Conservation Service). A visual inspection of the area may be sufficient to evaluate and determine the surface conditions and their relationship to the subsurface conditions (14). In some cases, surface conditions and subsurface conditions cannot be correlated by site inspection or reconnaissance. When this occurs, a more detailed study, possibly involving test drilling, will have to be conducted.

It is extremely important to sample the unconfined or surficial aquifer downgradient of potential pollution sources or spills to determine if it (the most easily contaminated aquifer) has been affected. Generally the direction of ground-water flow can be estimated by two vectors - one in the direction of surface water flow (i.e., downstream) and another toward the nearest surface water stream or river, if present. The relative magnitude of these vectors will vary according to site conditions and in some instances both direction and magnitude may be changed by construction activities. If both a shallow and a deep aquifer are involved in the zone of interest, a screening study will reveal whether or not the deep aquifer should be sampled and a more detailed study is required. To adequately assess subsurface conditions, a minimum of three wells is required; one in the upgradient portion of the area of interest, one in the middle portion, and one in the downgradient portion. In some cases, a more complex system of wells may be needed to define the subsurface conditions, especially in establishing the depth to the shallow ground-water aquifer and the direction of ground-water movement. Site conditions and the scope of the project will determine the total number of

wells required. Existing wells should be used when possible. Where permanent well installation is necessary, the wells should be installed according to the procedures in Section 9.

2.6.3 Purging Equipment and Techniques

2.6.3.1 General

Wells shall be purged before taking samples in order to clear the well of stagnant water which is not representative of aquifer conditions. The method of purging is to pump the well until three to five times the volume of standing water in the well has been removed and until the specific conductance, temperature, and pH of the ground water stabilizes. Normally, a combination of the two methods is employed (i.e., specific conductance, temperature, and pH are measured at intervals and three to five volumes are purged). If a well is pumped dry, this constitutes an adequate purge and the well can be sampled following recovery (15, 17). However, if possible, monitoring wells should not be pumped dry. If the well is pumped dry, water that has been trapped in the sandpack may be sampled. In addition, as water re-enters the well it may cascade down the well screen and strip volatile contaminants.

2.6.3.2 Equipment Available

Monitoring well purging is accomplished by using in-place plumbing/pumps or when in-place pumps are not available, by using either a peristaltic, turbine, bladder, centrifugal, or other appropriate pump, depending on well depth. A Teflon®, closed top bailer may be used for purging; however, bailing may stir up sediment in the well if conducted improperly.

Other monitoring equipment used during purging includes water level indicators, pH meters, thermometers, and conductivity bridges (See Section 3, Field Analytical Procedures).

2.6.3.3 Purging Techniques (Wells Without Plumbing or In Place Pumps)

2.6.3.3.1 General

For permanently installed wells, the depth of water shall be determined (if possible) before purging. This can be accomplished by attaching a weight on the end of a tape and lowering it into the well until it touches the water, or by use of a mechanical or electrical water level indicator (see Ground-Water Level Measurement Techniques, Section 4). All personnel shall exercise extreme caution during this procedure to prevent contamination of the ground water. This is a critical concern when samples for trace organic compounds or metals analyses are collected.

2.6.3.3.2 Using Pumps to Purge

When suction lift or centrifugal pumps are used, only the intake line is placed into the water column. To minimize contamination, the line placed into the water is either standard cleaned (see Section 6) Teflon®, in the case of the suction lift pumps, or standard cleaned stainless steel pipe attached to a hose, when centrifugal pumps are used.

When submersible pumps (bladder, turbine, displacement, etc.) are used, the pump itself is lowered into the water column. The pump must be cleaned as specified in Section 6.

2.6.3.3.3 *Using Bailers to Purge*

Standard cleaned (Section 6) closedtop Teflon® bailers with Teflon® leaders and new nylon rope are lowered into top of the water column, allowed to fill, and removed and then the water is discarded.

2.6.3.3.4 *Field Care of Purging Equipment*

Regardless of which method is used for purging, new plastic sheeting shall be placed on the ground surface around the well casing to prevent contamination of the pumps, hoses, ropes, etc., in the event they need to be placed on the ground during the purging or they accidentally come into contact with the ground surface. It is preferable that hoses used in purging that come into contact with the ground water be kept on a spool, both during transporting and during field use, to further minimize contamination from the transporting vehicle or ground surface.

2.6.3.3.5 *Purging Entire Water Column*

The pump/hose assembly or bailer used in purging should be lowered into the top of the standing water column and not deep into the column. This is done so that the purging will "pull" water from the formation into the screened area of the well and up through the casing so that the entire static volume can be removed. If the pump is placed deep into the water column, the water above the pump may not be removed, and the subsequent samples collected may not be representative of the ground water.

To minimize cross contamination between wells, no more than three to five feet of hose should be lowered into the water column. If the recovery rate of the well is faster than the pump rate, the pump may be left hanging at the initial level until an adequate volume has been purged. If the pump rate exceeds the recovery rate of the well, the pump will have to be lowered, as needed, to accommodate the drawdown.

After the pump is removed from the well, all wetted portions of the hose and the pump shall be cleaned as outlined in Section 6.

Careful consideration shall be given to using pumps to purge wells which are excessively contaminated with oily compounds, because it may be difficult to adequately decontaminate severely contaminated pumps under field conditions. When these type wells are encountered, alternative purging methods, such as bailers, should be considered.

2.6.3.4 Purging Techniques - Wells With In Place Plumbing

2.6.3.4.1 *General*

In-place plumbing is found at water treatment plants, industrial water supply wells, private residences, etc. The objective of purging is the same as with monitoring wells without in place pumps, i.e., to ultimately collect a sample representative of the ground water.

The volume to be purged depends on several factors: whether the pumps are running continuously or intermittently; how close to the source the sample can be collected; and the presence of any

storage/pressure tanks between the sampling point and the pump. If storage/pressure tanks are present, an adequate volume must be purged to totally exchange the volume of water in the tank.

2.6.3.4.2 Continuously Running Pumps

If the pump runs continuously, and the sample can be collected prior to a storage/pressure tank, no purge, other than opening a valve and allowing it to flush for a few minutes, is necessary.

2.6.5.4.3 Intermittently Running Pumps

If the pump runs intermittently, it is necessary to determine the volume to be purged, including storage/pressure tanks that are located prior to the sampling location. The pump should then be run continuously until the required volume has been purged.

2.6.4 Sampling Equipment and Techniques

2.6.4.1 Equipment Available

Sampling equipment used includes closed-top Teflon® bailers and the peristaltic pump/vacuum jug assembly.

Other monitoring equipment used during sampling includes water level indicators, pH meters, thermometers, and conductivity bridges (see Sections 3 and 4).

2.6.4.2 Sampling Techniques -- Wells With In Place Plumbing

Samples should be collected following purging from a valve or cold water tap as near to the well as possible. Samples should be collected directly into the appropriate containers (see Standard Sample Containers, Section 5).

2.6.4.3 Sampling Techniques -- Wells Without Plumbing

Following purging, samples should be collected using a peristaltic pump/vacuum jug procedure, if possible, or with a closed top Teflon® bailer. The pump used for purging generally should not be used for sampling. When the peristaltic pump is used, samples for purgeable organic compounds analyses should be collected using a bailer or by allowing the Teflon® tube to fill and then allowing the water to drain into the sample vials. All equipment shall be cleaned using the procedures described in Section 6.

When bailing, new plastic sheeting should be placed on the ground around each well to provide a clean working area. The nylon rope should be attached to the bailer via a Teflon® coated stainless steel wire. This coated wire is attached to the bailer semi-permanently and is decontaminated for reuse as the bailer is cleaned.

2.6.5 Special Sample Collection Procedures

2.6.5.1 Trace Organic Compounds and Metals

Special sample handling procedures shall be instituted when trace contaminant samples are being collected. All sampling equipment, including pumps, bailers, water level measurement equipment, etc., which come into contact with the water in the well must be cleaned in accordance with the cleaning procedures described in Section 6. Pumps shall not be used for sampling, unless the interior and exterior portions of the pump and discharge hoses can be thoroughly cleaned. Blanks should be collected to determine the adequacy of cleaning prior to collection of any sample using a pump. Peristaltic pumps using Teflon® tubing and a Teflon® insert can be used to collect samples without the sample coming into contact with the pump. This is accomplished by placing the Teflon® insert into the opening of a standard cleaned 4-liter glass container. The Teflon® tubing connects the container to the pump and sample source. The pump creates a vacuum in the container, thereby drawing the sample into the container without coming into contact with the pump tubing. Samples for purgeable organic compounds analyses shall be collected with well bailers. The procedures given in the General Considerations, Special Precautions for Trace Contaminant Sampling (Section 2.2.9) shall be followed.

2.6.5.2 Filtering

As a standard Branch policy, ground-water samples will not be filtered. However, if samples are filtered, then both filtered and non-filtered samples will be submitted for analyses. Proper well installation and development (Section 9) as well as proper well purging techniques should be utilized to minimize the turbidity of samples. If filtered samples for metals analyses must be collected, an additional unfiltered sample will also be collected for metals analyses.

Samples for organic compounds analyses shall not be filtered.

2.6.5.3 Bacterial Sampling

Whenever wells (normally potable wells) are sampled for bacteriological parameters, care must be taken to ensure the sterility of all sampling equipment and all other equipment entering the well. Further information regarding bacteriological sampling is available in Sampling for Organic Chemicals and Microorganisms in the Subsurface (19) as well as References 4 and 5.

2.6.6 Specific Sampling Equipment Quality Assurance Techniques

All equipment used to collect ground-water samples shall be cleaned as outlined in Section 6 and repaired, if necessary, before being stored at the conclusion of field studies. Cleaning procedures conducted in the field (Section 6), or field repairs shall be thoroughly documented in field records.

2.6.7 Auxiliary Data Collection

Water table measurements from the top of the well casings (referenced to National Geodetic Vertical Datum) in permanent wells, and ground surface elevations in temporary wells should be made to determine the general direction of ground-water flow and gradient. The methodology to be used to determine well water levels are given in Section 4. Tracer dyes and radioactive and thermal

detection methods can be used to determine direction and velocities of flow (14). Also, a study of the general topography and drainage patterns will generally indicate direction of ground-water flow.

Water table measurements shall not be taken until the water table has stabilized, preferably 24 hours after well installation for permanent wells (20). The ground surface elevation at the wells should be determined by standard engineering survey practices as outlined in Section 4.

In addition to water level measurements, the pumping rate used to purge a well, the volume of water in wells, and drillers' logs are examples of auxiliary data that should be collected during ground-water sampling activities. This information should be documented in field records. Methodology for obtaining these data are given in the following sections.

Temperature, specific conductance, and pH shall be measured each time a well is sampled. Stabilization of these parameters is measured during the purging process to evaluate the adequacy of the purging procedure. In this situation, the final measurements for these parameters prior to sampling shall be considered the measurement of record for the well. If these parameters were not evaluated during purging, they shall be obtained prior to sampling. Methodology for obtaining these data are given in Section 3.

2.6.7.1 Well Pumping Rate - Bucket/Stop Watch Method

The pumping rate of a pump can be determined by collecting the flow of water from the pump in a bucket of known volume and timing how long it takes to fill the bucket. The pumping rate should be in gallons per minute. This method shall be used only with pumps with a constant pump rate, such as gasoline powered or electric submersible pumps. It should not be used with battery powered pumps. As the batteries lose their charge, the pump rate decreases so that pumping rate calculations using initial, high pump rates are erroneously high.

2.6.7.2 Volume of Water in Wells

In order to purge wells, the volume of water in the well should be known. To determine the volume, the following method should be used; measure the distance from the bottom of the well to the static water level, then measure the inside diameter of the well or casing. Obtain the volume of the well by the formula:

$$V = 0.041\ d2h$$

Where h = depth of water in feet
d = diameter of well in inches
V = volume of water in gallons

If preferred, a quick reference nomograph or table may be used.

Additional ground-water related data can be obtained from most local, state, and federal agencies dealing with water resources. Some states require well drillers to be licensed, and all work performed on wells must be reported to the state on prescribed forms. These forms are available to the public, so a study of wells installed in the area of interest may provide background information as to the subsurface conditions. State geological surveys, as well as the USGS, have various types of water related papers and reports on all phases of ground-water studies in each state. City and county governments usually have departments that deal with water related projects that may provide

data for the local area. Federal agencies such as the SCS, U. S. Army Corps of Engineers, the Bureau of Reclamation, U. S. Forest Service, Science and Education Administration, and the U. S. Public Health Service have water programs which may provide data. Other sources include the Bureau of Mines, colleges, universities, and technical societies such as American Association of Petroleum Geologists, American Institute of Mining and Metallurgical Engineers, American Water Well Association, Association of Engineering Geologists, and Geological Society of America (14, 21).

2.7 Soil Sampling

2.7.1 General

Soil sampling at hazardous waste sites will typically be approached in a totally different manner than sampling of other media. Sampling locations and rationale for other media are usually easily defined. For example, ground water samples may be collected at existing monitoring wells; surface water and sediment samples are usually collected from well defined surface drainage patterns at easily rationalized locations with respect to the suspected problem; and waste sources, such as drums, tanks, and piles, are easily identified sampling targets. Occasionally, surface soils may be stained or show evidence of vegetative stress, indicating that a contaminant may be present, but in many cases there may not be any direct evidence to suggest that a particular location is a candidate for soil sampling. The sampler may, in fact, be faced with investigating a virtually invisible contaminant distribution pattern, both in the surficial material, as well as in the subsurface region.

2.7.2 Sampling Location/Site Selection

Areas selected for soil sampling shall be strategically located in order to collect a representative fraction of the soils with the minimum number of samples. Although it is not always feasible to conduct a site reconnaissance prior to an investigation, a site reconnaissance can eliminate many uncertainties with respect to site characteristics and result in more complete and successful soil sampling studies. A surface inspection of the subject area should be made to locate pertinent features (e.g., rock outcrops, drainage patterns, surface runoff, ponds, lakes, wet areas, seeps, springs, permanent structures, fill areas, erosional areas, depositional areas, etc.) and to evaluate the relationship between these features and potential sources of pollution. A knowledge of these relationships and conditions, particularly soil conditions (type and thickness of soil overburden) and water table conditions are extremely important in developing sampling plans.

In addition to what is normally considered soil, i.e., in situ weathered rock overburden, soil samples may also consist of what is more correctly considered sediment, which has been deposited by both overland sheet runoff, as well as flow in normally dry wet-weather swales. The location of sediment sampling locations in these types of depositional areas is a useful screening tool, providing an indication of the presence of contaminants from the larger area contributing the sediment.

Initial investigations at most sites will consist of "screening-type" studies. Sampling for these investigations will generally be confined to a small number of surface or shallow subsurface samples. Typically, samples would be collected from depositional areas within and around the periphery of the site, as well as from obviously contaminated areas. Based on the results of the initial site-screening studies, more detailed studies, involving considerably more samples and with a greater emphasis on subsurface sampling, are usually required to fully characterize soil contamination at a site.

Study plans or work plans for soil sampling investigations must be carefully conceived with respect to the study objectives. This, in turn, requires a careful consideration of the types of samples to be collected, as well as the sampling methods to be employed. These areas are discussed below.

2.7.3 Basic Considerations for Soil Sampling

Three basic considerations, with respect to sample type, should be evaluated when developing a soil sampling plan and establishing investigation objectives. Should the samples be random, biased, or grid-based? Will they be collected from the surface or subsurface? Will a particular sample be a grab sample or a composite sample? When all of these questions are answered, it will be found that many investigations will involve the collection of most combinations of the above types of samples. A discussion of these considerations is found in the following sections.

2.7.3.1 Random, Biased and Grid-Based Sampling

Generally, unless there is a strong indication of contamination, such as staining, or there are distinct depositional areas which provide excellent screening samples, soil samples collected for small investigations with limited areal extent, such as screening site investigations, must be randomly selected from several areas within the suspected area of contamination. Random in this sense is synonymous with casual, i.e., locations are often subjectively selected based purely on personal judgement.

If any areas show evidence of contamination, such as staining or vegetative stress, biased samples should be collected from each of the areas to characterize the contamination present in each area. If surface drainage patterns such as dry washes or swales are discernable, soil/sediment samples may be collected from the deposits in these features to characterize the immediate areas. Background and control samples are also biased, since they are collected in locations dictated by expected clean conditions or by anticipated impact from adjacent off-site areas.

When soil sampling investigations involve large areas, measured in acres for example, a systematic approach must be taken, not necessarily to the exclusion of other approaches, to characterize the presence and distribution of contaminants. In these situations, a grid-based soil sampling program is employed. There is no single grid size that is appropriate for all sites; however, in most cases, the smaller the site, the smaller the grid size. Common grid sizes are developed on 50-foot and 100-foot centers, although other sizes may be appropriate in given situations. It may be appropriate and acceptable to integrate several different grid sizes in a single investigation.

When the site is extremely large, over several acres for example, it may be impossible to consider sampling every grid and it will be necessary to statistically select a sub-set of the total number of grids in order to reduce the number of samples collected for the study. On the other hand, it may sometimes be appropriate to sample every grid and use relatively inexpensive and quick screening-level analytical techniques to define the areas which must be sampled and analyzed for a higher level of data quality. Because the screening level analysis is relatively quick, the second phase sampling can sometimes be conducted during the same investigation. In all cases, however, the grid centers should be located using a site survey and semi-permanently marked to facilitate relocating the sample locations for subsequent sampling.

2.7.3.2 Surface and/or Subsurface Soil Samples

In most initial investigations, particularly site screening-type studies, surface soil samples may comprise the great majority of soil samples collected. These are collected to look for the possible presence and distribution of contaminants in surficial materials. Subsurface soil sampling may be limited during initial investigations, but it may comprise the major portion of the soil sampling effort during subsequent phases of the investigation where the vertical extent of contamination in identified areas of surface contamination is the major objective.

2.7.3.3 Grab versus Composite Samples

When a sample is needed to identify and quantify compounds at a specific location or interval, a grab sample is collected. Grab samples are limited in areal extent (for surface samples) or vertical extent (for subsurface samples). The sample should be comprised of no more than the minimum amount of soil necessary to make up the volume of sample dictated by the required sample containers. Composite samples are a mixture of a given number of subsamples and are collected to characterize the average composition of a given surface area or vertical interval. Areal composites are comprised of subsamples collected from the surface within the selected area. The number of subsamples forming a composite should remain consistent within the context of the study, i.e., a number and pattern for collection of subsamples within a grid should be selected and, for a given grid size, should not be changed. Likewise, if one of the objectives of the study is to determine if any contamination is present within a particular vertical interval, a vertical composite sample, comprised of vertically discrete samples collected over the selected interval may be collected. As with the areal composites, the number of subsamples is dependent on the objectives of the study. With the low analytical detection limits available today, compositing can usually be used to determine the presence or absence of compounds in the area or interval sampled.

There are two potential problems associated with compositing for which the sampler must be aware. Even though modern analytical detection limits allow for qualitative screening in many cases using compositing techniques, the risk still remains that low concentrations, present in individual composite aliquots, may be diluted to the extent that the total composite concentration is below the minimum quantification limit. Also, if the subsamples are predominantly moist and clayey, it will be very difficult to produce a homogenous mixture. The resulting sample, as represented by the portion selected by the analytical chemist, may not be representative, either qualitatively or quantitatively, of an average of all of the subsamples.

2.7.4 Sampling Methodology

This discussion of soil sampling methodology reflects both the equipment used (required/needed) to collect the sample, as well as how the sample is handled and processed after retrieval. Selection of equipment is usually based on the depth of samples, but it is also controlled, to a certain extent, by the characteristics of the material. Simple, manual techniques and equipment, such as hand augers, are usually selected for surface or shallow, subsurface soil sampling. As the depth of the sampling interval becomes greater, some type of powered sampling equipment is usually needed to overcome torque induced by soil resistance and depth. The following is an overview of the various sample collection methods employed over three general depth classifications: surface, shallow subsurface, and deep subsurface. Any of the deep collection methods described may be used to collect samples from the shallower intervals. See Section 2.2.10 for special sampling considerations for purgeable organic compounds analyses.

2.7.4.1 Manual (Hand Operated) Collection Techniques and Equipment

These methods are used primarily to collect surface and shallow subsurface soil samples. Surface soils are generally classified as soils between the ground surface and 6 to 12 inches below ground surface. The shallow subsurface interval may be considered to extend from approximately 12 inches below ground surface to a site-specific depth at which sample collection using manual, i.e., hand-powered, methods becomes impractical.

2.7.4.2 Surface Soils

Surface soils may be collected with a wide variety of equipment. Spoons, shovels, hand-augers, push tubes, and post-hole diggers, made of the appropriate material, may be used to collect surface soil samples. As discussed in the section on powered equipment, surface soil samples may also be collected in conjunction with the use of heavy equipment.

Surface samples are removed from the ground and placed in pans, where mixing, as appropriate (Section 2.2.10), occurs prior to filling of sample containers. Section 2.11.5 contains specific procedures for handling samples for purgeable organic compounds analyses. If a thick, matted root zone is encountered at the surface, it should be removed before the sample is collected.

2.7.4.3 Subsurface Soils

Hand-augering is the most common manual method used to collect subsurface samples. Typically, 4-inch auger-buckets with cutting heads are pushed and twisted into the ground and removed as the buckets are filled. The auger holes are advanced one bucket at a time. The practical depth of investigation using a hand-auger is related to the material being sampled. In sands, augering is usually easily accomplished, but the depth of investigation is controlled by the depth at which sands begin to cave. At this point, auger holes usually begin to collapse and cannot practically be advanced to lower depths, and further samples, if required, must be collected using some type of pushed or driven device. Hand-augering may also become difficult in tight clays or cemented sands. At depths approaching 20 feet, torquing of hand-auger extensions becomes so severe that in resistant materials, powered methods must be used if deeper samples are required. Some powered methods, discussed later, are not acceptable for actual sample collection, but are used solely to gain easier access to the required sample depth, where hand-augers or push tubes are generally used to collect the sample.

When a vertical sampling interval has been established, one auger-bucket is used to advance the auger hole to the first desired sampling depth. If the sample at this location is to be a vertical composite of all intervals, the same bucket may be used to advance the hole, as well collect subsequent samples in the same hole. However, if discrete grab samples are to be collected to characterize each depth, a new bucket must be placed on the end of the auger extension immediately prior to collecting the next sample. The top several inches of soil should be removed from the bucket to minimize the chances of cross-contamination of the sample from fall-in of material from the upper portions of the hole. Section 2.11.5 contains additional sample handling procedures.

Another hand-operated piece of soil sampling equipment commonly used to collect shallow subsurface soil samples is the Shelby or "push tube". This is simply a thin-walled tube, generally of stainless steel construction and having a beveled leading edge, which is twisted and pushed directly into the soil. This type of sampling device is particularly useful if a relatively undisturbed sample is required. The sampling device is removed from the push-head, then the sample is extruded

from the tube into the pan with a spoon or special extruder. Even though the push-head is equipped with a check valve to help retain samples, the Shelby tube will generally not retain loose and watery soils, particularly if collected at lower depths.

2.7.4.3.1 *Powered Sampling Devices*

Powered sampling devices and sampling aids may be used to acquire samples from any depth but they are generally limited to depths of 20 feet or less. Among the common types of powered equipment used to collect or aid in the collection of subsurface soil samples are Little Beaver®-type two-man power augers; split-spoon samplers driven with a drill rig drive-weight assembly or hydraulically pushed using drill rig hydraulics; continuous split-spoon samplers; specialized hydraulic cone penetrometer rigs; and back-hoes. The use of each of these is described below.

2.7.4.3.2 *Power Augers*

Two-man power augers are commonly used to aid in the collection of subsurface soil samples at depths where hand augering is impractical. This type of equipment is technically a sampling aid and not a sampling device, and 20 to 25 feet is the typical lower depth range for this equipment. It is used to advance a hole to the required sampling depth, at which point a hand auger is usually used to collect the sample.

2.7.4.3.3 *Drill Rigs*

Drill rigs offer the capability of collecting soil samples from greater depths. For all practical purposes, the depth of investigation achievable by this method is controlled only by the depth of soil overlying bedrock, which may be in excess of 100 feet.

When used in conjunction with drilling, split-spoon samplers are usually driven either inside a hollow-stem auger or inside an open borehole after rotary drilling equipment has been temporarily removed. The spoon is driven with a 140-pound hammer through a distance of up to 24 inches and removed. If geotechnical data are also required, the number of blows with the hammer for each six-inch interval is also recorded.

Continuous split-spoon samplers may be used to obtain five-foot long, continuous samples approximately 3 to 5 inches in diameter. These devices are located inside a five-foot section of hollow-stem auger and advanced with the auger during drilling. As the auger advances, the central core of soil moves into the sampler and is retained until retrieval.

2.7.4.3.4 *Cone Penetrometer Rigs*

A recent innovation is now available, which involves the modification of a standard split-spoon. The spoon has been modified with a releasable tip which keeps the spoon closed during the sampling push. Upon arrival at the desired depth, the tip can be remotely released and the push continued. During the subsequent push, the released tip floats freely up the inside of the spoon as the soil core displaces it. Split-spoon soil samples, therefore, can be collected without drilling, as has historically been required, by simply pushing the device to the desired depth. This technique is particularly beneficial at highly contaminated sites, because cuttings are not produced as with drill rigs. The push rods are generally retrieved with very little residue. This results in minimal exposure to

sampling personnel and very little contaminated residue is produced as a result of equipment cleaning.

2.7.4.3.5 *Back-Hoes*

Back-hoes are often utilized in shallow subsurface soil sampling programs. Samples may either be collected directly from the back-hoe bucket or they may be collected from the trench wall if proper safety protocols are followed. Trenches offer the ability to collect samples from very specific intervals and allow visual correlation with vertically and horizontally adjacent material. Prior to collecting samples from trench walls, the wall surface must be dressed with a stainless steel shovel, spatula, knife, or spoon to remove the surface layer of soil which was smeared across the trench wall as the bucket passed. If back-hoe buckets are not cleaned according to the procedures described in Section B.8.3 of this manual, samples must be collected from material which has not been in contact with the bucket surface.

2.7.5 Special Techniques and Considerations

2.7.5.1 Collection of Soil Samples for Purgeable Organic Compound (VOA) Analyses

These samples should be collected in a manner that minimizes disturbance of the sample. For example, when sampling with a hand auger, the VOA sample may be collected directly from the auger bucket or immediately after an auger bucket is emptied into the pan. The sample should be placed in the appropriate container with no head-space, if possible, as is the practice with water samples. Samples for VOA analysis are not mixed (Section 2.2.10).

2.7.5.2 Dressing Soil Surfaces

Any time a vertical or near vertical surface, such as is achieved when shovels or back-hoes are used for subsurface sampling, is sampled, the surface should be dressed to remove smeared soil. This is necessary to minimize the effects of cross-contamination due to smearing of material from other levels.

2.7.5.3 Sample Mixing

It is extremely important that soil samples be mixed as thoroughly as possible to ensure that the sample is representative of the interval sampled. Soil samples should be mixed as specified in Section 2.2.10.

2.7.5.4 Special Precautions for Trace Contaminant Soil Sampling

The procedures outlined in Section 2.2.9 shall be followed. All soil sampling equipment used for sampling for trace contaminants should be constructed of stainless steel where possible. Pans used for mixing shall be made of Pyrex®, or equivalent, glass. In no case will chromium, cadmium, or galvanized plated or coated equipment be used for soil sampling operations. Similarly, no painted or plastic equipment shall be used. All paint and primer must be removed from soil sampling equipment by sandblasting or other means before such equipment can be used for collecting soil samples.

2.7.5.5 Specific Sampling Equipment Quality Assurance Techniques

Drilling rigs and other major equipment used to collect soil samples shall be identified so that this equipment can be traced through field records. A log book shall be established for this equipment so that all cleaning, maintenance and repair procedures can be traced to the person performing these procedures and to the specific repairs made. Sampling spoons, hand augers, Shelby tubes, and other minor disposable type equipment are exempted from this equipment identification requirement.

- All equipment used to collect soil samples shall be cleaned as outlined in Appendix B and repaired, if necessary, before being stored at the conclusion of field studies.

- Any cleaning conducted in the field (Section 6) or field repairs should be thoroughly documented in field records.

2.7.5.6 Auxiliary Data Collection

In addition to information pertaining to an area or specific site/location that may be available in EPA files from previous investigations (i.e., site screenings, water quality, well monitoring studies, etc.), information and data may be obtained from various city, county, state, and other federal agencies.

Samples should be accurately tagged and labeled with all pertinent site information at the time of sampling. See Section 1 for sample labeling and field recording procedures. The latitude and longitude shall be obtained for each site for future STORET data entry.

2.8 Air Toxics Monitoring

2.8.1 Volatile Organic Compounds (VOC) Sampling With SUMMA® Electropolished Stainless Steel Canisters Using Method TO-14

2.8.1.1 General

The following is a synopsis of procedures which should be strictly adhered to for the cleanup and use of Summa® canisters in sampling air for Volatile Organic Compounds (VOC). This summary is adapted from Method TO-14 of the COMPENDIUM OF METHODS FOR THE DETERMINATION OF TOXIC ORGANIC COMPOUNDS IN AMBIENT AIR.

The following procedures must be followed in the preparation and use of Summa® canisters for sampling VOC.

- All new Summa® canisters must be individually checked for contamination before use. One of each batch of 10 Summa® canisters that are subsequently cleaned must be analyzed to check for contamination.

- All sampler tubing, fittings, and wetted parts of valves must be solvent washed in hexane and heated to >100o C. These parts should then be assembled and flushed with nitrogen for at least 8 hours prior to use in the sample train or in the canister cleanup apparatus.

- Each canister's valve and fitting will be inspected for damage before cleaning. Any damaged valve will be replaced with a previously cleaned (see procedure above)

valve. After replacing any valve, the canister will be cleaned and analyzed to verify that it is free of contamination.

- If any canister is used to sample a high concentration source, it must be cleaned and analyzed to verify it is free of contamination before it can be used again.

- Chain-of-custody must be maintained for all samples.

2.8.1.2 SUMMA® Canister Cleanup

The following cleanup procedure will be followed for the preparation of all Summa® canisters:

- The canisters should initially be pressurized to >2 atm with humidified nitrogen then evacuated to 1 atm. This filling and evacuation sequence shall be repeated five times to dilute any residual contaminants. The addition of the water from the humidified nitrogen may also displace some of the more reactive contaminants that could adhere to active sites on the wall of the canister. After the fifth evacuation to 1 atm, the vacuum pump will be valved on and left on for a minimum of 3 hours or until a vacuum of <150 millitorr is reached. The identification number of the canister, the date and the final vacuum will be recorded in the canister cleanup logbook. After cleaning, the canister's valve should be capped with a Swagelok® plug. A label will then be affixed to the canister denoting the date it was cleaned and the name of the person who performed the cleaning.

  1. (The nitrogen should be certified 99.999% pure by the manufacturer. A molecular sieve scrubber should be attached to the nitrogen line after the regulator to remove any trace impurities).

2.8.1.3 Sample Collection

Two types of VOC samples can be collected with Summa® canisters. The canister can be opened and allowed to fill rapidly to obtain a grab sample or filled slowly by using a flow controller to collect a time integrated sample. With either type of sample, the following general procedures should be followed:

- A pre-numbered sample tag should be tied to the handle of the Summa® canister prior to sampling.

- A Chain-Of-Custody Record should be completed detailing time of sampling, sampling interval, and signed by the person taking the sample.

- After the sample has been collected, the Summa® canister should be capped, the pre-numbered tag should be completed, and the canister should be placed in a shipping container with a copy of the Chain-Of-Custody Record and sealed with sample custody tape.

2.8.1.4 Grab Sample Collection

Before a grab sample for VOC analysis is collected in a Summa® canister, the canister inlet valve should be fitted with a pre-cleaned (Section 2.8.1.2) stainless steel particulate filter. At the sample collection location, the main valve should be opened and the canister allowed to fill. After about one minute (when no audible sound of rushing gas can be heard), close and cap the main valve of the Summa® canister.

2.8.1.5 Time Integrated Sample Collection

This sample collection method involves the use of a flow controller or a sampler containing a flow controller to slowly meter the flow of air entering a Summa® canister. With this method, a sample is collected over a longer period of time than with a grab sample. If a constant flowrate was maintained, the resulting sample will have a VOC content that is the average of the VOC concentrations for the sampling interval (a time integrated sample).

The following procedures should be followed to collect time integrated samples:

- All sampler systems should be checked for contamination prior to use or after any major repair This is accomplished by metering zero air or nitrogen1 to the inlet of the sampler. Excess zero air or nitrogen flow should be vented with a Swagelok® tee from the sampler inlet to atmosphere.

The evacuated canister should then be filled at the normal sampling rate with the zero gas.

- Initial flowrates will be determined with a mass flow meter. The initial flowrate and initial vacuum (at least 29 inches of Hg) should be recorded on the sample data sheet. Adjust the flowrate so that at the end of the sampling interval the ending pressure of the canister is approximately 0.9 atm.

- Final flowrates should also be determined with a mass flow meter. Final flowrate and final vacuum should be recorded on the sample data sheets. The final vacuum should be between 5 inches and 1 inch of Hg. The final flowrate should be at least 1 scc/min.

After sample collection, all canisters should be double checked to verify that each has a pre-numbered tag with all information filled out. Place the canister in a shipping container and seal the container with sample custody tape.

2.9 References

1. Memorandum re: "National Guidance Package for Compliance with Department of Transportation Regulations in the Shipment of Environmental Laboratory Samples." U. S. Environmental Protection Agency, Office of Planning and Management, March 6, 1981.

2. NPDES Compliance Inspection Manual, United States Environmental Protection Agency, Enforcement Division, Office of Water Enforcement and Permits, EN-338, 1988.

3. Handbook for Monitoring Industrial Wastewater, United States Environmental Protection Agency, Technology Transfer, 1973.

4. Handbook for Evaluating Water Bacteriological Laboratories, United States Environmental Protection Agency, ORD, Municipal Environmental Research Laboratory, Cincinnati, Ohio, 1975.

5. Microbiological Methods for Monitoring the Environment, Water and Wastes, United States Environmental Protection Agency, ORD, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, 1978.

6. Kittrell, F. W., "A Practical Guide to Water Quality Studies of Streams," United States Department of Interior, Federal Water Pollution Control Administration: Cincinnati, Ohio, 1969.

7. Lauff, G. H., ed., Estuaries, American Association for the Advancement of Science: Washington, D.C., Publication No. 83, 1967.

8. Fischer, H. B., E. J. List, R. C. Koh, J. Inberger, and N. H. Brooks, Mixing in Inland and Coastal Waters, Academic Press: New York, 1979.

9. Ippen, A. T., Estuary and Coastline Hydrodynamics, McGraw-Hill Book Company, Inc.: New York, 1966.

10. Reid, G. K. and R. D. Wood, Ecology of Inland Waters and Estuaries, 2nd Edition, D. Van Nostrand Company: New York, 1976.

11. Kaplovsky, A. J., "Estuarine Pollution Investigation Employing "Same-Slack" Technique," Journal of the Water Pollution Control Federation, Volume 29, No. 9, pg. 1042, 1957.

12. Freed, J. R., P. R. Abell, D. A. Dixon, R. E. Huddleston, M. W. Slimak, and J. Pawlow, "Sampling Protocols for Analysis of Toxic Pollutants in Ambient Water, Bed Sediment, and Fish," Interim Final Report, 3 February 1980, for Office of Water Planning and Standards, United States Environmental Protection Agency, 1980.

13. "RCRA Ground-Water Monitoring Enforcement Guidance: RCRA Ground-Water Monitoring Compliance Order Guidance (Final) and RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (Draft)," US-EPA, Office of Waste Programs Enforcement and Office of Solid Waste and Emergency Response, August 1985.

14. "Groundwater," Section 18, USDA-SCS National Engineering Handbook, United States Department of Agriculture, Soil Conservation Service, 1978.

15. Procedures Manual for Groundwater Monitoring at Solid Waste Disposal Facilities, United States Environmental Protection Agency, Office of Water and Waste Management, SW-611, 1977.

16. Water Quality Monitoring at Solid Waste Disposal Sites in Minnesota, Minnesota Pollution Control Agency, Solid Waste Division, 1979.

17. Manual of Ground-Water Sampling Procedures, United States Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, 1981. and Waste Management, SW-611, December 1980.

18. Barcelona, Michael J., et.al., A Guide to the Selection of Materials for Monitoring Well Construction and Groundwater Sampling, Illinois State Water Survey, Department of Energy and Natural Resources, Champaign, Illinois, SWS Contract Report 327, August 1983.

19. Sampling for Organic Chemicals and Microorganisms in the Subsurface, United States Environmental Protection Agency, EPA-600/2-77-176, 1977.

20. "Engineering Geology," Section 8, National Engineering Handbook, United States Department of Agriculture, Soil Conservation Service, 1978.

21. Geologic Site Exploration, United States Department of Agriculture, Soil Conservation Service, EWP Technical Guide No. 4, 1969.

22. Preparation of Soil Sampling Protocol: Techniques and Strategies, US-EPA600/4-83-020, EMSL, Las Vegas, August 1983.

23. Field Health and Safety Manual, United States Environmental Protection Agency, Region IV, 1990 Edition.

24. Safety Manual for Hazardous Waste Site Investigations, United States Environmental Protection Agency, Draft, 1979.

25. Characterization of Hazardous Waste Sites - A Methods Manual: Volume 1 -Site Investigations, US-EPA, EMSL, Las Vegas, EPA-600/4-84-075, April 1985.

26. Characterization of Hazardous Waste Sites - A Methods Manual: Volume II - Available Sampling Methods, 2nd Edition, US-EPA, EMSL, Las Vegas, EPA600/4-84-076, December 1984.

27. Enforcement Considerations for Evaluation of Uncontrolled Hazardous Waste Disposal Sites by Contractors, US-EPA, NEIC, 1980.

28. Test Methods for Evaluating Solid Waste - Physical/Chemical Methods (SW-846), US-EPA, Office of Solid Waste and Emergency Response, Washington, D.C., July 1982.

29. Data Quality Objectives for Remedial Response Activities. EPA/540/G-87/003 (OSWER Directive 9355.0-7B) March 1987.

30. IDW Management Guidance Manual, 2nd. Draft. May 25, 1990. USEPA Office of Emergency and Remedial Response.

SECTION 3
FIELD ANALYTICAL PROCEDURES

3.1 General

Field analytical equipment used should be suitable for the analysis to be accomplished and properly calibrated. In addition to being accurate, field analyses must be conducted on a sample which is representative of the source from which it was collected. Therefore, the type of sample and location of the sampling site are critical. A detailed discussion of sample type and sample site selection is given in Section 2 for the various media investigated.

The objectives of this section are to:

- list the specific field analytical techniques that shall be used;
- list the specific quality control procedures and calibration techniques for each piece of field analytical equipment used;
- list the source of all reagents and standards used to perform field analyses and/or calibrate field analytical equipment; and
- specify the training required to perform the listed field analyses.

Specific field analytical methodology for each parameter is given in Section 8.

3.2 Specific Analytical Techniques

The specific field analytical techniques used by Branch personnel are listed below and the specific procedures for each analytical technique and field test are presented in Appendix D.

Analytical Parameter	Method	Reference	Equipment
Temperature	Calibrated glass (mercury),	1	Mercury filled glass, dial(mechanical), or electro-mechanical dial type metric thermometer, or thermistor with electronic readout
pH	Electrometrically using a glass electrode in combina tion with a reference poten tial or a combination electrode	1	Portable field pH meter
Dissolved Oxygen (DO)	Modified Winkler or membrane electrode	1	Standard DO kit with fresh sodium thiosulfate, or membrane electrode and electronic readout

Analytical Parameter	Method	Reference	Equipment
Specific Conductance	Wheatstone bridge type or equivalent meter corrected to 25°C	1	Self-contained conductivity meter, Wheatstone bridge type, or equivalent with automatic temperature compensation to 25°C or "dial in" temperature compensation
Total Chlorine Residual	Back titration, iodometric with starch or amperometric end-point or DPD colorimetric	1	Iodometric backtitration kit with fresh reagents, or amperometric titrator with fresh reagents, or DPD kit with color standards
Tracer-Fluorescence	Analysis of fluorescent dyes using a fluorometer	2	Thodamine WT dye and Turner fluorometer
Salinity	Electrodeless Inductive Conductivity Cell Salinometer	3	Beckman RS5-3 Portable Salinometer and Hydrolab surveyor II Meter

3.3 Specific Quality Control Procedures

Quality assurance procedures for field analysis, and field analytical and test instrumentation calibration are an essential part of these standard operating procedures. All field analytical procedures shall be conducted in duplicate at least 10 percent of the time. A record of these duplicate analyses shall be kept in field logbooks. A significant difference in the replicate analyses (greater than specified in the following sections) shall result in recalibration of the instruments used, re-examination of the analytical methodology being used, or re-examination of the sampling location.

All field analyses must be traceable to the specific individual performing the analyses. Time records shall be kept in local time using the military 2400 hour format and shall be recorded to the minute. This information shall be entered into the field logbooks for all field analyses performed.

A specific calibration and/or standardization plan for all field analytical equipment is presented in this subsection. Included in this plan are: calibration and maintenance intervals; listing of required calibration standards and conditions requiring recalibration.

3.3.1 Temperature

3.3.1.1 Initial Calibration

All thermometers shall be initially calibrated against a National Bureau of Standards (NBS) certified thermometer or one traceable to NBS certification.

3.3.1.2 Inspection and Calibration

Each glass mercury filled thermometer shall be inspected before each field trip to see that it is not cracked and has no air space in the mercury column. If a mechanical dial-type thermometer is used,

it should not have a broken face cover or otherwise show damage. A cross-check with a calibrated NBS certified thermometer shall be made at least semi-annually. Thermistors and electronic readout units should be calibrated in the same manner. Recording thermometers shall be checked for recording accuracy before each use. The recorder time scale accuracy shall be checked semi-annually. Before using a thermometer in the field, a visual observation shall be made to assure that it has not been damaged. If a thermistor is used, the instrument shall be checked against a thermometer before field use. Cross-checks and duplicate field analyses should agree within $\pm$0.5oC.

3.3.1.3 Calibration Records

A logbook shall be maintained with each thermometer number and/or equipment property number recorded. All calibration information including individuals making the calibrations and dates of calibration shall be recorded.

3.3.1.4 Reporting Units

Report all temperature data to the nearest 0.50C.

3.3.2.1 Equipment

Only electronic (portable) pH meters with automatic temperature compensation (ATC) should be used. Temperature resistant, combination electrodes should be employed in conjunction with the meters. pH test paper will be used only for determining pH ranges, for determining approximate pH values, or for concentrated hazardous waste samples which would damage the instrument.

3.3.2.2 Equipment Inspection and Calibration

The pH meter shall be checked before each field trip for any mechanical or electrical failures, weak batteries, and cracked or fouled electrodes. The slope of the meter shall also be checked initially with three fresh standard buffer solutions (e.g., 4, 7, and 10). All pH recorders shall be checked for recording accuracy and time scale accuracy. While in the field, the meter shall be calibrated daily before use with two buffers bracketing the expected sample pH. Thereafter, the meter shall be checked against two buffers when moving to a new sample location. Fresh buffer solutions shall be used for each field trip. In case of an apparent pH violation, the electrode shall be checked with pH 7.0 buffer and recalibrated to the closest reference buffer. Then the sample shall be retested. Duplicate tests should agree within 0.1 standard unit.

3.3.2.3 Reporting Units

Report pH to the nearest 0.1 standard unit.

3.3.3 Dissolved Oxygen (DO)

3.3.3.1 Equipment

Modified Winkler kits and membrane electrode DO meters should be used.

3.3.3.2 Equipment Inspection and Calibration

DO meters shall be checked before each field trip by inspecting the membrane for air bubbles and holes. If the membrane is dry, it shall be replaced and soaked in water before calibrating. Calibration should be made against the modified Winkler test.

DO kits shall be refilled with new standardized sodium thiosulfate before each field trip. Each solution shall be checked for clarity and volume.

Before using the DO meter each day, duplicate deionized or known clean water samples shall be collected by siphoning water from a bucket into two DO bottles. These duplicate samples shall be analyzed by the modified Winkler test for DO content. The DO meter shall be calibrated against the DO content measured by the Winkler test by placing the DO probe in the bucket containing the water used for the Winkler test.

While using the DO meter, the instrument shall be recalibrated at least twice per day or if a change in water quality is noted. If the sample temperature is 50C greater than the calibration temperature, the meter shall also be recalibrated.

Duplicate analyses should agree with $\pm$ 0.1 mg/l.

3.3.3.3 Reporting Units

Results for the DO test should be reported to the nearest 0.1 mg/l.

3.3.4 Specific Conductance

3.3.4.1 Equipment

A portable specific conductance meter, Wheatstone bridge type or equivalent should be used.

3.3.4.2 Inspection and Calibration

Each conductivity meter shall be checked before each field trip. Batteries shall be checked, and conductivity cells shall be cleaned and checked against known conductivity standards (KCl).

3.3.4.3 Field Calibration

Before using in the field, check instrument daily with known standards. Refer to the instrument instructions for temperature conductance calculations. Duplicate field analyses should agree within $\pm$ 10 percent.

3.3.4.4 Reporting Units

Results should be expressed in micromhos/centimeter (umhos/cm) corrected to 250C. Results should be reported to the nearest ten units for readings under 1,000 umhos/cm and the nearest 100 units for readings over 1,000 umhos/cm.

3.3.5 Total Chlorine Residual

3.3.5.1 Equipment

The iodimetric back titration method with a starch-iodide end point or amperometric end point or a Hach DR 100 colorimetric (DPD) kit may be used.

3.3.5.2 Inspection and Calibration

Each titration kit or meter shall be checked before each field trip by inspecting the meter for battery strength and fresh reagents. The normality of the iodate should be checked with a distilled water blank to establish a correction factor for the titrant. This will also serve to check the response of the amperometric titrator. Duplicate chlorine residual analyses should agree within $\pm$ 0.01 mg/l.

If the Hach DR 100 colorimeter (DPD) kit is used, the method must agree with the requirements of Method 408E, "Standard Methods," 16th Edition, or Method 330.5 "Methods for Chemical Analysis of Water and Wastes," and calibration scales must be calibrated on site at a minimum of three points (blank and two standards) that bracket the expected sample concentration.

3.3.5.3 Reporting Units

Results should be reported to the nearest 0.01 mg/l residual chlorine.

3.3.6 Fluorescent Tracing

3.3.6.1 Tracer

Rhodamine WT dye is the recommended standard tracer.

3.3.6.2 Fluorometer

A filter fluorometer (fluorometer) is the instrument used to determine intensity of emitted light or concentration of dye in the sample.

3.3.6.3 Fluorometer Calibration and Calibration Standards

Before a fluorometer is used in the field, it shall be checked against a set of standard dye solutions. All standard concentrations shall be made relative to the stated concentration of the manufacturer's solution.

All standard solutions shall be made with distilled water. Sufficient solution volumes shall be made to permit calibration checks. Calibration checks shall be conducted whenever the fluorometer has been turned off for an extended period of time.

The fluorometer and all associated equipment shall be thoroughly cleaned between uses.

3.3.6.4 Reporting Units

Turner Design fluorometer results shall be reported as $\pm$ 1 percent of full scale concentration.

3.3.7 Salinity

3.3.7.1 Equipment

A portable salinometer, electrical conductivity type shall be used.

3.3.7.2 Inspection and Calibration

Each salinometer shall be checked before every field trip. Batteries shall be checked and the cell inspected to determine if it is free of marine growth and salt. The meter shall be checked against the resistor loop supplied with the meter.

3.3.7.3 Reporting Units

Results should be reported to the nearest 0.1 part per thousand of salinity.

3.4 References

1. "Guidelines for Establishing Test Procedures for the Analysis of Pollutants," Federal Register, Volume 49, No. 209, 40 CFR 136, October 26, 1984, and any subsequent revisions.

2. Wilson, J. F., Fluorometric Procedures for Dye Tracing: USGS Techniques of Water-Resources Investigations, Book 3, Chapter A12, United States Department of Interior, Geological Survey, 1968.

3. Standard Methods for the Examination of Water and Wastewater, 1985, 16th Edition.

4. Methods for Chemical Analysis of Water and Wastes, EPA, 600/4-79-020, and all current revisions.

SECTION 4
FIELD PHYSICAL MEASUREMENTS

4.1 General

Field measurements of topographic features, water levels, time of travel, geophysical parameters, and physical dimensions are frequently required during comprehensive water quality, groundwater, hazardous waste, wastewater treatment system, and related field investigations. The scope of such measurements obviously depends on the purpose of the particular investigation.

All sampling locations used during field investigations shall be depicted on an accurate drawing or a topographic or other standard map, or be referenced in such a manner that their location(s) are firmly established. The Region IV library has a complete collection of 7.5 minute USGS (1:24,000 scale) topographic maps and a map copier available.

Each field measurement made shall be traceable to the actual person making the measurement and to the field equipment used to make that measurement. All equipment maintenance and calibration records shall be kept in log books and field records so that all such procedures are traceable. All time records shall be kept in local time using the 2400 hour format, and time shall be recorded to the nearest minute.

The specific objectives of this section are to:

- present the standard practices used to make physical field measurements;
- list the field equipment utilized to make such measurements: and
- present specific quality control procedures to insure that such measurements are accurate.

4.2 Ground Water Level Measurement

4.2.1 General

The measurement of ground water level in wells is frequently conducted in conjunction with ground water sampling. Data from such measurements are needed to determine the "free" water surface and can be used to establish ground water flow direction and gradients.

Total well depth measurements, along with ground water level measurements, are necessary to determine the volume of water in a well casing prior to purging the well during ground water sampling.

All ground water level measurements, as well as total depth measurements, shall be made in reference to an established reference point on the well casing. This reference point shall be documented in field records. To be useful for establishing ground water gradient, the reference point should be tied in with the NGVD (National Geodetic Vertical Datum) or a local datum. An arbitrary datum common to all wells in a group may be used for an isolated group of wells, if necessary.

4.2.2 Specific Ground Water Level Measuring Techniques

Measuring the depth to the free ground water surface can be accomplished by the following methods (8). Method accuracies are noted below for each of the specific methods described.

4.2.2.1 Popper or Bell Sounder

A bell- or cup-shaped weight that is hollow on the bottom is attached to a measuring tape and lowered into the well. A "popping" sound is made when the weight strikes the surface of the water. An accurate reading can be determined by lifting and lowering the weight in short strokes, and reading the tape when the weight barely strikes the water. Measurements shall be recorded to the nearest 0.1 foot.

4.2.2.2 Weighted Tape

This method is similar to the "bell sounder" method, except that any suitable weight, not necessarily one designed to create an audible pop, can be used to suspend the tape. The weight should, ideally, be made of a relatively inert material and should be easily cleaned. Measurements shall be made and recorded to the nearest 0.1 foot.

4.2.2.3 Chalked Tape

Chalk rubbed on a weighted steel tape will discolor or be removed when in contact with water. Distance to the water surface can be obtained by subtracting the wet chalked length from the total measured length. The tape should be withdrawn quickly from the well because water has a tendency to rise up the chalk due to capillary action. Measurements shall be made and recorded to the nearest 0.01 foot. This method is not recommended if samples are to be collected for analyses of organic or inorganic contaminants.

4.2.2.4 Electric Water Level Indicators

This instrument consists of a spool of dual conductor wire, a probe attached to the end, and an indicator. When the probe comes in contact with the water, the circuit is closed and a meter light and/or buzzer attached to the spool will signal the contact. Penlight or 9-volt batteries are normally used for a power source. Measurements shall be made and recorded to the nearest 0.01 foot.

4.2.2.5 Other Methods

There are other types of water level indicators and recorders available on the market such as the sliding float method, air line pressure method, and electrical and automatic recording methods. These methods are primarily used for closed systems or permanent monitoring wells. Acoustic water level indicators are also available which measure water levels based on the measured return of an emitted acoustical impulse. Accuracies for these methods vary and should be evaluated before selection. Any method not capable of providing measurements to within 0.1 foot shall not be used.

4.2.3 Total Well Depth Measurement Techniques

The bell sounder, weighted tape, or electric water level indicators described in Section 4.2.2 can be used to determine the total well depth. This is accomplished by lowering the tape or cable until the

weighted end is felt resting on the bottom of the well. Because of tape buoyancy and weight effects encountered in deep wells with long water columns, it may be difficult to determine when the tape end is touching the bottom of the well. Care must be taken in these situations to ensure accurate measurements. All total well depth measurements must be made and recorded to the nearest 0.1 foot.

4.2.4 Equipment Available

The following Branch equipment is available for ground water level and total well depth measurements:

- weighted steel measuring tapes, and
- electric water level indicators.

4.2.5 Specific Quality Control Procedures

All devices used to measure ground water levels shall be calibrated against the Invar steel surveyor's chain. These devices shall be calibrated to 0.01 foot per 10 feet length. Before each use, these devices shall be prepared according to the manufacturer's instructions (if appropriate) and checked for obvious damage. These devices should be decontaminated according to the procedures specified in Section 6 prior to use at the next well. All calibration and maintenance data shall be recorded in a log book.

4.3 Time-of-Travel

4.3.1 General

Three principal methods are used to determine travel time in streams, i.e., surface floats, measurements of cross sectional velocity, and tracers such as dye.

A very rough method for preliminary estimates of time-of-water travel consists of dropping sticks or other buoyant objects from bridges in the stream reach under observation, and noting the time required for them to float an estimated 10 feet or some other convenient distance. The velocity estimates are too inaccurate for use in interpretation of data or final reporting, but can be useful in preliminary planning of studies and in subsequent more precise measurements of time-of-water-travel.

Stream velocities at gaging stations, measured by the U. S. Geological Survey in developing rating curves, may be applied to the entire reach under observation to estimate time-of-water travel. This is somewhat more refined than the floating objects estimates, but can still be far from accurate. There rarely are more than one or two gaging stations in most stream reaches being studied. Stream channels generally are restricted at gaging stations and velocities there are generally higher than average velocities throughout the reach. Cross sectional velocities can also be determined at locations designated for a particular study.

Tracer dyes provide a direct and highly accurate method of determining time-of-travel. This is the preferred method if resources are available.

4.3.2 Tracers

The most accurate method of measuring time-of-travel involves following a tracer. Some conservative industrial waste constituents, salt, or radioisotopes may serve as tracers; however, dye is most common. The most frequently used dye is Rhodamine WT that can be detected in concentrations as low as 0.01 ppb by a fluorometer.

Prior to injection into the stream, the concentrated dye should be diluted with the stream water. This will help insure immediate maximum dispersion. Addition of concentrated dye without dilution may result in incomplete dispersion, particularly in shallow streams. Calibration curves should be developed for each study with particular emphasis on accounting for natural background fluorescence.

The dye should be distributed across the stream at the upstream point, as nearly instantaneously as possible. The ideal distribution produces a narrow band of tracer in a uniform concentration across the stream. The band of tracer mixes with water ahead of and behind it by diffusion, or longitudinal mixing, as it moves downstream to produce an increasingly wider band. The peak concentration remains near, but somewhat downstream of, the center line of the band and decreases as longitudinal mixing proceeds. The times-of-water-travel to downstream points are the differences between the time the dye was added to the stream and the times the centroid of the dye mass arrives at downstream points. The length of the dye cloud and the peak concentrations produces a measure of instream dispersion.

If Rhodamine WT dye is used as the tracer, peak concentrations from 1.0 to 50 ppb allow satisfactory definition of the dye concentration curve.

Most methods of calculating the dosage of dye needed at the upstream point involve estimates of one or more stream characteristics, such as flow, velocity, length of reach, volume in the reach, cross-sectional area, average depth, and the roughness coefficient, "n", of Manning's formula. The USGS has produced excellent publications regarding to time-of-travel techniques, i.e., "Measurement of Time-of-Travel and Dispersion by Dye Tracing" (9) and "Fluorometric Procedures for Dye Tracing" (10).

The stream should be sampled frequently as the dye arrives at the downstream point to define the tracer concentration versus time curve with special emphasis on the peak. The frequency may be varied from once each minute to once every 10 to 15 minutes, depending on how wide the band of dye has become at the sampling point. The dye may be missed altogether by overestimating the time required for it to travel downstream. Much time may be wasted, on the other hand, waiting for it to arrive if the time-of-travel is underestimated. All information that will contribute to the best possible preliminary estimate of the time required should be used.

There are two primary methods by which the stream water can be sampled and analyzed for dye. A submersible pump can be used to pump dye continuously through a fluorometer or the stream samples can be grabbed (either by hand or by automatic sampler) at specified frequencies and then placed into the fluorometer individually. With the "flow-through" version, a strip chart recorder connected to the fluorometer can be used to plot the tracer concentration versus time. Readings directly from the fluorometer scale or conversion to dye concentration can be manually plotted against time when the grab sampling technique is used.

A version of the grab sampling technique would be to use an automatic water sampler which discharges into separate bottles. The sampler is pre-set to collect samples at certain intervals; at the end of the sample collection time, the discrete samples shall be analyzed and the concentration determined for each. The concentrations are then plotted against time.

For proper determination of travel time, samples should continue to be analyzed until the stream background concentration following the peak is measured. With a time versus concentration plot from background level to peak to background level, the centroid, and thus actual travel time, can be determined.

The Water Supply Branch of the Water Management Division should be contacted prior to conducting tracer studies in freshwater systems to insure that tracer concentrations do not impart color to downstream public or private water supplies.

4.4 References

1. Breed, C. B. and G. L. Hosmer, The Principles and Practices of Surveying Volume I, Elementary Surveying, Eleventh Edition, John Wiley and Sons, Inc.: New York, New York.

2. Breed, C. B., and G. L. Hosmer, The Principles and Practices of Surveying Volume II, Higher Surveying, Eighth Edition, John Wiley and Sons, Inc.: New York, New York.

3. Compton, R. R., Manual of Field Geology, John Wiley and Sons,Inc.: New York, New York.1.

4. 18 U.S.C. Section 1385 provides, in pertinent part, "whoever, except in cases and under circumstances expressly authorized by the Constitution or Art of Congress, willfully uses any part of the Army or Air Force to execute the laws of the United States shall be fined not more than $10,000 or imprisoned not more than two (2) years, or both."

5. Little, J. A., "Coordination of Remote Sensing Activities" (a memorandum to all Division Directors in Region IV), April 2, 1980.

6. Vick H. C., "Detailed Instructions on Enviropod Preparation, Installation and Usage," 1978.

7. Hill, David W., "Enviropod Flight Planning," Program H., March 29, 1979.

8. Groundwater, Section 18, USDA-SCA National Engineering Handbook, revised June 1978.

9. Kilpatrick, F. A., L. A. Martens, and J. F. Wilson, "Measurement of Time of Travel and Dispersion by Dye Tracing," Chapter A9, Applications of Hydraulics, Book 3, United States Geological Survey, 1968.

10. Wilson, J. F., "Fluorometric Procedures for Dye Tracing," Chapter A12, Applications of Hydraulics, Book 3, United States Geological Survey, 1968.

11. Cobb, E. D. and J. F. Bailey, "Measurement of Discharges by Dye-Dilution Methods," Chapter 14, Hydraulic Measurement and Computation Book 1, United States Geological Survey, 1965.

12. "Tracer Simulation of Soluble Waste Concentrations," Journal of the Environmental Engineering Division, Proceedings of the ASCE, Volume 99, No. EE4, August 1973.

SECTION 6
STANDARD CLEANING PROCEDURES

6.1 General

6.1.1 Introduction

The cleaning procedures outlined in this appendix are for use in cleaning sampling and other field equipment as well as sample containers prior to field use. Sufficient clean equipment and sample containers should be transported to the field so that an entire inspection or investigation can be conducted without the need for field cleaning of equipment. However, this will not always be possible when using specialized field equipment. Field cleaning procedures are included to cover these special areas. Emergency field sample container cleaning procedures are also included; however, they should not be used unless absolutely necessary. Specific cleaning procedures are presented in the following sections.

These procedures are the standard operating procedures (SOP). Sampling and field equipment cleaned in accordance with these procedures meet the minimum requirements for DQO Level IV field work, i.e., the standard level for field work. Alternative field decontamination procedures may be substituted as outlined in Section 2.2 when samples are to be analyzed for data uses at a lower DQO level. Deviations from these procedures must be documented in the approved study plan, field records, and investigative reports.

6.1.2 Cleaning Materials

The cleaning materials referred to in this appendix are described in the following paragraphs.

The laboratory detergent shall be a standard brand of phosphate-free laboratory detergent such as Liquinox®. The use of any other detergent must be justified and documented in the field logbooks and inspection or investigative reports.

The nitric acid solution (10 percent) shall be made from reagent-grade nitric acid and deionized water.

The standard cleaning solvent shall be pesticide-grade isopropanol. However, other solvents may be substituted for a particular investigation if needed. Pesticide-grade acetone or methanol are both acceptable. However, it should be noted that if pesticide-grade acetone is used, the detection of acetone in samples collected with acetone rinsed equipment is suspect. Pesticide-grade methanol is much more hazardous to use than either pesticide-grade isopropanol or acetone, and its use is discouraged. Pesticide-grade hexane and petroleum ether are not miscible with water; therefore, these two solvents are not effective rinsing agents unless equipment is dry. The use of any solvent other than pesticide-grade isopropanol for equipment cleaning purposes must be justified and its use must be documented in field logbooks and inspection or investigation reports.

Tap water may be used from any municipal water treatment system. The use of an untreated potable water supply is not an acceptable substitute for tap water.

Deionized water is defined as tap water that has been treated by passing through a standard deionizing resin column. The deionized water should contain no heavy metals or other inorganic

compounds (i.e., at or above analytical detection limits) as defined by a standard Analytical Support Branch (ASB) inductively coupled Argon Plasma Spectrophotometer (ICP) scan. Organic-free water is defined as tap water that has been treated with activated carbon and deionizing units. The Milli-Q® system also produces organic-free water. Organic-free water should contain no pesticides, herbicides, extractable organic compounds, and less than 5 ug/l of purgeable organic compounds as measured by a low level ASB GC/MS scan.

During cleaning operations, the substitution of a higher grade water (i.e., deionized or organic-free water for tap water) is permitted and need not be noted as a variation of this SOP. However, the deionized and organic-free water utilized must be subjected to the specific quality control procedures as outlined in Section 6.2.2.

The solvents, nitric acid solution, laboratory detergent, and rinse waters used to clean equipment shall not be reused, except as specifically permitted in the footnote for Step 3, Section 6.3.

6.1.3 Marking of Cleaned Sampling Equipment and Containers

All equipment and sample containers that are cleaned utilizing these procedures shall be tagged, labeled, or marked with the date that the equipment was cleaned. Also, if there was a deviation from the standard cleaning procedures outlined in this section, this fact should be noted on the label.

When sample containers are cleaned and prepared, they should be cleaned in standard sized lots of 100 to facilitate the quality control procedures outlined in Section 6.2.

6.1.4 Marking and Segregation of Used Field Equipment

Field or sampling equipment that needs to be repaired will be identified with a red tag. Any problems encountered with the equipment and needed repairs shall be noted on this tag. Field equipment or reusable sample containers needing cleaning or repairs will not be stored with clean equipment, sample tubing, or sample containers. All plastic wrapped equipment, containers and tubing not used in the field may be placed back in stock after the following precautions are taken:

- Soap and water rinse plastic containers. Allow to air dry.
- If plastic wrapping leaks after soap/water rinse, remove equipment and place into cleaning process.

6.1.5 Decontamination of Equipment Used to Collect Samples of Toxic or Hazardous Waste

Equipment that is used to collect samples of hazardous materials or toxic wastes or materials from hazardous waste sites, RCRA facilities, or in-process waste streams shall be decontaminated before it is returned from the field. At a minimum, this decontamination procedure shall consist of washing with laboratory detergent and rinsing with tap water. More stringent decontamination procedures may be required, depending on the waste sampled.

6.1.6 Proper Disposal of Cleaning Materials

The solvent used to rinse sampling equipment and containers shall be collected and disposed of through an approved hazardous waste disposal contract. Similarly, spent nitric acid shall be collected

and disposed of through the same disposal contract. These procedures apply whether the cleaning operations take place in the washroom or in the field.

6.1.7 Safety Procedures to be Utilized During Cleaning Operations

The materials used to implement the cleaning procedures outlined in this Section can be dangerous if improperly handled. Due caution must be exercised by all personnel and all applicable safety procedures shall be followed. At a minimum, the following precautions shall be taken in the washroom and in the field during these cleaning operations:

- Safety glasses with splash shields or goggles, neoprene gloves, and a neoprene laboratory apron will be worn during all cleaning operations. When cleaning power augering or drill rig equipment, safety boots will be worn.
- All solvent rinsing operations will be conducted under a fume hood or in the open (never in a closed room).
- No eating, smoking, drinking, chewing, or any hand to mouth contact shall be permitted during cleaning operations.

6.1.8 Storage of Field Equipment and Sample Containers

All field equipment and sample containers shall be stored in a contaminant free environment after being cleaned using the procedures outlined in this Section.

6.2 Specific Quality Control Procedures for Cleaning Operations

6.2.1 General

This section establishes guidelines for specific quality control procedures to monitor the effectiveness of the sampling equipment and sample container cleaning procedures outlined in this Section. These procedures shall be carried out by field personnel and the results monitored by the Quality Assurance Officer. All quality control procedures shall be recorded in a logbook. All quality control data shall be maintained in a separate quality assurance file. Upon receipt of quality control data from the laboratory, the Quality Assurance Officer shall review these data to identify any abnormalities or contamination of sampling equipment or sample containers. If problems are detected, the Quality Assurance Officer shall immediately initiate an investigation to determine the cause of the problem(s) and institute immediate corrective action.

6.2.2 Rinse Water

The quality of the deionized and organic-free water used shall be monitored by collecting samples once per quarter in standard precleaned, sample containers and submitting them to the laboratory for a standard ICP scan. Organic-free water will also be submitted for low level pesticides, herbicides, and extractable and purgeable compounds analyses. When field deionizing and/or organic-free water units are utilized, more frequent quality control samples will be collected. An initial sample and samples at weekly intervals are the minimum number considered acceptable.

6.2.3 Sampling Equipment Cleaned in Washroom

The effectiveness of the equipment cleaning procedures used in the washroom shall be monitored by rinsing cleaned equipment (equipment used to collect samples for trace organic compounds and metals analyses) with organic-free or Milli-Q® water and submitting the rinse water to the laboratory for low level analysis of extractable organic compounds including pesticides and a standard ICP scan. At least one piece of field equipment shall be selected for this procedure each month. An attempt should be made to select different pieces of equipment for this procedure, each time equipment is washed, so that a representative sampling of all equipment is obtained over a 12-month period.

6.2.4 Sampling Equipment Cleaned in the Field

The effectiveness of field cleaning procedures shall be monitored by rinsing field cleaned equipment with organic-free water and submitting the rinse water in standard sample containers to the laboratory for analysis as outlined in Section 6.2.3. Any time equipment is cleaned in the field, at least one such quality control sample shall be collected. No more than five percent of the equipment cleaned during large scale field studies shall be subjected to these procedures.

Additional samples may be required to document quality assurance of field cleaning procedures. Any time a source of cleaning materials or rinse water is used other than that specified in Section 6.1.2, a sample of that cleaning material or rinse water shall be submitted in standard sample containers as specified in Section 6.2.2.

6.2.5 Glass Disposable Sample Containers for Organic Compounds and Plastic Containers for Metals Analyses and Other Specified Organic Compounds

The sample containers will be submitted to the laboratory for analysis utilizing the same standard low level analytical techniques as outlined in Section 6.2.3. The sample containers will be supplied to the laboratory at the rate of one percent of each kind of container used.

6.2.6 Plastic Disposable Sample Containers for Oxygen Demand, Nutrients, and General Inorganics

These containers will be filled with deionized or organic-free water, preserved as required, and submitted to the laboratory for the designated parameters for each sample container. These sample containers will be selected at random from the stock at the rate of approximately one percent of each kind of container of the total used.

6.2.7 Reusable Composite Sample and Organic-Free Water Containers

These containers will be rinsed with organic-free water and the rinse water will be submitted to the laboratory as outlined in Section 6.2.3. Approximately one percent of all such containers cleaned will be subjected to this procedure.

6.3 Cleaning Procedures for Teflon® or Glass Field Sampling Equipment Used for the Collection of Samples for Trace Organic Compounds And/or Metals Analyses*

1. Equipment will be washed thoroughly with laboratory detergent and hot water using a brush to remove any particulate matter or surface film.

2. The equipment will be rinsed thoroughly with hot tap water.

3. Rinse equipment with at least a 10 percent nitric acid solution.**

4. Rinse equipment thoroughly with tap water.

5. Rinse equipment thoroughly with deionized water.

6. Rinse equipment twice with solvent and allow to air dry for at least 24 hours.

7. Wrap equipment in one layer of aluminum foil. Roll edges of foil into a "tab" to allow for easy removal. Seal the foil wrapped equipment in plastic and date.

8. Rinse the Teflon® or glass sampling equipment thoroughly with tap water in the field as soon as possible after use.

* When this sampling equipment is used to collect samples that contain oil, grease, or other hard to remove materials, it may be necessary to rinse the equipment several times with pesticide-grade acetone or hexane to remove the materials before proceeding with Step 1. In extreme cases, it may be necessary to steam clean the field equipment before proceeding with Step 1. If the field equipment cannot be cleaned utilizing these procedures, it should be discarded.

** Small and awkward equipment such as vacuum bottle inserts and well bailer may be soaked in the nitric acid solution instead of being rinsed with it. Fresh nitric acid solution should be prepared for each cleaning session.

6.4 Cleaning Procedures for Stainless Steel or Metal Sampling Equipment Used for the Collection of Samples for Trace Organic Compounds And/or Metals Analyses*

1. Wash equipment thoroughly with laboratory detergent and hot water using a brush to remove any particulate matter or surface film.

2. Rinse equipment thoroughly with hot tap water.

3. Rinse equipment thoroughly with deionized water.

4. Rinse equipment twice with solvent and allow to air dry for at least 24 hours.

5. Wrap equipment in one layer of aluminum foil. Roll edges of foil into a "tab" to allow for easy removal. Seal the foil wrapped equipment in plastic and date.

6. Rinse the stainless steel or metal sampling equipment thoroughly with tap water in the field as soon as possible after use.

* When this sampling equipment is used to collect samples that contain oil, grease, or other hard to remove materials, it may be necessary to rinse the equipment several times with pesticide-grade acetone or hexane to remove the materials before proceeding with Step 1. In extreme cases, when equipment is painted, badly rusted, or coated with materials that are difficult to remove, it may be necessary to steam clean, wire brush, or sandblast equipment before proceeding with Step 1. Any metal sampling equipment that cannot be cleaned using these procedures should be discarded.

6.5 Cleaning Procedures for Sample Tubing

6.5.1 Silastic® Rubber Pump Tubing Used In Automatic Samplers and Other Peristaltic Pumps

The Silastic® rubber pump tubing need not be replaced in peristaltic pumps where the sample does not contact the tubing or where the pump is being used for purging purposes (i.e., not being used to collect samples).

The Silastic® tubing shall be precleaned as follows:

1. Flush tubing with hot tap water and phosphate-free laboratory detergent.
2. Rinse tubing thoroughly with hot tap water.
3. Rinse tubing with deionized water.
4. Install tubing in automatic sampler or peristaltic pump.
5. Cap both ends of tubing with aluminum foil.

6.5.2 Teflon® Sample Tubing

Use only new Teflon® tubing precleaned as follows for collection of samples for organic compounds analyses:

1. Teflon® tubing shall be precut in 25-foot lengths before cleaning.
2. Rinse outside of tubing with solvent.
3. Flush interior of tubing with solvent.
4. Dry overnight in the drying oven.
5. Wrap tubing and cap ends with aluminum foil and seal in plastic to prevent contamination during storage.

6.5.3 Stainless Steel Tubing

1. Wash with laboratory detergent and hot water using a long, narrow, bottle brush.

2. Proceed with Steps 2-6 as outlined in Section 6.4 (footnote applies).

6.5.4 Glass Tubing

Use new glass tubing, precleaned as follows:

1. Rinse thoroughly with solvent.

2. Air dry for at least 24 hours.

3. Wrap tubing completely with aluminum foil and seal in plastic (one tube/pack) to prevent contamination during storage.

4. Discard tubing after use.

6.6 Miscellaneous Equipment Cleaning Procedures

6.6.1 Well Sounders or Tapes Used to Measure Ground Water Levels*

1. Wash with laboratory detergent and tap water.

2. Rinse with tap water.

3. Rinse with deionized water.

4. Allow to air dry overnight. (doesn't apply to field cleaning)

5. Wrap equipment in aluminum foil (with tab for easy removal), seal in plastic, and date.

6.6.2 Submersible Pumps and Hoses Used to Purge Ground Water Wells*

6.6.2.1 Fultz Pump Cleaning Procedure

CAUTION: To avoid damaging the Fultz pump

- Never run pump when dry
- Never switch directly from forward to reverse mode without pausing in the "OFF" position

1. Pump a sufficient amount of soapy water through the hose to flush out any residual purge water.

2. Using a brush, scrub the exterior of the contaminated hose and pump with hot soapy water. Rinse the soap from the outside of the hose with tap water. Next rinse the hose with deionized water and recoil onto the spool.

3. Pump a sufficient amount of tap water through the hose to flush out soapy water.

4. Pump a sufficient amount of deionized water through the hose to flush out the tap water, then purge with the pump in reverse mode.

5. Rinse the outside of the pump housing and hose with deionized water (approximately 1/4 gal.).

6. Equipment will be placed in a polyethylene bag or wrapped with polyethylene film to prevent contamination during storage or transit. Insure that a set of rotors, fuses, and cables are attached to each cleaned pump.

   * The same procedure applies whether this equipment is cleaned in the washroom or in the field.

6.6.2.2 Goulds Pump Cleaning Procedure

1. Using a brush, scrub the exterior of the contaminated hose and pump with soapy water.

2. Rinse the soap from the outside of pump and hose with tap water.

3. Rinse the tap water residue from the outside of pump and hose with deionized water.

4. Equipment should be placed in a polyethylene bag or wrapped with polyethylene film to prevent contamination during storage or transit.

6.6.3 Portable Power Augers Such as the Little Beaver®

1. The engine and power head should be cleaned with a power washer, steam jenny, or hand washed with a brush using detergent (does not have to be laboratory detergent but should not be a degreaser) to remove oil, grease, and hydraulic fluid from the exterior of the unit. These units should be rinsed thoroughly with tap water.

2. All auger flights and bits shall be cleaned utilizing the procedures outlined in Section 6.4 (including footnotes) or Section 6.7.3 (including footnotes if appropriate).

6.6.4 Large Soil Boring and Drilling Rigs

See Section 9, "Design and Installation For Permanent Monitoring Wells".

6.6.5 Miscellaneous Sampling and Flow Measuring Equipment

Miscellaneous flow measuring and sampling equipment shall be washed with laboratory detergent, rinsed with hot tap water, followed by a thorough deionized water rinse, and dried before being stored. This procedure is not used for any equipment utilized for the collection of samples for trace organic compounds or metals analyses.

6.6.6 ISCO Flow Meters, Field Analytical Equipment, and Other Field Instrumentation

The exterior of sealed, watertight equipment such as ISCO flow meters should be washed with a mild detergent (for example, liquid dishwashing detergent) and rinsed with tap water before storage. The interior of such equipment may be wiped with a damp cloth if necessary.

Other field instrumentation should be wiped with a clean, damp cloth; pH meter probes, conductivity probes, DO meter probes, etc., should be rinsed with deionized water before storage.

The desiccant in flow meters and other equipment should be checked and replaced if necessary each time the equipment is cleaned.

6.6.7 Ice Chests and Shipping Containers

All ice chests and reusable containers shall be washed with laboratory detergent (interior and exterior) and rinsed with tap water and air dried before storage. In the event that an ice chest becomes severely contaminated, in the opinion of the field investigator, with concentrated waste or other toxic material, it shall be cleaned as thoroughly as possible, rendered unusable, and properly disposed.

6.6.8 Pressure Field Filtration Apparatus

1. Proceed with steps 1 through 5 as outlined in Section 6.3, assembling and applying pressure to the apparatus after each rinse step (water and acid) to drive rinse material through the porous glass filter holder in the bottom of the apparatus.

2. Assemble the apparatus and cap both the pressure inlet and sample discharge lines with aluminum foil to prevent contamination during storage.

6.6.9 Organic-Free Water Storage Containers

1. These containers will be used only for transporting organic-free water.

2. New containers shall be prepared as outlined in Section 6.5.5, Steps 1-5, then rinsed thoroughly with organic-free water, filled with water and capped.

3. Used containers shall be capped with one layer of Teflon® paper, and one layer of aluminum foil immediately after being used in the field.

4. The exterior of the container shall be washed with laboratory detergent and rinsed with deionized water.

5. The interior of the container shall be rinsed twice with solvent.

6. The interior of the container shall be thoroughly rinsed with organic free water. The container shall be filled with organic-free water and capped with one layer of Teflon® paper, and one layer of aluminum foil. Organic-free water will not be stored in the containers longer than three days prior to a loadout.

6.6.10 Portable Solvent Rinse System

1. Replace Teflon® tubing if necessary. Wash nozzle and tubing fittings with hot, soapy water.

2. Rinse with D.I. water.

3. Wrap nozzle and tubing ends with aluminum foil.

6.6.11 Vehicles

All vehicles utilized should be washed (if possible) at the conclusion of each field trip. This routine maintenance should minimize any chance of contamination of equipment or samples due to contamination of vehicles. When vehicles are used in conjunction with hazardous waste site inspections, or on studies where pesticides, herbicides, organic compounds, or other toxic materials are known or suspected to be present, a thorough interior and exterior cleaning is mandatory at the conclusion of such investigations. It shall be the responsibility of the project leader and/or field investigators to see that this procedure is followed.

All vehicles shall be equipped with trash bags and/or trash containers to facilitate vehicle cleaning. All personnel are responsible for keeping field vehicles clean by removing all trash and other debris before it accumulates. All contaminated trash and equipment must be kept separate from ordinary trash and must be properly disposed of on-site or upon return to the facility for proper disposal.

6.7 Field Equipment Cleaning Procedures

6.7.1 General

Sufficient clean equipment should be transported to the field so that an entire study can be conducted without the need for field cleaning. However, this is not possible for some specialized items of field equipment such as portable power augers (Little Beaver®), well drilling rigs, soil coring rigs, and other large pieces of field equipment. In addition, particularly during large scale studies, it is not practical or possible to transport to the field all of the precleaned field equipment required. The following procedures are to be utilized when equipment must be cleaned in the field.

6.7.2 Equipment Used for Routine Sample Collection Activities

For routine operations involving classic parameter analyses, water quality sampling equipment such as Kemmerers, buckets, DO dunkers, dredges, etc., may be cleaned with sample or deionized water between sampling locations. A brush may be used to remove deposits of material or sediment, if necessary. If deionized water is used, water samplers should be flushed with the sample at the next sampling location before the sample is collected. It should be emphasized that these procedures

cannot be used to clean equipment for the collection of samples for organic compounds or trace metals analyses.

Flow measuring equipment such as weirs, staff gages, velocity meters, and other stream gaging equipment may be cleaned with tap water after use between measuring locations, if necessary.

6.7.3 Teflon®, Glass, Stainless Steel or Metal Equipment Used to Collect Samples for Organic Compounds and Trace Metals Analyses*

1. Clean with tap water and laboratory detergent using a brush if necessary to remove particulate matter and surface films.

2. Rinse thoroughly with tap water.

3. Rinse thoroughly with deionized water.

4. Rinse twice with solvent.

5. Rinse thoroughly with organic-free water and allow to air dry as long as possible.

6. If organic-free water is not available, allow equipment to air dry as long as possible. Do <u>not</u> rinse with deionized or distilled water.

7. Wrap with aluminum foil, if appropriate, to prevent contamination if equipment is going to be stored or transported

* Portable power augers (such as the Little Beaver®) or large soil boring/drill rigs should be cleaned before boring or drilling operations. (See Sections 6.6.3 and 6.6.4)

6.8 <u>Preparation of Disposable Sample Containers</u>

6.8.1 General

No sample container (with the exception of the glass and plastic compositing containers) may be reused. All disposable sample containers will be stored in their original packing containers. When packages of uncapped sample containers are opened, they will be placed in new plastic garbage bags and sealed to prevent contamination during storage. Specific precleaning instructions for disposable sample containers are given in the following sections. These instructions apply to precleaned disposable sample containers whether they are purchased from a contractor or are precleaned by SBP personnel.

6.8.2 One-Pint Storemore, One-Quart Storemore, One-Half-Gallon, and One-Gallon Plastic Containers for Oxygen Demand, Nutrients, Classic Inorganic, Sulfide, and Cyanide Analyses

<u>ONLY NEW CONTAINERS WILL BE USED</u>

6.8.3 One-Half- and One-Gallon Amber Glass Bottles (Water Samples), and 8, 16, and 32-Ounce Clear Widemouth Jars (Soil, Sediment, Sludge, and Concentrated Waste) With Teflon® Lined Caps for Organic Compounds (Excluding Purgeables) and Metals Analysis

1. Wash bottles and jars, Teflon® liners, and caps in hot tap water and laboratory detergent.

2. Rinse three times with tap water.

3. Rinse with nitric acid solution.*

4. Rinse three times with deionized water.

5. Rinse bottles, jars, and liners (not caps) with solvent.*

6. Oven dry bottles, jars, and liners at 125°C. Allow to cool.

7. Place liners in caps and cap containers.

8. Store containers in contaminant-free area.

* Some bottle cleaning contractors use pesticide-grade methylene chloride to solvent rinse sample containers. Also some contractors use 1:1 reagent-grade nitric acid to rinse sample containers. For the purpose of cleaning sample containers as outlined in Sections 6.8.3 and 6.8.5, both of these deviations from the information contained in Section 6.1.2 are permitted.

6.8.4 40-ml Glass Vials for Water Samples (Purgeable Organic Compounds Analysis) and 250 ml Amber Glass Narrow Necked Bottles for Water Samples (TOX Analysis) with Teflon® Lined Septa; and 4-Ounce (120 ml) Clear Widemouth Glass Jars with Teflon® Liner for Soil Samples (Purgeable Organic Compounds Analysis)

1. Wash vials, bottles and jars, Teflon® liners and septa, and caps in hot tap water and laboratory detergent.

2. Rinse all items with deionized water.

3. Oven dry at 125°C.

4. Seal vials, bottles, and jars with liners or septa as appropriate and cap.

5. Store vials, bottles, and jars in a contaminant free area.

6.8.5 One Liter Polyethylene Bottle for Metals and General Inorganics

1. Wash polyethylene bottles and caps in hot water with laboratory detergent.

2. Rinse both with nitric acid solution.

3. Rinse three times with deionized water.

4. Invert bottles and dry in contaminant free environment.

5. Cap bottles.

6. Store in contaminant free area.

6.9 Emergency Disposable Sample Container Cleaning

New one-pint or one-quart mason jars may be used to collect samples for analyses of organic compounds and metals in waste and soil samples in an emergency. These containers would also be acceptable on an emergency basis for the collection of water samples for extractable and pesticide organic analyses as well as metals analyses. These jars cannot be used for the collection of water samples for purgeable organic analyses.

The rubber sealing ring should not be in contact with the jar and aluminum foil should be used, if possible, between the jar and the sealing ring. If possible, the jar and aluminum foil should be rinsed with pesticide-grade methanol* and allowed to air dry before use. Several empty bottles and lids should be submitted to the laboratory as blanks for quality control purposes.

* Pesticide-grade petroleum ether or hexane may also be used.

SECTION 7
SAMPLE SHIPPING PROCEDURES

7.1 Introduction

Samples collected during field investigations or in response to a hazardous materials incident must be classified by the project leader, prior to shipping by air, as either environmental or hazardous materials samples. In general, environmental samples include drinking water, most groundwater and ambient surface water, soil, sediment, treated municipal and industrial wastewater effluent, biological specimens, or any samples not expected to be contaminated with high levels of hazardous materials. The guidance for complying with US-DOT regulations in shipping environmental laboratory samples is given in the "National Guidance Package for Compliance with Department of Transportation Regulations in the Shipment of Environmental Laboratory Samples" (1). Additional guidance is given in a letter to M. D. Lair, P.E., from Thomas J. Charlton, P.E., Chief Standards Division, Office of Hazardous Materials Regulation, Materials Transportation Bureau, US-DOT (2).

Samples collected from process wastewater streams, drums, bulk storage tanks, soil, sediment, or water samples from areas suspected of being highly contaminated may require shipment as dangerous goods. Regulations for packing, marking, labeling, and shipping of dangerous goods by air transport are promulgated by the United Nations International Civil Aviation (IATA), which is equivalent to UN/ICAO. The transportation of hazardous materials (dangerous goods) by EPA personnel is covered by EPA Order 1000.18

7.2 Shipment of Dangerous Goods

The project leader is responsible for determining if samples collected during a specific field investigation meet the definitions for dangerous goods. If a sample is collected of a material that is listed in the Dangerous Goods List, Section 4.2, IATA (3), then that sample must be identified, packaged, marked, labeled, and shipped according to the instructions given for that material. If the composition of the collected sample(s) is unknown, and the project leader knows or suspects that it is a regulated material (dangerous goods), the sample may not be offered for air transport. If the composition and properties of the waste sample or highly contaminated soil, sediment, or water sample are unknown, or only partially known, the sample may not be offered for air transport. Regulations concerning the air transport of dangerous goods are currently in flux. Dangerous goods must not be offered for air transport without contacting the ESD dangerous goods shipment designee.

7.3 Shipment of Environmental Samples

Samples collected by SBP personnel and designated by the project leader as environmental samples shall be shipped using the method described below. However, if the environmental samples are preserved, the amount of preservative must not exceed the amounts indicated in Table SEC 7.3.1. If the amount of preservative added to a sample exceeds that listed in the table, then that sample may be considered dangerous goods and shall be shipped in accordance with procedures described in the current Dangerous Goods Regulations (IATA). In addition, the shipment of prepreserved sample containers or bottles of preservatives (i.e., NaOH pellets, HCl, etc.) which are designated as dangerous goods by IATA pursuant to the appropriate IATA regulations. The shipment of nitric acid is forbidden on all aircraft.

Environmental samples shall be packed prior to shipment by air using the following procedures:

1. Select a sturdy cooler in good repair. Secure and tape the drain plug with fiber or duct tape. Line the cooler with a large heavy duty plastic bag.

2. Allow sufficient outage (ullage) in all bottles (except VOA's) to compensate for any pressure and temperature changes (approximately 10 percent of the volume of the container).

3. Be sure the lids on all bottles are tight (will not leak).

4. Place all bottles in separate and appropriately sized polyethylene bags and seal the bags with tape (preferably plastic electrical tape). Up to three VOA bottles may be packed in one Whirl-Pak® container.

5. Optionally, place three to six VOA vials in a quart metal can and then fill the can with vermiculite.

6. Place two to four inches of vermiculite in the bottom of the cooler and then place the bottles and cans in the cooler with sufficient space to allow for the addition of more vermiculite between the bottles and cans.

7. Put "blue ice" (or ice that has been placed in heavy duty polyethylene bags and properly sealed) on top of or between the samples. Fill all remaining space between the bottles or cans with vermiculite. Securely fasten the top of the large garbage bag with tape (preferably plastic electrical tape).

8. Place the Chain-of-Custody Record and the CLP Traffic Report Form (if applicable) into a plastic bag, tape the bag to the inner side of the coolers lid, and then close the cooler and securely tape (preferably with fiber tape) the top of the cooler shut. Chain-of-custody seals should be affixed to the top and sides of the cooler within the securing tape so that the cooler cannot be opened without breaking the seal.

9. The shipping containers must be marked "THIS END UP", and arrow labels which indicate the proper upward position of the container should be affixed to the container. A label containing the name and address of the shipper shall be placed on the outside of the container. Labels used in the shipment of hazardous materials (such as Cargo Only AirCraft, Flammable Solids, etc.) are not permitted to be on the outside of the container used to transport environmental samples and shall not be used.

TABLE SEC 7.3.1

CHEMICALS LISTED IN THE DANGEROUS GOODS LIST (SECTION 4.2, IATA)
USED FOR PRESERVING SAMPLES

Preservative	Sample Type/ Parameter	pH Recommendation	Quantity of Preservative Added Per Liter	Wt. % of Preservation
HCl	VOCs	<2 -≥1	4 drops conc. HCL/40 ml (2)	0.22%
	Analysis			
$HgCl_2$	Nitrogen Species	N.A.	40 mg 0.004% (1)	
HNO_3	Metals, Hardness	<2 - ≥1	5 ml of conc. (70%)	0.35% (1)
H_2SO_4	Nitrogen Species COD, Oil & Grease, P (hydrolyzable) Organic Carbon, Phenols	<2 - ≥1	2 ml of 36N 0.35% (1)	
NaOH	Cyanide, Sulfides	>12 -≤13	2 ml of 10N	0.080% (1)
Freezing*	Biological - Fish & Shellfish Tissue	N.A. 0°C. (Dry Ice)	N.A	N.A.

* Dry ice (Carbon dioxide, solid) is classified as dangerous goods by IATA. Samples preserved with dry ice must be packaged, labeled, and marked as specified in the current IATA regulations and advance arrangements must be made between the shipper and each carrier.

N.A. Not applicable.

7.4 References

1. "Final Regulation Package for Compliance with DOT Regulations in the Shipment of Environmental Laboratory Samples," Memo from David Weitzman, Work Group Chairman, Office of Occupational Health and Safety (PM-273), US-EPA, April 13, 1981.

2. Letter from Thomas J. Charlton, P.E., Chief, Standards Division, Office of Hazardous Materials Regulation, Materials Transportation Bureau, US-DOT to Myron D. Lair, P.E., Chief, Hazardous Waste Section, ESB, ESD, Region IV, US-EPA, March 22, 1985.

3. Dangerous Goods Regulations, International Air Transport Authority (IATA). 31st. Edition, Effective January 1, 1991.

SECTION 8
STANDARD FIELD ANALYTICAL METHODS

Method 8.1 Temperature

8.1.1 Scope and Application

This method is applicable to ground, surface, and saline waters as well as domestic and industrial wastes.

8.1.2 Summary of Method

Temperature measurements may be made with any high quality mercury-filled thermometer or thermistor with analog or digital read-out devices.

8.1.3 Comments

Measurement devices shall be routinely checked against a precision thermometer.

8.1.4 Test Procedure

1. Use only a previously calibrated mercury-filled thermometer or thermistor that has been inspected according to the procedure outlined in Section 3.3.1 - Temperature.

2. Allow thermometer or thermistor enough time to equilibrate to outside temperature when removed from a field vehicle.

3. Insert thermometer or thermistor in-situ when possible or in a grab sample. Swirl the thermometer or thermistor in the sample and take the temperature reading when the mercury column or read-out needle stops moving; record temperature to the nearest 0.5°C.

8.1.5 Precision and Accuracy

Precision and accuracy for this method have not been determined.

8.1.6 References

Standard Methods for the Examination of Water and Wastewater, 16th Edition p. 126, Method 212 (1985).

Methods for Chemical Analyses of Water and Wastes, US-EPA, 170.1 (1983).

Method 8.2 Ph (Hydrogen Ion Concentration)

8.2.1 Scope and Application

This method is applicable to ground, surface, and saline waters, as well as domestic and industrial wastes.

8.2.2 Summary of Method

The pH of a sample is determined electrometrically using either a glass electrode in combination with a reference potential or a combination electrode, and a pH meter.

8.2.3 Interferences

1. The glass electrode, in general, is not subject to solution interferences from color, turbidity, colloidal matter, oxidants, reductants, or high salinity.

2. Errors due to the presence of sodium at pH levels greater than 10 can be reduced or eliminated by using a "low sodium error" electrode.

3. Coatings of oily material or particulate matter can impair electrode response. Remove these coatings by gentle wiping with a laboratory tissue followed by a distilled water rinse.

4. Temperature effects on the electrometric measurement of pH are controlled by using instruments having temperature compensation or by calibrating the electrode meter system at the temperature of the samples.

5. Poorly buffered solutions with low specific conductance values (less than 200 umhos) may cause fluctuations in the pH readings. Equilibrate electrode by immersing in several portions of sample before taking pH measurement.

8.2.4 Reagents

Secondary standard buffer solutions (pH 4, pH 7, and pH 10) purchased from commercial vendors shall be used.

8.2.5 Buffering

1. Follow the instructions provided with each type of pH meter.

2. Each meter/electrode system must be buffered at a minimum of two points which bracket the expected pH of the samples. The buffer solutions should be approximately three pH units or more apart. Approximate pH values may be obtained by using multi-range pH paper.

8.2.6 Test Procedure

1. Allow the meter to equilibrate to ambient temperature when it is removed from a field vehicle.

2. Buffer the meter at the temperature of the buffer solution as outlined above in Section 8.2.5.

3. Check sample with pH paper to determine proper pH buffer range. Rebuffer meter to proper range if necessary.

4. If the sample temperature differs by more than 2°C from the buffer solutions, adjust for the temperature differences.

5. Thoroughly rinse the electrode with distilled water.

6. Immerse the electrode in-situ when possible or in a grab sample. Swirl the electrode at a constant rate until the meter reading reaches equilibrium. The rate of stirring used should minimize the air transfer rate at the air-water interface of the sample.

7. Note and record sample pH; repeat measurement on successive volumes of sample or in-situ until values differ by no more than 0.1 pH unit. Two or three volumes are usually sufficient.

8. In the case of low specific conductance samples, such as encountered with some ground waters, add 1 ml of 1M potassium chloride solution per 100 mls of sample and follow steps 6.5 and 6.6.

9. When the meter is moved to another sampling location, recheck the meter calibration by inserting the probe into the pH 7 buffer solution and follow operational steps outlined in the owners manual.

8.2.7 Apparatus

- Orion Model 399A
- Orion SA 250
- Hydrolab Surveyor II
- YSI 3530, 3500 Water Quality Monitoring System

Note -- Follow the operating instructions for the specific meters listed above.

8.2.8 Precision and Accuracy

Under normal conditions the accuracy is $\pm$ 0.1 pH unit.

8.2.9 References

Standard Methods for the Examination of Wastewater, 16th Edition, p. 429, Method 423 (1985).

Instruction Manual for Models 399 A/F, 399 A/L Analog pH Meter and SA 250, Orion Research Incorporated.

Instruction Manual for Surveyor II, Hydrolab Corporation.

Instruction Manual for YSI Water Quality Monitoring System using the Model 3530 pH electrode assembly.

Annual Book of ASTM Standards, Part 31, "Water", Standard D1293-78(B). Methods for Chemical Analysis of Water and Wastes, US-EPA, 150.1 (1983).

Procedure No. 501, pH Measurement in Low Ionic Strength Solutions, Orion Application Information, Orion Research Incorporated.

Method 8.3 Dissolved Oxygen (Modified Winkler, Full Bottle Technique)

8.3.1 Scope and Application

The Winkler dissolved oxygen (DO) method with the azide modification is applicable for use with most wastewater and ground and surface waters that contain nitrate nitrogen and not more than 1 mg/l of ferrous iron. Other reducing or oxidizing materials should be absent.

The azide modification is not applicable for the following samples:(a) samples containing sulfite, thiosulfate, polythionate, appreciable quantities of free chlorine, or hypochlorite; (b) samples high in suspended solids; (c) samples containing organic substances which are readily oxidized by free iodine in an acid solution; (d) untreated domestic sewage; (e) biological flocs; or (f) samples with color which interferes with end point detection. In instances where the azide modification is not applicable, the DO probe should be used.

8.3.2 Summary of Method

The sample is treated with manganous sulfate, potassium hydroxide, and potassium iodide and finally sulfuric acid. The initial precipitate of manganous hydroxide (Mn(OH)2) combines with the DO in the sample to form a brown precipitate, manganic hydroxide (Mn(OH)2). Upon acidification, the manganic hydroxide forms manganic sulfate which acts as an oxidizing agent to release free iodine from the potassium iodide. The iodine, which is stoichiometrically equivalent to the DO in the sample is then titrated with sodium thiosulfate or phenylarsine oxide (PAO).

8.3.3 Interferences

There are a number of interferences to the DO test which are mentioned above in 8.3.1. Most of the common interferences in the Winkler procedure may be overcome by use of the membrane electrode method (8.4).

8.3.4 Sample Handling

Where possible, collect the sample in a 300-ml BOD bottle. Special care should be used to avoid entrainment of atmospheric oxygen or loss of DO.

Sample should be collected with a DO Dunker (APHA-type) at depths less than five feet. A Kemmerer type sampler is recommended for depths greater than five feet.

When a Kemmerer sampler is used, the BOD sample bottle should be filled to overflowing by inserting the outlet tube of the sampler to the bottom of the BOD bottle; the tube is slowly withdrawn as the bottle is allowed to overflow. Care must be taken to prevent turbulence and the formation of bubbles when filling the bottle.

If an APHA-type DO Dunker is not available and a shallow depth sample is needed, a bucket may be used to collect a sample of water. A siphon tube should be used to fill the BOD bottle. Coil the tube in the bucket to fill the tube. Place one end of the tube near the bottom of a BOD bottle and allow the water to fill and overflow the bottle as outlined in Section 8.3.4.

8.3.5 Reagents

Three bottles are used to contain the reagents. They are labeled (1) manganous sulfate solution, (2) alkaline-iodide-azide solution, and (3) concentrated sulfuric acid. Starch solution and sodium thiosulfate or PAO (0.0375N) are stored in separate bottles.

8.3.6 Test Procedure

1. To the sample in the BOD bottle, add 2 mls of manganous sulfate solution followed by 2 mls of alkaline-iodide-azide solution; stopper with care to exclude air bubbles, and mix well by inverting the bottle several times.

2. When the precipitate settles, add 2 mls of concentrated sulfuric acid, re-stopper the bottle and mix by inverting the bottle several times. Complete the analysis within 45 minutes.

3. Transfer the entire bottle contents by inversion into a 500-ml wide mouth flask and titrate with 0.0375N thiosulfate solution or PAO to a pale straw color. Add 1-2 ml of starch solution and continue to titrate to the first disappearance of the blue color.

Note: Occasionally, a dark brown or black precipitate persists in the bottle after the addition of the acid. This precipitate will dissolve if the solution is kept for a few minutes longer than usual; or if particularly persistent, add a few more drops of acid.

8.3.7 Calculation

Each ml of 0.0375N sodium thiosulfate (PAO) titrant used is equivalent to 1 mg/l DO when the entire contents of the 300-ml BOD bottle are titrated.

To express the results as percent saturation at 760 mm atmospheric pressure, the solubility data in Table 421:1 (Whipple and Whipple, p. 413-414, Standard Methods, 16th Edition 1985), may be used. Carefully measure the temperature at the time of sample collection.

8.3.8 Precision and Accuracy

Reproducibility of this method is approximately 0.2 mg/l of DO at the 7.5 mg/l level due to equipment tolerances and uncompensated displacement errors.

8.3.9 References

Standard Methods for the Examination of Water and Wastewater, 16th Edition, p. 418, Method 421 B (1985).

Annual Book of ASTM Standards; Part 31, "Water," Standard D1589-60(A).

Methods for Chemical Analysis of Water and Wastes, US-EPA, 360.2 (1983).

Method 8.4 Dissolved Oxygen (Membrane Electrode)

8.4.1 Scope and Application

The membrane electrode (ME) probe method for DO measurements is recommended for those samples containing materials which interfere with the modified Winkler procedure as listed in Section 8.3.1 of Method 8.3.

The ME probe method may be used as a substitute for the modified Winkler procedure provided that the meter itself is standardized against the Winkler method on samples free of interferences.

8.4.2 Summary of Method

The most common ME instruments for determination of DO in water are dependent upon electrochemical reactions. Under steady-state conditions, the current or potential can be correlated with DO concentration. Interfacial dynamics at the ME-sample interface are a factor in probe response and a significant degree of interfacial turbulence is necessary. For precision performance, turbulence should be constant.

Refer to the manufacturer's instructions for calibrating and operating each specific DO meter.

8.4.3 Interferences

- Dissolved organic materials are not known to interfere in the output from DO probes.
- Dissolved inorganic salts are a factor in the performance of DO probes
- Reactive gases which pass through the ME probes may interfere. For example, chlorine will depolarize the cathode and cause a high probe output. Long-term exposures to chlorine will coat the anode with the chloride of the anode metal and eventually desensitize the probe. Hydrogen sulfide will interfere with ME probes if the applied potential is greater than the half-wave potential of the sulfide ion.
- Dissolved oxygen ME probes are temperature sensitive, and temperature compensation is normally provided by the manufacturer.

8.4.4 Apparatus

- YSI Model 57 DO Meter
- YSI 5700 Series DO Probe
- Hydrolab Surveyor II

8.4.5 Sample Handling

Refer to Section 8.3.4 (Method 8.3).

8.4.6 Calibration

1. Fill a clean bucket with uncontaminated or deionized water and place the ME probe into the bucket. Using the siphon method described in Section 8.3.4.4 of Method 8.3, fill duplicate BOD bottles and determine the DO by the Winkler method.

2. Adjust the meter according to manufacturer's instructions. Be sure to adjust the meter to the temperature of the water in the bucket, then calibrate the DO indicator dial to read the average DO concentration of the two samples determined by the Winkler test.

8.4.7 Test Procedure

1. When making measurements be sure that the ME stirring apparatus is working, adjust the temperature compensator, and read the DO dial to the nearest 0.1 mg/l.

2. Keep the probe in water when not in use to prevent the membrane from drying out.

3. If the sample temperature is 5°C greater than the calibration temperature, the meter should be recalibrated to the temperature of the sample.

4. Recalibrate against the Winkler test when the DO readings show a distinct change in DO levels, or when the probe has been in waters high in sulfide.

8.4.8 Precision and Accuracy

Manufacturer's specification claims 0.1 mg/l repeatability with ± 1 percent accuracy.

8.4.9 References

Standard Methods for the Examination of Water and Wastewater, 16th Edition p. 395, Method 421 F (1985).

Methods for Chemical Analysis of Water and Wastes, US-EPA, 360.1 (1983).

Instruction Manual YSI Model 57, Dissolved Oxygen Meter, Science Division, Yellow Springs Instrument Company.

Surveyor II Operating Manual, Hydrolab Corporation.

Method 8.5 Specific Conductance

8.5.1 Scope and Application

This method is applicable to ground, surface, and saline waters, as well as domestic and industrial wastes.

8.5.2 Summary of Method

- The specific conductance of a sample is measured by use of a self-contained conductivity meter, Whetstone bridge-type, or equivalent.
- Samples are preferably analyzed at 25°C. If not, temperature corrections are made and results reported at 25°C.

8.5.3 Test Procedure

1. Follow instructions manual for specific field conductivity meter used.
2. Check the meter with two standard solutions of approximate specific conductances of 100 and 1,000 umhos/cm, or standards that bracket the expected sample conductance. If the meter does not read within one percent of the standards, determine what the problem is and correct it before proceeding. Most field instruments read conductivity directly; with those instruments, follow the manufacturer's instructions. Report the results to the nearest ten units for readings under 1,000 umhos/cm and the nearest 100 units for readings over 1,000 umhos/cm.
3. Record the actual sample temperature when the measurement is made. The meter reading should be converted to specific conductance at 25°C using the information in the manufacturer's instruction manual.

8.5.4 Apparatus Section

- Beckman SoluBridge® Model RB-5/RB-6
- YSI Model 3530 Flow Through Cell
- Hydrolab Corporation Surveyor II

8.5.5 Precision and Accuracy

The conductivity meters listed above have an accuracy of ± 2 percent of reading. With satisfactory equipment, results within 1 percent of the true value should be obtained.

8.5.6 References

Standard Methods for the Examination of Water and Wastewater, 16th Edition, p. 76, Method 205 (1985).

Annual Book of ASTM Standards, Part 31, "Water," Standard D1125-64, P. 120.

Methods for Chemical Analysis of Water and Wastes, US-EPA, 120.1 (1983).

Instruction Manual, SoluBridge® RB-5/RB-6, Beckman Instruments, Inc., Rev. January 1982.

Surveyor II Operating Manual, Hydrolab Corporation, Rev. A February 1985.

YSI Model 3560 Water Quality Monitoring System Instructions, July, 1988.

Method 8.6 Chlorine, Total Residual (Titrimetric, Amperometric)

8.6.1 Scope and Application

The amperometric titration method applies to all types of waters and wastes that do not contain a substantial amount of organic matter.

8.6.2 Summary of Method

Chlorine (hypochlorite ion, hypochlorous acid) and chloramines stoichiometrically liberate iodine from potassium iodide at pH 4 or less.

The iodine is titrated with standard reducing agents such as sodium thiosulfate or PAO using an amperometric meter to determine the end point.

The results are calculated as mg/l Cl even though the actual measurement is of total oxidizing power. This is because chlorine is the dominant oxidizing agent present.

8.6.3 Interferences

- Vigorous stirring can lower chlorine values by volatilization.
- If necessary, dilute with chlorine demand free water. Water containing organic compounds will reduce the chlorine.
- Copper and silver poison the electrode.

8.6.4 Apparatus

- Fisher Porter Model 17T2000 amperometric titrator.
- A 1 ml microburet.

8.6.5 Reagents

- Phenylarsine oxide (PAO) (0.00564N), commercially available. Standardize with potassium biiodate.
- Five percent potassium iodide (KI) solution (50 gms/1).

- Acetate buffer solution (pH 4).

8.6.6 Procedure

1. Place 200 mls of sample in the sample container.

2. Attach to the electrode assembly.

3. Add 1.0 ml KI solution.

4. Add 1.0 ml acetate buffer.

5. Titrate with 0.00564N PAO.

6. As each increment is added, the needle deflects toward the left. When the needle no longer deflects, subtract the last drop added from the buret reading to obtain the mg/l Cl. Less and/or slower deflection signals that the end point is near.

8.6.7 Calculations

For 0.00564N PAO and a 200-ml sample there are no calculations. The buret reading is in mg/l. The last increment, when the needle does not reflect toward the left, must be subtracted.

8.6.8 Precision and Accuracy

Precision and accuracy of the procedure is $\pm$0.03 mg/l at a concentration of 0.41 mg/l for domestic sewage and 82 percent recovery.

8.6.9 References

Standard Methods for the Examination of Water and Wastewater, 16th Edition, p. 303, Method 408 C (1985).

Annual Book of ASTM Standards, Part 31, "Water," Standard D 1253-76(A).

Methods for Chemical Analysis of Water and Wastes, US-EPA, 330.1 (1983).

Instruction Bulletin for Model 17T2000 Amperometric Titrator, Fisher and Porter Company.

Method 8.7 Chlorine, Total Residual (Titrimetric, Back-iodometric) (Starch or Amperometric End Point)

8.7.1 Scope and Application

The iodometric back titration method is applicable to all types of waters, but is primarily used for wastewater because it eliminates any contact between the full concentration of liberated iodine and the wastewater.

8.7.2 Summary of Method

- Chlorine (hypochlorite ion, hypochlorous acid) and chloramines stoichiometrically liberate iodine from potassium iodide at pH 4 or less.
- The iodine quantitatively oxidizes a standardized reducing agent such as sodium thiosulfate or PAO.
- The excess reducing agent is then determined by titrating with a standard iodate (0.00564N) solution. The starch end point color change is from clear to blue.
- A subtraction of the excess amount of reducing agent is included in the calculations and the results are reported as mg/l Cl even though the actual measurement is of total oxidizing power. This is because chlorine is the dominant oxidizing agent present.

8.7.3 Interferences

- Manganese, iron, and nitrite interference may be minimized by buffering to pH 4 before the addition of KI.
- High concentrations of organics may cause uncertainty of the end point. This uncertainty can be reduced by acidifying to pH 1.0 if manganese, iron, or nitrite are absent.
- Turbidity and color may make the end point difficult to detect in the back idometric starch method. Practice runs with spiked samples may be necessary.

8.7.4 Apparatus

- Fisher Porter Model 17T2000 amperometric titrator.
- Standard laboratory glassware.
- A 1.0 ml microburet.

8.7.5 Reagents

- PAO solution (0.00564N); standardize with potassium biiodate.
- Standard iodate solution (0.00564N).
- Starch indicator.
- Phosphoric acid (10 percent).
- Potassium iodide (KI) five percent solution.

8.7.6 Procedure

1. Analyze 200 mls of distilled water (blank) prior to the analysis of the sample.

2. Starch - iodide end point.

   a. Pipet 5 mls of 0.00564N PAO solution into the flask.

   b. Add 1 ml five percent KI solution and 2 mls of 10 percent phosphoric acid solution.

   c. Add 200 mls of sample.

   d. Mix well.

   e. Add approximately 1 ml of indicator (starch).

   f. Titrate with 0.00564N potassium iodate solution to the first appearance of a blue color.

3. Amperometric End Point

   a. Perform steps a through e (above) or follow the directions of the manufacturer of the amperometric titrator.

   b. Place the solution in the proper position on the amperometric titrator.

   c. Titrate with 0.00564N iodate solution. Observe the response of the meter needle. As the end point is approached, the needle will temporarily deflect, then return to or near its original position. Continue dropwise. When the needle deflects and remains deflected, the end point has been exceeded by one drop. As an insurance of the proper end point in clear solutions, add 1 ml of starch solution before beginning the titration. The first appearance of a blue color should correspond to the needle deflection on the amperometric meter. Subtract 1/20th of a ml from the buret reading and record the result.

8.7.7 Calculations

$$\text{mg/l Cl} = \frac{(A-B) \times 200}{C}$$

Where:
A = ml of iodate used by the blank
B = ml of iodate used in the titration
C = ml of sample

8.7.8 Precision and Accuracy

Precision of the method is ±0.09 mg/l at a concentration of 1.10 mg/l for domestic sewage and 76 percent recovery.

8.7.9 References

Standard Methods for the Examination of Water and Wastewater, 16th Edition, p. 300, Method 408 B (1985).

Annual Book of ASTM Standards, Part 31 "Water," Standard D 1253-76(C).

Methods for Chemical Analysis of Water and Wastes, US-EPA, 330.2 (1983).

Instruction Manual for Model 17T2000 Amperometric Titrator, Fisher Porter Company.

Method 8.8 Chlorine, Total Residual (Dpt Colorimetric - Hach Kit)

8.8.1 Scope and Application

N,N-diethyl-p-phenylenediamine (DPD) may be used for natural waters and waters treated with chlorine.

8.8.2 Summary of Method

- Chlorine (hypochlorite ion, hypochlorous acid and chloramines) stoichiometrically liberate iodine from potassium iodide at pH 4 or less.
- A reaction between the liberated iodine and N,N-diethyl-p-phenylenediamine (DPD) produces a red colored solution at a pH of 6.2 - 6.5.
- The solution is spectrophotometrically compared to a series of standards. In the Hach kit colorimeter, the dial face is calibrated to give a direct readout in mg/l chlorine.

8.8.3 Interferences

- Any oxidizing agents; these are usually present at insignificant concentrations. Oxidized manganese interferes with the DPD reagent (1 ug/l MnO4 ~ 1 ug/l Cl2).
- Turbidity and color will essentially prevent the colorimetric analysis.

8.8.4 Apparatus

- Hach DR-100 colorimeter. The Hach reagents and colorimeter or spectrophotometer are EPA - acceptable for NPDES monitoring if used in accordance with approved procedures. The preprinted calibration scales provided by the manufacturer, based upon factors developed under ideal conditions, are only acceptable if verified. The

calibration scale must be initially verified using multiple standards and a blank. Each day of use, the calibration scale or curve must be verified with a blank and at least one high and one low standard representative of the linear working range. These standard checks must agree within ± 10% of the original scale or a new curve must be prepared. Verification data should be recorded and maintained on file. See Standard Methods

- 1-cm and 2.5-cm cells.

8.8.5 Reagents or Standards

- DPD total chlorine powder pillows. The DPD tablets must be discarded if there is evidence of decomposition. The tablets deteriorate rapidly in the presence of moisture, and with age become difficult to dissolve. Look for caking and brown color.

  NOTE: Do not handle tablets with the hands! The DPD oxalate is toxic; take care to avoid ingestion.

- 1N sulfuric acid and 1N sodium hydroxide.

- Chlorine demand water. See Standard Methods1, Method 408 B.3.m for directions for preparing or ASTM, Standard D1193, Consumption of Potassium Permanganate.

- Potassium permanganate stock -- Prepare a stock solution containing 891 mgs/1000 mls.

- Potassium permanganate working stock 10 ppm -- Prepare a working stock solution containing 10 mg/l KMnO4 by diluting 10 mls of D.8.5.4 stock solution to 1 liter. Stock is stable for approximately 5 days.

- Potassium permanganate calibration standards --Prepare calibration standards from the working stock solution and/or KMnO4 calibration standard solutions each day of use.

  NOTE: KMnO4 standards will fade rapidly, within 15 minutes, when chlorine demand-free water is not used.

Calibration Standard mg/l	mls of Working Stock/100mls
0.05	10.0 of 0.5 mg/l Std.
0.10	10.0 of 1.0 mg/l
0.5	5.0 of 10 mg/l
1.0	10.0 of 10 mg/l
2.0	20.0 of 10 mg/l

8.8.6 Procedure Total Chlorine Concentration Range 0-2 ug/l

1. Fill a clean 2.5-cm cell to the 10-ml mark with sample.

2. Samples should have a pH between 6 and 7. If necessary, adjust pH with 1N sulfuric acid or 1N sodium hydroxide.

3. Open a DPD total chlorine powder pillow and add the contents to the sample cell. Cap the cell and swirl to mix. It is not necessary for all the particles to dissolve to obtain an accurate reading. The pH of the sample containing the DPD-buffer pillow must be between 6.2 - 6.5 units.

4. Allow at least three minutes, but not more than six minutes, before moving to the next step.

5. Open the light shield, turn the right set knob fully clockwise and place the 1-cm cell holder in the left set position of the sample well. Press down firmly to seat the cell holder.

6. Hold the button down, meanwhile adjust the left set knob to align the meter needle with the arrow at the extreme left of the scale arc. Remove the cell holder.

7. Fill a clean 2.5-cm sample cell with the sample. Cap the cell and place into the cell holder. Press down to seat and close the light shield.

8. Set zero on colorimeter by holding the on button down and adjusting the right set knob. Open the light shield and remove the sample cell.

9. Fill a clean 1-cm sample cell with the solution from step 2, cap the cell and place it in the cell holder.

10. Press the "on" button down and hold until the meter stabilizes. Read and record the mg/l total chlorine from the upper (2.5-cm) scale arc.

8.8.7 Procedure - Total Chlorine Concentrations of 0-3.5 mg/l

1. For total chlorine, 0-3.5 mg/l, follow steps in 8.8.6 steps 1-5.

2. Follow the directions in 8.8.6 step 6 except instead of removing the cell holder, rotate it to the right position.

3. Fill a clean 1-cm sample cell with the sample. Cap the cell and place it into the cell holder.

4. Set zero as in 8.8.6 step 8.

5. Fill a clean 1-cm sample cell with the solution from 8.8.6 step 2.

6. Hold the on button down until the meter stabilizes. Read and record the mg/l total chlorine from the lower (1-cm) scale arc.

8.8.8 Precision and Accuracy

The precision and accuracy of the method is ±0.03 mg/l at a concentration of 1.07 for domestic sewage. The recovery is 100 percent.

8.8.9 Calculations

No calculations are required for the kit, the readings are directly in mg/l of total chlorine.

8.8.10 References

Standard Methods for the Examination of Water and Wastewater, 16th Edition, 1985, p. 292, Method 408E.

Methods for Chemical Analysis of Water and Wastes, US-EPA, 330.5 (1979).

Instruction Manual, DR 100 Colorimeter, Model 41100-02, DPD Method for Chlorine, Hach Company, June 1983.

Annual Book of ASTM Standards, Part 31 "Water", ASTM, Standard D 1193, Consumption of Potassium Permanganate.

Method 8.9 Fluorometric Determination of Dye Tracer

8.9.1 Scope and Application

This method covers the determination of fluorescence as it relates to commercially available tracer dyes. Rhodamine dyes are fluorescent at a wave length of 590 millimicrons, making them detectable without major interferences in all natural waters.

8.9.2 Summary of Method

Fluorescent dyes emit light upon irradiation from an external source. The emitted light is proportional to the tracer concentration within the sample.

8.9.3 Sample Handling

- Since tracers are photoreactive, care should be taken to protect samples from light sources.
- All samples should be stored in glass containers.

8.9.4 Interferences

- Temperature shifts the fluorescent properties of the tracers; thus all samples should be analyzed at the same temperature as the calibration standards.

- Natural conditions such as the presence of chlorophyll or tannins and lignins in the waters to be traced can impart background fluorescence. Calibration standards should be made from these ambient waters to account for any potential background.

- Sample turbidity may interfere. In highly turbid waters, accuracy may be enhanced by filtration prior to analysis.

8.9.5 Apparatus

- Turner Fluorometer Model 10-005.

- Calibration glassware.

8.9.6 Standards

8.9.6.1 Flow-Through Configuration

Working stocks (use water sample from study areas as dilution water).

(A) Dilute 1 ml dye to 1 liter dilution water (solution "A" = 1 ppt).

(B) Dilute 10 mls of solution "A" to 1 liter solution "B" = 10 ppm.

(C) Dilute 100 mls of solution "A" to 1 liter solution "C"= 100 ppm.

8.9.6.2 Cuvette or Pour-Through Configuration

Working stocks (use water sample from study area as dilution water).

(A) Dilute 10 mls dye to 1 liter: solution "A" = 10 ppt

(B) Dilute 10 mls "A" to 1 liter: solution "B" = 100 ppm

(C) Dilute 1 ml "A" to 1 liter: solution "C" = 10 ppm

(D) Dilute 10 mls to 1 liter: solution "D" = 1 ppm

From these stocks

(A) Each ml "B" to 1 liter adds 100 ppb

(B) Each ml "C" to 1 liter adds 10 ppb

(C) Each ml "D" to 1 liter adds 1 ppb

8.9.7 Procedure

8.9.7.1 Turner Fluorometer; Model 10-005

1. Allow fluorometer to warm up for 10 minutes.

2. Using background water, adjust for background fluorescence by setting instrument on most sensitive scale (x31.6 and x100 sensitivity) to read 0.

3. Machine circuitry is designed such that one calibration standard, e.g., 100 ppb, produces linear responses throughout a range of 0.05 to 300 ppb.

4. Above 300 ppb, emissions from the irradiated dye sample interfere with one another producing a nonlinear condition. Thus, when working above 300 ppb calibration curves are required.

5. Even though a single 100 ppb standard produces a linear response in the range of 0.1 to 300 ppb, a second standard, e.g., 10 ppb, should be used as a check.

6. Depending upon sensitivity needs, a 100 ppb standard can be used to provide a wide range of tracer concentrations. A typical application by the Branch involves setting a 100 ppb standard to equal 10 on the minimum sensitivity scale (xMS and x100). With this setting, tracer concentrations in the range of 0.05 to 300 ppb can easily be determined.

8.9.8 Precision and Accuracy

Precision and accuracy for this method have not been established.

8.9.9 Reference

Wilson, James F., Jr., Fluorometric Procedures for Dye Tracing: USGS Techniques for Water-Resources Investigations, Book 3, Chapter A12 (1968).

Operating and Service Manual, Model 10 Series Fluorometers, Turner Designs, October 1981.

Method 8.1 Salinity

8.10.1 Scope and Application

This method is applicable for brackish to saline waters having a salinity range of 0 to 40 parts per thousand.

8.10.2 Summary of Method

The salinity measurement is based upon the direct proportionality between the magnitude of an induced electric current and the electrical conductivity of the water in which it is induced.

8.10.3 Comments

Routinely check meter against a resistor which is matched to the meter.

8.10.4 Test Procedure

1. Follow instructions manual for Beckman RS5-3 Portable Salinometer or other salinometer used.

2. Record the temperature, specific conductance and salinity as determined. Read salinity to nearest 0.1 ppt.

8.10.5 Precision and Accuracy

Beckman Model RS5-3 Portable Salinometer has an accuracy of ± 0.05 parts per thousand salinity, ± 0.05°C temperature, and ± 0.05 millimhos/cm specific conductance. The Hydrolab Surveyor II Salinometer has an accuracy of ± 0.7 parts per thousand salinity, 1% full scale for conductivity, and $\pm$ 0.1°C for temperature.

8.10.6 Apparatus

Beckman Model RS5-3 Portable Salinometer.

8.10.7 References

Standard Methods for the Examination of Water and Wastewater, 15th Edition, p. 100 Method 209A (1980).

Instruction Manual, RS5-3 Portable Salinometer, Beckman Instruments, Inc., Revised March 1973.

SECTION 9
DESIGN AND INSTALLATION FOR PERMANENT MONITORING WELLS

9.1 Introduction

The design and installation of permanent monitoring wells involve the drilling of boreholes into various types of geologic formations that exhibit varying subsurface conditions. Designing and installing permanent monitoring wells in these geologic environments may require several different drilling methods and installation procedures. The selection of drilling methods and installation procedures shall be based on field data collected during a hydrogeologic site investigation and/or a search of existing data. Each permanent monitoring well shall be designed and installed to function properly throughout the entire anticipated life of the monitoring program. When designing monitoring wells the following questions shall be considered:

- What are the short- and long-term objectives?
- How long will the monitoring program last?
- What contaminants are to be monitored?
- What types of well construction materials are to be used?
- What kinds of analyses are needed?
- What are the surface and subsurface geologic conditions?
- What aquifer(s) is going to be monitored?
- Over what depth(s) will the well be screened?
- What is the anticipated total depth of the well?
- What are the general site conditions?
- What are the potential health and safety hazards?
- Are these wells going to serve more than one purpose (i.e., monitoring, pump test, extraction)?

Each of the previous questions can be expanded into many subtopics depending on the complexity of the project. In designing permanent monitoring wells, the most reliable obtainable data shall be utilized. Once the data have been assembled and the well design has been completed, a drilling method(s) has to be selected. The preferred drilling procedure for installing wells is the hollow-stem auger method. However, site conditions may not always be amenable to using the hollow-stem auger method. When this occurs, an alternate method shall be selected that will perform acceptably under the encountered site conditions. It is advisable to select several alternate methods and be prepared to use them if a field problem suddenly occurs that warrants a drilling change. The following procedures for designing and installing monitoring wells cover the different aspects of selecting materials, drilling boreholes, and installing monitoring devices. This discussion is presented so that

standard practices and procedures will be employed by all EPA staff and contractors who are associated with the design, drilling, and installation of permanent monitoring wells in Region IV.

9.2 Drilling Methods

The following drilling methods are listed in order of preference; however, final selection shall be based on actual site conditions.

9.2.1 Hollow-stem Auger

This type of auger consists of a hollow, steel stem or shaft with a continuous, spiralled steel flight, welded onto the exterior side of the stem, connected to an auger bit, which when rotated, transports cuttings to the surface. This method is best suited in soils that have a tendency to collapse when disturbed.

A monitoring well can be installed inside of hollow-stem augers with little or no concern for the caving potential of the soils and/or water table. However, retracting augers in caving sand conditions while installing monitoring wells can be extremely difficult or impossible since the augers have to be extracted without being rotated. If caving sands are encountered during monitoring well installations, a drilling rig must be used that has enough power to extract the augers from the borehole without rotating them. A bottom plug or pilot bit assembly can be fastened onto the bottom of the augers to keep out most of the soils and/or water that have a tendency to clog the bottom of the augers during drilling. Potable water (analyzed for contaminants of concern) may be poured into the augers (where applicable) to equalize pressure so that the inflow of formation materials and water will be held to a minimum when the bottom plug is released. Rubber "O" rings are normally furnished with new augers to make the augers water "tight"; however, rubber "O" rings are not acceptable for ESD drilling operations. Only Teflon® "O" rings are acceptable. Water-tight center plugs are not acceptable because they create suction when being extracted from the augers. This suction forces or pulls cuttings and formation materials into the augers, thus defeating the purpose of the centerplug. Auguring without a center plug or pilot bit assembly is permitted, provided that the soil plug which is formed in the bottom of the auger is removed when sampling or installing well casings. Removing the soil plug from the augers can be accomplished by washing out the plug using a side discharge rotary bit, or augering out the plug with a solid-stem auger bit sized to fit into the hollow-stem auger. The type of bottom plug or pilot bit assembly proposed for the drilling activity shall be approved by SBP prior to drilling operations. Boreholes can be augered to depths of 150 feet or more (depending on the auger size), but generally boreholes are augured to depths less than 100 feet.

9.2.2 Solid-stem Auger

This type of auger consists of a solid stem or shaft with a continuous spiralled steel flight, welded onto the stem, and connected to an auger bit. When rotated, cuttings are transported to the surface. This auger method is used in cohesive and semi-cohesive soils that do not have a tendency to collapse when disturbed. Boreholes can be augered to depths of 200 feet or more (depending on the auger size), but generally boreholes are augured to depths less than 150 feet.

Both of the previously discussed auger methods can be used in unconsolidated soils and semi-consolidated (weathered rock) soils, but not in competent rock. Each method can be employed without introducing foreign materials into the borehole such as drilling fluids, thus minimizing the

potential for cross-contamination. Minimizing the risk of potential cross contamination is one of the most important factors to consider when selecting the drilling method(s) for a project.

9.2.3 Rotary Method

This method consists of a drill pipe or drill stem coupled to a drilling bit that rotates and cuts through the soils. The cuttings produced from the rotation of the drilling bit are transported to the surface by drilling fluids which generally consist of water, drilling mud, or air. The water, drilling mud, or air is pumped down through the drill pipe, and out through the bottom of the drilling bit. The cuttings are forced to the surface between the borehole wall and the drill pipe. The drilling fluids not only force the cuttings to the surface but also keeps the drilling bit cool. When considering this method, it is important to evaluate the potential for contamination when fluids and/or air are introduced into the borehole. If the rotary method is selected as one of the drilling methods, water rotary is the preferred method, followed by air rotary and mud rotary.

9.2.3.1 Water Rotary

When using water rotary, potable water (that has been analyzed for contaminants of concern) shall be used. If potable water (or a higher quality water) is not available, then potable water will have to be transported to the site or an alternative drilling method must be selected. Water rotary is the preferred rotary method because potable water is the only fluid introduced into the borehole during drilling. Water does not clog the formation materials, thus reducing well development time. The potable water will, however, flow out into the surrounding formation materials (if permeable) and mix with the natural formation water. This mixing of the drilling water and the natural formation water should be evaluated when determining the drilling method. Generally, most of the drilling water will be recovered during well development.

9.2.3.2 Air Rotary

When using air rotary, the air compressor shall have an in-line organic filter system to filter the air coming from the compressor. The organic filter system shall be regularly inspected to insure that the system is functioning properly. Air compressors that do not have in-line organic filter systems are not acceptable for air rotary drilling. A cyclone velocity dissipator or similar air containment system shall also be used to funnel the cuttings to one location instead of letting the cuttings blow uncontrolled out of the borehole. The conventional air rotary method does not control cuttings blowing out of the borehole, and is not acceptable unless the above mentioned cyclone velocity dissipator or similar containment system is employed. Any air rotary method that allows cuttings to blow uncontrolled out of the borehole and does not direct them to a discharge point with minimal disturbance shall not be acceptable. Air rotary that employs the dual-tube (reverse circulation) drilling system is acceptable since the cuttings are contained in the drill stems and blown to the surface through the cyclone velocity dissipator and to the ground with little surface disturbance.

9.2.3.3 Mud Rotary

Mud rotary is the least preferred rotary method because contamination can be introduced into the borehole from the constituents in the drilling mud, and it is very difficult to remove the drilling mud from the borehole after drilling and during well development. The drilling mud can also carry contaminants from a contaminated zone to an uncontaminated zone, thereby cross-contaminating the borehole. If mud rotary is selected, only potable water and pure (no additives) bentonite drilling

muds shall be used. All materials used shall have adequate documentation as to manufacturer's recommendations and product constituents. The proper field QA/QC procedures shall be initiated before and during drilling to minimize the potential for contamination. These QA/QC procedures shall include, but not be limited to, sampling and analyzing of all drilling materials such as drilling muds, bentonite pellets, grouts, sand, etc., and the potable water to be used during drilling (Section 9.9).

9.2.4 Other Methods

Other types of drilling procedures are also available, such as the cable-tool, the jetting method, and the boring (bucket auger) method. These methods are used in the installation of water and irrigation wells, but are not common methods for monitoring well installations. If these methods are selected for monitoring well installations, they shall be approved by a senior staff geologist or engineer before field work is initiated.

9.3 Borehole Requirements

9.3.1 Annular Space

The borehole shall be of sufficient diameter so that well construction can proceed without major difficulties. To assure adequate size, a minimum 2-inch annular space is required between the casing and the borehole wall (or the hollow-stem auger wall). For example, an 8-inch borehole is required to install a 4-inch outside diameter (OD) casing. However, if the inside diameter (ID) of the casing is 4 inches, the borehole will have to be larger than 8 inches to include the 2-inch annular space and the outside diameter (OD) of the casing (4-inch ID plus the casing wall thickness). The 2-inch annular space around the casing will allow the filter pack, bentonite pellet seal, and the annular grout to be placed at an acceptable thickness. Also, the 2-inch annular space will allow up to a 1.5-inch diameter tremie tube for placing the filter pack, pellet seal, and grout at the specified intervals. An annular space less than the 2-inch minimum will not be acceptable. When installing a well inside of hollow-stem augers, the inside diameter (ID) of the augers is the area to be considered when determining the 2-inch annular space.

9.3.2 Overdrilling The Borehole

Sometimes it is necessary to overdrill the borehole so any soils that have not been removed or have fallen into the borehole during auger or drill stem retrieval, will fall to the bottom of the borehole below the depth where the filter pack and well screen are to be placed. Normally, 3 to 5 feet is sufficient for overdrilling. The borehole can also be overdrilled to allow for placement of a sump in the well below the well screen. A sump usually consists of a 5- or 10-foot section of well casing located below the well screen. Sumps serve as catch basins or storage areas for sediment that flows into the well and drops out of suspension and for high density non-aqueous phase liquids. Sumps are added to the well screens when the wells are screened in aquifers that are naturally turbid and will not yield clear formation water (free of visible sediment) even after extensive development. The sediment can then be periodically pumped out of the sump preventing the well screen from clogging or "silting up". If the borehole is overdrilled too much, it can be backfilled to the designed depth with bentonite pellets or the filter sand that is to be used for the filter pack.

9.3.3 Filter Pack Placement

When placing the filter pack into the borehole, a minimum of 6 inches of the filter pack material shall be placed under the bottom of the well screen to provide a firm footing and an unrestricted flow under the screened area. Also, the filter pack shall extend a minimum of two feet above the top of the well screen. The filter pack shall be placed by the tremie or positive displacement method. Placing the filter pack by "pouring" may be acceptable in certain situations; however, this will be discussed in the next section.

9.3.4 Filter Pack Seal-Bentonite Pellet Seal (Plug)

A seal shall be placed on top of the filter pack. This seal shall consist of a high solids, pure bentonite material. The solids content shall be at least 20 percent. Bentonite materials that have a solids content of 20 percent or greater are available in powder form or in the form of pellets compressed to a density of 70-80 lbs/cu.ft. The preferred method of placing bentonite pellets is by the positive displacement or the tremie method. Use of the tremie method minimizes the risk of pellets bridging in the borehole and assures the placement of pellets (also sand and grout) at the proper intervals. Pouring of the pellets (and filter pack materials) is acceptable in shallow boreholes (less than 50 feet) where the annular space is large enough to prevent bridging and to allow measuring (with a tape measure) to insure that the pellets have been placed at the proper intervals. In order to insure that the pellets have been placed at the proper intervals, the pellets shall be tamped, with an appropriate tamping tool, while the measuring is being conducted. The tamping process minimizes the potential for pellet bridging by forcing any pellets, that have lodged against the borehole wall and/or the well casing, down to the proper interval. The bentonite seal shall be placed above the filter pack at a minimum of two feet vertical thickness. The hydration time for the bentonite pellets shall be a minimum eight hours or the manufacturer's recommended hydration time, whichever is greater. In all cases, the proper depths shall be documented by measuring and not by estimating. Other forms of bentonite such as granular bentonite, and bentonite chips have limited applications, and are not recommended for the bentonite seal unless special conditions warrant their use. In any case, deviation from bentonite pellets for the seal, such as a 30 percent solids bentonite grout, shall be approved by a senior staff geologist. If for some reason, the water table is temporarily below the pellet seal interval, potable water (or a higher quality water) shall be used to hydrate the pellets.

9.3.5 Grouting The Annular Space

The annular space between the casing and the borehole wall shall be filled with either a high solids, pure (no additives), bentonite grout, a neat cement grout, or a cement/bentonite grout. Each type of grout to be used shall be evaluated as to its intended use and integrity. The grout shall be placed into the borehole, by the tremie method, from the top of the bentonite seal to within 2 feet of the ground surface or below the frostline, whichever is greater. The tremie tube shall have a side discharge port or a bottom discharge port, to minimize damage to the filter pack and/or the bentonite pellet seal, during grout placement. The grout shall be allowed to "set" or cure for a minimum of 24 hours before the concrete surface pad is installed. All grouts shall be prepared in accordance with the manufacturer's specifications. Bentonite grouts shall have a minimum density of 9.4 lbs/gal to ensure proper set-up. The density of the bentonite grouts shall be measured while mixing and no pumping of grout into the borehole will be allowed until the minimum density of 9.4 lbs/gal is attained. In addition, the grouting operation shall not cease until the grout flowing out of the borehole has a minimum density of 9.4 lbs/gal. A mud balance shall be used to measure the specified grout density. Estimating the grout density shall not be acceptable. Drilling muds will not be acceptable for

grouting. Cement grouts shall be mixed using 6.5 to 7 gallons of water per 94-lb bag of portland cement (Type I). The addition of bentonite (5-to-10 percent) to the cement grout is for elasticity and the reason for its use shall be documented. The specific mixtures and other types of cements and/or grouts shall be evaluated on a case by case basis.

9.3.6 Above Ground Riser Pipe And Outer Protective Casing

The well casing, when installed and grouted, shall extend above the ground surface a minimum of 2.5 feet. In high traffic areas, the well casing may be located below grade, with a water proof cover. A vent hole shall be drilled or cut into the top of the well casing cap to permit pressure equalization, if applicable. An outer protective casing shall be installed into the borehole after the annular grout has "set" for at least 24 hours. The outer protective casing shall be of steel construction with a hinged, locking cap. Generally, an outer protective casing used over a 2-inch well casing is 4 inches square by 5 feet long. Similarly, a protective casing used over 4-inch well casings is 6 inches square and 5 feet long. Round protective casings are also acceptable. A protective casing shall have sufficient clearance around the inner well casing, so that the outer protective casing will not come into contact with the inner well casing after installation. The protective casing shall have a minimum of two weep holes for drainage. These weep holes shall be a minimum 1/4 inch in diameter and drilled into the protective casing just above the top of the level of concrete inside the protective casing to prevent water from standing inside of the protective casing. A protective casing made of aluminum or other soft metals is not acceptable because it is not strong enough to resist tampering. The protective casing is installed by pouring concrete into the borehole on top of the grout. The protective casing is then pushed into the wet concrete and borehole a minimum of 2 feet. Extra concrete may be needed to fill the inside of the protective casing so that the level of the concrete inside of the protective casing is at or above the level of the surface pad. The protective casings shall extend a minimum of 3 feet above the ground surface or to a height so that the cap of the inner well casing is exposed when the protective casing is opened.

9.3.7 Concrete Surface Pad

A concrete surface pad shall be installed around each well at the same time as the outer protective casing is being installed. The surface pad shall be formed around the well casing. Concrete shall be placed into the formed pad and into the borehole (on top of the grout) in one operation making a contiguous unit. The protective casing is then installed into the concrete as described in the previous section. The size of the concrete surface pad is dependent on the well casing size. If the well casing is two inches in diameter, the pad shall be 3 feet x 3 feet x 6 inches. If the well casing is 4 inches in diameter, the pad shall be 4 feet x 4 feet x 6 inches. Round concrete surface pads are also acceptable. The finished pad shall be sloped so that drainage will flow away from the protective casing and off of the pad. In addition, a minimum of one inch of the finished pad shall be below grade or ground elevation to prevent washing and undermining by soil erosion. At each site, all locks on the outer protective casings shall be keyed alike.

9.3.8 Surface Protection-Bumper Guards

If the monitoring wells are located in a high traffic area, a minimum of three bumper guards consisting of steel pipes 3 to 4 inches in diameter and a minimum 5-foot length shall be installed to a minimum depth of 2 feet below the ground surface in a concrete footing and extend a minimum of 3 feet above ground surface. Concrete shall also be placed into the steel pipe to provide additional

strength. Steel rails and/or other steel materials can be used in place of steel pipe but approval must be granted by a senior staff geologist or engineer prior to field installation.

9.4 Construction Techniques

9.4.1 Well Installation

The borehole shall be bored, drilled, or augered as close to vertical as possible, and checked with a plumb bob or level. Slanted boreholes will not be acceptable unless specified in the design. The depth and volume of the borehole, including the overdrilling if applicable, shall have been calculated and the appropriate materials procured prior to drilling activities. The well casings shall be secured to the well screen by flush-jointed threads and placed into the borehole and plumbed by the use of centralizers and/or a plumb bob and level. Another method of placing the well screen and casings into the borehole and plumbing it at the same time is to suspend the string of well screen and casings in the borehole by means of the wireline on the drill rig. The string of well screen and casings can be placed into the borehole and plumbed in one easy operation. This wireline method is especially useful if the borehole is deep and a long string of well screen and casings have to be set and plumbed.

No lubricating oils or grease shall be used on casing threads. Teflon tape can be used to wrap the threads to insure a tight fit and minimize leakage. No glue of any type shall be used to secure casing joints. Teflon® "O" rings can also be used to insure a tight fit and minimize leakage; however, "O" rings made of other materials are not acceptable if the well is going to be sampled for organic compounds.

Before the well screen and casings are placed on the bottom of the borehole, at least 6 inches of filter material shall be placed at the bottom of the borehole to serve as a firm footing. The string of well screen and casing shall then be placed into the borehole and plumbed. Centralizers can be used to plumb a well, but centralizers shall be placed so that the placement of the filter pack, bentonite pellet seal, and annular grout will not be hindered. Centralizers placed in the wrong places can cause bridging during material placement. Monitoring wells less than 50 feet deep generally do not need centralizers. If centralizers are used they should be placed below the well screen and above the bentonite pellet seal. The specific placement intervals shall be decided based on site conditions. When installing the well screen and casings through hollow-stem augers, the augers shall be slowly extracted as the sand pack, bentonite seal, and grout are tremied and/or poured into place. The extraction of the augers will allow the materials, being placed through the augers, to flow into the borehole instead of flowing up into the bottom of the augers causing potential bridging problems. After the string of well screen and casing is plumb, the filter material shall then be placed around the well screen (preferably by the tremie method) up to the designated depth. After the filter pack has been installed, the bentonite pellet seal shall be placed (preferably by the tremie method) directly on top of the filter pack up to the designated depth or a minimum of 2 feet above the filter pack. The bentonite pellet seal shall be allowed to hydrate a minimum of eight hours or the manufacturer's recommended hydration time, whichever is longer. After the pellet seal has hydrated for the specified time, the grout shall then be pumped by the tremie method into the annular space around the casings up to within 2 feet of the ground surface or below the frostline, whichever is greater. The grout shall be allowed to set for a minimum of 24 hours before the surface pad and protective casing are installed. After the surface pad and protective casing are installed, bumper guards shall be installed (if needed). The bumper guards (a minimum of 3 bumper guards per well) shall be placed around or incorporated into the concrete surface pad in a configuration that provides maximum

protection to the well. Each piece of steel pipe or approved material shall be installed into an 8- to 10-inch diameter hole, to a minimum depth of 2 feet below ground surface, and filled with concrete. As previously stated, the bumper guard shall extend above the ground surface a minimum of 3 feet. The total length of each bumper guard shall be a minimum of 5 feet.

After the wells have been installed, the outer protective casing shall be painted with a highly visible enamel paint. Care must be taken not to introduce any paint into the well. The wells shall be permanently marked with the well number, date installed, site name, elevation, etc., either on the cover or an appropriate place that will not be easily damaged and/or vandalized.

If the monitoring wells are installed in a high traffic area such as a parking lot, in a residential yard, or along the side of a road it might be desirable to complete the wells flush with the ground surface and install water-tight traffic covers. Traffic covers are designed to extend from the ground surface down into the concrete plug around the well casing. The covers shall have seals that make the unit water-tight when closed and secured. The traffic covers shall be installed as far above grade as practical to minimize standing water and promote runoff.

9.4.2 Double Cased Wells

Double cased wells shall be constructed when there is reason to believe that interconnection of two aquifers by well construction may cause cross contamination, and/or when flowing sands make it impossible to install a monitoring well using conventional methods. A pilot borehole shall be bored through the overburden and/or the contaminated zone into the clay confining layer or bedrock. An outer casing (sometimes called surface or pilot casings) shall then be placed into the borehole and sealed with grout. The borehole and outer casing shall extend into tight clay a minimum of five feet and into competent bedrock a minimum of two feet. The total depths into the clay or bedrock will vary, depending on the plasticity of the clay and the extent of weathering and/or fracturing of the bedrock. The size of the outer casing shall be of sufficient inside diameter (ID) to contain the inner casing, and the 2-inch minimum annular space. In addition, the borehole shall be of sufficient size to contain the outer casing and the 2-inch minimum outer annular space, if applicable. The outer casing shall be grouted by either the tremie method or by pressure grouting to within 2 feet of the ground surface. The grout shall be pumped into the annular space between the outer casing and the borehole wall. This can be accomplished by either placing the tremie tube in the annular space and pumping the grout from the bottom of the borehole to the surface, or placing a grout shoe or plug inside the casing at the bottom of the borehole and pumping the grout through the bottom grout plug and up the annular space on the outside of the casing. If the outer casing is set into very tight clay, both of the above methods might have to be used, because the clay usually forms a tight seal in the bottom and around the outside of the casing preventing grout from flowing freely during grout injection. On the other hand, outer casing set into bedrock normally will have space enough to allow grout to flow freely during injection. A minimum of 24 hours shall be allowed for the grout plug (seal) to "set" or cure before attempting to drill through it. The grout mixture used to seal the outer annular space can be either a neat cement, cement/bentonite, cement/sand, or a pure bentonite grout. However, the seal or plug at the bottom of the borehole and outer casing shall consist of a Type I portland cement/bentonite or cement/sand mixture. The use of a pure bentonite grout for a bottom plug or seal is not acceptable, because the bentonite grout sets or cures to a gel and is not rigid enough to withstand the stresses of drilling. When drilling through the seal, care shall be taken to avoid cracking, shattering, and/or washing out of the seal, which will be discussed in the next section. If caving conditions exist so that the outer casing cannot be sufficiently sealed by grouting, the outer casing shall be driven into place with a grout seal placed in the bottom of the casing.

Removal of outer casings, which are sometimes called temporary surface casings, after well screens and casings have been installed and grouted is not acceptable. Trying to remove outer surface casings after the inner casings have been grouted could only jeopardize the structural integrity of the well.

9.4.3 Bedrock Wells

The installation of monitoring wells into bedrock can be accomplished in two ways:

1. The first method is to drill or bore a pilot borehole through the soil overburden into the bedrock. An outer casing is then installed into the borehole by setting it into the bedrock, and grouting it into place as described in the previous section. After the grout has set, the borehole can then be advanced through the grout seal into the bedrock. The preferred method of advancing the borehole into the bedrock is rock coring. Rock coring makes a smooth, round hole through the seal and into the bedrock without cracking and/or shattering the seal. Roller cone bits are used in soft bedrock, but extreme caution shall be taken when using a roller cone bit to advance through the grout seal in the bottom of the borehole because excessive water and "down" pressure can cause cracking, eroding(washing), and/or shattering of the seal. Low volume air hammers have been used to advance the borehole, but they have a tendency to shatter the seal because of the hammering action. Any proposed method will be evaluated on its own merits, and will have to be approved by a senior staff geologist before drilling activities begin. When the drilling is complete, the finished well consists of an open borehole from the ground surface to the bottom of the well. There is no inner casing, and the outer surface casing, installed down into bedrock, extends above the ground surface, and also serves as the outer protective casing. If the protective casing becomes cracked or is sheared off at the ground surface, the well is open to direct contamination from the ground surface and will have to be repaired immediately or abandoned. In some instances, the outer surface casing is cut off at the surface or below the surface, depending on the design, and a separate outer protective casing is installed. Another limitation to the open rock well is that the entire bedrock interval serves as the monitoring zone. In this situation, it is very difficult or even impossible to monitor a specific zone, because the contaminants being monitored could be diluted to the extent of being nondetectable. The use of open bedrock wells are generally not acceptable in the Superfund and RCRA programs because of the uncontrolled monitoring intervals. However, some site conditions might exist, especially in cavernous limestone areas (Karst topography) or in areas of highly fractured bedrock, where the installation of the filter pack and its structural integrity are questionable. Under these conditions the design of an open bedrock well may be warranted.

2. The second method of installing a monitoring well into bedrock is to install the outer surface casing and drill the borehole (by the approved method) into bedrock, and then install an inner casing and well screen with the filter pack, bentonite seal, and annular grout. The well is completed with a surface protective casing and concrete pad. This well installation method

gives the flexibility of isolating the monitoring zone(s) and minimizing inter-aquifer flow. In addition, it gives structural integrity to the well, especially in unstable areas (steeply dipping shales, etc.) where the bedrock has a tendency to shift or move when disturbed. Omitting the filter pack around the well screen is a general practice in some open rock borehole installations, especially in drinking water and irrigation wells. However, without the filter pack to protect the screened interval, sediment particles from the well installation and/or from the monitoring zone could clog the well screen and/or fill the screened portion of the well rendering it inoperable. Also, the filter pack serves as a barrier between the bentonite seal and the screened interval. Rubber inflatable packers have been used to place the bentonite seal when the filter pack is omitted. This method is not acceptable because the packers have to remain in the well permanently and, over a period of time, will decompose and possibly contribute contaminants to the monitoring zone.

9.5 Well Construction Materials

Well construction materials are chosen based on the goals and objectives of the proposed monitoring program and the geologic conditions at the site(s). In this section, the different types of available materials will be discussed.

9.5.1 Well Screen And Casing Materials

When selecting the materials for well construction, the prime concern shall be to select materials that will not contribute foreign constituents, either by leaching or sorption, into the monitoring zone and compromising the integrity of the well and future analytical data. If the monitoring program is designed to analyze for organic compounds, stainless steel materials shall be used (where applicable). If the monitoring program calls for the analyses of inorganic compounds only, then PVC materials may be acceptable. Generally, PVC materials are not acceptable for monitoring organic compounds because of their sorption and leaching properties. Another concern is to select materials that will be rugged enough to endure the entire monitoring period. Site conditions will generally dictate the kind of materials that can be used. A preliminary field investigation shall be conducted to determine the geologic conditions, so that the most suitable materials can be selected. The best grade or highest quality material for that particular application should be selected. Each manufacturer can supply the qualitative data for each grade of material that is being considered. All materials selected for monitoring well installation shall be evaluated and approved by a senior staff geologist prior to field activities.

Well screen and casing materials generally used in monitoring well construction on RCRA and Superfund sites are listed in order of preference:

(1) Stainless Steel (304 or 316)
(2) Rigid PVC meeting NSF Standard 14 (NSF WC)
(3) Other (where applicable)

There are other materials used for well screens and casings such as black iron, carbon steel, galvanized steel, and fiberglass, but these materials are not recommended for use in long term monitoring programs on hazardous waste sites because of their low resistance to chemical attack and constituent distribution to the ground water.

In addition to material selection, the minimum diameter for well screens and casings used for permanent monitoring wells shall be 2 inches (inside diameter) (ID). The wall thickness has to be considered when selecting the 2-inch well screen and casing, because a 2-inch ID screen or casing having a total wall thickness greater than 1/8 inch will make the outside diameter (OD) 2 1/4 inches which will reduce the required 2-inch annular space. This is especially true for PVC and Teflon®. Schedule 5 stainless steel, which is commonly used for permanent monitoring wells has a very thin wall thickness (approximately 1/16 inch thick) which reduces the 2-inch annular space by only 1/8 inch. However, all minimum requirements for well design and installation shall be adhered to when selecting the appropriate materials. For example, if the ID of the screen or casing is 2 inches and the OD is 2 1/2 inches, then the borehole will have to be at least 6 1/2 inches in diameter to satisfy the minimum requirements.

The length of well screens in permanent monitoring wells should be long enough to effectively monitor the interval or zone of interest. However, well screens designed for long-term monitoring purposes shall normally not be less than 5 feet in length. Well screens less that 5 feet long are routinely acceptable in temporary monitoring wells where ground water samples are collected for screening purposes only.

9.5.2 Filter Pack Materials

The filter pack materials shall consist of clean, well-rounded-to-rounded, hard, insoluble particles of siliceous composition. The required grain-size distribution or particle sizes of the filter pack materials shall be selected based upon a sieve analysis conducted on the soil samples collected from the aquifer materials and/or the formation(s) to be monitored. Filter pack materials shall not be acceptable unless proper documentation can be furnished as to the composition, grain-size distribution, cleaning procedure, and chemical analysis. If a data search reveals that there is enough existing data to adequately design the well screen and filter pack, then it may not be necessary to conduct a sieve analysis on the formation materials to be monitored. However, all data and design proposals will be evaluated and approved by senior staff geologist before field activities begin.

9.5.3 Filter Pack And Well Screen Design

The majority of monitoring wells are installed in shallow ground water aquifers that consist of silts, clays, and sands in various combinations. These shallow aquifers are not generally characteristic of sand aquifers used for drinking water. Therefore, a more technical approach rather than an estimative approach shall be taken in the design of filter packs and well screens for monitoring wells. The filter pack and well screen design shall be based (as stated above) on the results of a sieve analysis conducted on soil samples collected from the aquifer or the formation(s) that will be monitored. The data from the sieve analysis are plotted on a grain-size distribution graph, and a grain-size distribution curve is generated. From this grain-size distribution curve, the uniformity coefficient (Cu) of the aquifer material is determined. The Cu is the ratio of the 60 percent finer material (D60) to the 10 percent finer material (D10)

$$Cu = \frac{D60}{D10}$$

The Cu ratio is a way of grading or rating the uniformity of grain size. For example, a Cu of unity means that the individual grain sizes of the material are nearly all the same, while a Cu with a large

number means a large range of sizes. As a general rule, a Cu of 2.5 or less shall be used in designing the filter pack and well screen. Before designing the filter pack and well screen, the following factors shall be considered:

- Select the well screen slot openings that will retain 90 percent of the filter pack material.
- The filter pack material shall be of the size that minimizes head losses through the pack and also prevents excessive sediment (sand, silt, clay) movement into the well.
- A filter material of varying grain sizes is not acceptable because the smaller particles fill the spaces between the larger particles thereby reducing the void spaces and increasing resistance to flow. Therefore, filter material of the same grain size and well rounded is preferred.
- The filter pack design is based on the gradation of the finest aquifer materials being analyzed.

General Steps To Consider In Designing A Filter Pack:

1. Construct a grain-size distribution curve on a grain-size distribution graph from the sieve analysis of the aquifer materials. The filter pack design (as stated above) is based on the gradation of the finest aquifer materials.
2. Multiply the D30 size (from the grain-size distribution graph) by a factor of four to nine (Pack-Aquifer ratio). A factor of four is used if the formation is fine-grained and uniform (Cu is less than 3), six if it is coarse-grained and non-uniform; and up to nine if it is highly non-uniform and contains silt. Head losses through filter packs increase as the Pack-Aquifer(P-A) ratios decrease. In order to design a fairly stable filter pack with a minimum head loss, the D30 size shall be multiplied by a factor of four.
3. Plot the point from step 2 on the 30 per cent abscissa of a grain-size distribution graph and draw a smooth curve with a uniformity coefficient of approximately 2.5.
4. A curve for the permissible limits of the filter pack is drawn plus or minus 8 per cent of the desired curve with the Cu of 2.5.
5. Select the slot openings for the well screen that will retain 90 per cent or more of the filter pack material.

The specific steps and procedures for sieve analysis and filter pack design can be found in soil mechanics, ground water, and water well design books. The staff geologists and/or engineers shall be responsible for the correct design of the monitoring wells and shall be able to perform the design procedures.

9.6 Safety Procedures for Drilling Activities

A site health and safety plan shall be developed and approved by the Health and Safety Officer or designee prior to any drilling activities, and shall be followed during all drilling activities. The driller or designated safety person shall be responsible for the safety of the drilling team performing the drilling activities. All personnel conducting drilling activities shall be qualified in proper drilling and safety procedures. Before any drilling activity is initiated, the area shall be surveyed with the necessary detection equipment to locate, flag or mark, all under ground utilities such as electrical lines, natural gas lines, fuel tanks and lines, water lines, etc. Before operating the drill rig, a pilot hole shall be dug (with hand equipment) to a depth of two to three feet to check for undetected utilities or buried objects. Proceed with caution until a safe depth is reached where utilities normally would not be buried. The following safety requirements shall be adhered to while performing drilling activities:

- All drilling personnel shall wear safety hats, glasses, and steel toed boots. Ear plugs are required and shall be provided by the safety officer or driller.
- Work gloves (cotton, leather, etc.) shall be worn when working around or while handling drilling equipment.
- All personnel directly involved with the drilling rig shall know where the kill switches are located in case of emergencies.
- All personnel shall stay clear of the drill rods or augers while in motion, and shall not grab or attempt to attach a tool to the drill rods or augers until they have completely stopped rotating.
- Do not hold drill rods or any part of the safety hammer assembly while taking standard penetration tests or while the hammer is being operated.
- Do not lean against the drill rig or place hands on or near moving parts at the rear of the rig while it is operating.
- Keep the drilling area clear of any excess debris, tools, or drilling equipment.
- Do not climb on the drilling rig while it is being operated or attempt to repair the rig while it is being operated. The driller shall direct the work on the rig.
- Do not move or pickup any drilling equipment unless directed by the driller and/or the project leader.
- Each drill rig shall have a first-aid kit, and fire extinguisher located on the rig quickly accessible for emergencies.
- Work clothes shall be firm fitting, but comfortable and free of straps, loose ends, strings etc., that might catch on some moving part of the drill rig.
- Rings or other jewelry shall not be worn while working around the drill rig.

- The drill rig shall not be operated within a minimum distance of 20 feet of overhead electrical power lines and/or buried utilities that might cause a safety hazard. In addition, the drill rig shall not be operated while there is lightning in the area of the drilling site. If an electrical storm moves in during drilling activities, vacate the area until it is safe to return.

9.7 Well Development

A newly completed monitoring well should not be developed for at least 24 hours after the surface pad and outer protective casing are installed. This will allow sufficient time for the well materials to "set" and cure before development procedures are initiated. The main purpose of developing new monitoring wells is to remove the residual materials remaining in the wells after installation has been completed, and to try to re-establish the natural hydraulic flow conditions of the formation, disturbed by well construction, around the immediate vicinity of the well. The new monitoring well shall be developed until the column of water in the well is free of visible sediment, and the pH, temperature, and specific conductivity have stabilized. In most cases the above requirements can be satisfied; however, in some cases the pH, temperature, and specific conductivity stabilizes but the water remains turbid. In this case the well may still contain well construction materials, such as drilling mud in the form of a mud cake and/or formation soils, that have not been washed out of the borehole. Excessive or thick drilling muds can not be flushed out of a borehole with one or two well volumes of purge water. Continuous flushing for several days may be necessary to complete the well development. If the well is pumped to near dryness or dryness, the water table shall be allowed to sufficiently recover before the next development period is initiated. Caution should be taken when using high rate pumps and/or large volume air compressors during well development because excessive high rate pumping and high air pressures can damage or destroy the well screen and filter pack. The onsite geologist shall make the decision as to the development completion of each well. All field decisions shall be documented in the field log book.

The following development procedures are generally used to develop monitoring wells:

- Pumping
- Compressed air (with the appropriate organic filter system)
- Bailing
- Surging
- Backwashing ("rawhiding")
- Jetting

The previous methods can be used, both individually and in combination, in order to achieve the most effective well development. The selected development method(s) shall be approved by a senior staff geologist before any well installation activities are initiated.

9.8 Well Abandonment

When a decision is made to abandon a monitoring well, the borehole shall be sealed in such a manner that the well can not act as a conduit for migration of contaminants from the ground surface to the water table or between aquifers. To properly abandon a well, the preferred method is to completely remove the well casing and screen from the borehole, clean out the borehole, and backfill with a cement or bentonite grout, neat cement, or concrete. In order to comply with state well abandonment requirements, the appropriate state agency shall be notified (if applicable) of monitoring well abandonment. However, some state requirements are not explicit and are very interpretive, so a technically sound well abandonment method shall be designed based on the site geology, well casing materials, and general condition of the well(s).

9.8.1 Abandonment Procedures

The preferred method shall be to completely remove the well casing and screen from the borehole. This may be accomplished by augering with a hollow stem auger over the well casing down to the bottom of the borehole, thereby removing the grout and filter pack materials from the hole. The well casing shall then be removed from the hole with the drill rig. The clean borehole can then be backfilled with the appropriate grout material. The backfill material shall be placed into the borehole from the bottom to the top by pressure grouting with the positive displacement method (tremie method). The top two feet of the borehole shall be poured with concrete to insure a secure surface seal (plug). If the area has heavy traffic use, and/or the well locations need to be permanently marked, then a protective surface pad(s) and/or steel bumper guards shall be installed. The concrete surface plug can also be recessed below ground surface if the potential for construction activities exists. This abandonment method can be accomplished on small diameter (one-inch to four-inch) wells without too much difficulty. With wells having six-inch or larger diameters, the use of hollow stem augers for casing removal is very difficult or almost impossible. Instead of trying to ream the borehole with a hollow stem auger, it is more practical to force a drill stem with a tapered wedge assembly or a solid stem auger into the well casing and extract it out of the borehole. Wells with little or no grouted annular space and/or sound well casings can be removed in this manner. However, old wells with badly corroded casings and/or thickly grouted annular space have a tendency to twist and/or break-off in the borehole. When this occurs, the well will have to be grouted with the remaining casing left in the borehole. The preferred method in this case shall be to pressure grout the borehole by placing the tremie tube to the bottom of the well casing, which will be the well screen or the bottom sump area below the well screen. The pressurized grout will be forced out through the well screen into the filter material and up the inside of the well casing sealing holes and breaks that are present. The tremie tube shall be retracted slowly as the grout fills the casing. The well casing shall be cut off even with the ground surface and filled with concrete to a depth of two feet below the surface. If the casing has been broken off below the surface, the grout shall be tremied to within two feet of the surface and then finished to the ground surface with concrete. The surface pad or specified surface protection shall then be installed.

Well casings consisting of PVC material may be more difficult to remove from the borehole than metal casings, because of its brittleness. If the PVC well casing breaks during removal, the borehole shall be cleaned out by using a drag bit or roller cone bit with the wet rotary method to grind the casing into small cuttings that will be flushed out of the borehole by the selected drilling fluid. Another method is to use a solid-stem auger with a carbide auger head to grind the PVC casing into small cuttings that will be brought to the surface on the rotating flights. After the casing materials have been removed from the borehole, the borehole shall be cleaned out and pressure grouted with

the approved grouting materials. As previously stated, the borehole shall be finished with a concrete surface plug and adequate surface protection, unless directed otherwise.

9.9 Cleaning and Decontamination

All drilling rigs, drilling and sampling equipment, backhoes, and all other associated equipment involved in the drilling and sampling activities shall be cleaned and decontaminated before entering the designated drill site. All equipment should be inspected before entering the site to ensure that there are no fluids leaking and that all gaskets and seals are intact. All drilling and associated equipment entering a site shall be clean of any contaminants that may have been transported from another hazardous waste site, thereby minimizing the potential for cross-contamination. Before site drilling activities are initiated, all drilling equipment shall be thoroughly cleaned and decontaminated at the designated cleaning/decontamination area. The following requirements and procedures are to be strictly adhered to on all drilling activities.

Any portion of the drill rig, backhoe, etc., that is over the borehole (kelly bar or mast, backhoe buckets, drilling platform, hoist or chain pulldowns, spindles, cathead, etc.) shall be steam cleaned and wire brushed before being brought on the site to remove all rust, soil and other material which may have come from other hazardous waste sites. The drill rig and/or other equipment associated with the drilling and sampling activities shall be inspected to insure that all oil, grease, hydraulic fluid, etc., have been removed, and all seals and gaskets are intact and there are no fluid leaks. No oils or grease shall be used to lubricate drill stem threads or any other drilling equipment being used over the borehole or in the borehole without EPA approval. If drill stems have a tendency to tighten during drilling, Teflon® string can be used on the drill stem threads. The drill rig(s) shall be steam cleaned prior to drilling each borehole. In addition, all downhole drilling, sampling, and associated equipment that will come into contact with the downhole equipment and sample medium shall be cleaned and decontaminated by the following procedures.

1. Clean with tap water and laboratory grade, phosphate-free detergent, using a brush, if necessary, to remove particulate matter and surface films. Steam cleaning and/or high pressure hot water washing may be necessary to remove matter that is difficult to remove with the brush. Hollow-stem augers, drill rods, shelby tubes, etc., that are hollow or have holes that transmit water or drilling fluids, shall be cleaned on the inside and outside. The steam cleaner and/or high pressure hot water washer shall be capable of generating a pressure of at least 2500 PSI and producing hot water and/or steam (200°F plus).

2. Rinse thoroughly with tap water(potable)

NOTE: Tap water (potable) may be applied with a pump sprayer. All other decontamination liquids (D.I. water, organic-free water, and solvents), however, must be applied with non-interfering containers. These containers shall be made of glass, Teflon®, or stainless steel. This aspect of the decontamination procedures used by the driller will be inspected by the site geologist and/or other responsible person prior to beginning of operations.

3. Rinse thoroughly with deionized water.

4. Rinse twice with solvent (pesticide grade isopropanol).

5. Rinse thoroughly with organic-free water and allow to air dry. Do not rinse with deionized or distilled water.

NOTE: Organic-free water can be processed on-site by purchasing or leasing a mobile deionization-organic filtration system.

NOTE: In some cases when no organic-free water is available, it is permissible (with approval) to leave off the organic-free water rinse and allow the equipment air dry before use.

6. Wrap with aluminum foil, if appropriate, to prevent contamination if equipment is going to be stored or transported. Clean plastic can be used to wrap augers, drill stems, casings, etc., if they have been air dried.

7. All downhole augering, drilling and sampling equipment shall be sandblasted before Step #1 if painted, and/or if there is a buildup of rust, hard or caked matter, etc., that can not be removed by steam and/or high pressure cleaning. All sandblasting shall be performed prior to arrival on site.

8. All well casing, tremie tubing, etc., that arrive on-site with printing and/or writing on them shall be removed before Step #1. Emery cloth or sand paper can be used to remove the printing and/or writing. Most well material suppliers can supply materials without the printing and/or writing if specified when materials are ordered.

9. Well casing, tremie tubing, etc., that are made of plastic (PVC) shall not be solvent rinsed during the cleaning and decontamination process. Used plastic materials that cannot be cleaned are not acceptable and shall be discarded.

Cleaning and decontamination of all equipment shall occur at a designated area on the site, downgradient, and downwind from the clean equipment drying and storage area. The cleaning and decontamination area shall contain a wash water and/or waste pit excavated either with a backhoe or other heavy equipment. The pit and surrounding area shall be lined with heavy duty plastic sheeting and designed to promote runoff of the wash/rinse water into the pit. If a pit cannot be excavated, a catch basin can be constructed out of wood and lined with plastic to contain the waste/rinse water until it can be containerized. All cleaning of drill rods, auger fights, well screen and casing, etc., will be conducted above the plastic sheeting using saw horses or other appropriate means. At the completion of the drilling activities, the pit shall be backfilled with the appropriate material designated by the site project leader, but only after the pit has been sampled, and the waste/rinse water has been pumped into 55-gallon drums for disposal. No solvent rinsates will be placed in the pit unless prior approval is granted. All solvent rinsates shall be collected in separate containers for proper disposal.

Tap water (potable) brought on the site for drilling and cleaning purposes shall be contained in a pre-cleaned tank of sufficient size so that drilling activities can proceed without having to stop and haul water. A stainless steel water tank with a minimum capacity of 1,000 gallons is preferred.

All materials used in the drilling activities shall be sampled for QA/QC purposes. These materials include drilling mud (dry and wet), filter pack materials, bentonite pellets, grout (wet and dry), and the tap water from the storage tank. Other QA/QC samples shall be collected such as equipment rinse blanks, field blanks, etc., in accordance with procedures described before.

9.10 Drilling Log

A system of logging all pertinent data collected during drilling operations shall be maintained. The test hole locations should be recorded and referenced to the site map and/or datum base so that each location can be permanently established. It is imperative that drilling logs be concise, complete, and described in a manner that is easily understood to all who read them. The following items shall be included in the logging data:

- hole number and location;
- description of soils and subsurface conditions (if applicable);
- type of drilling equipment, driller, and drilling company (if applicable);
- method of drilling;
- type and size of casing;
- type and size of well screen;
- depth to well screen;
- type of pump and pumping rate;
- drilling and sampling times;
- depth to water table, and date and time measured;
- type of samples taken and depths from which taken;
- volume of water purged;
- type of well (permanent or temporary);
- type of sampling equipment and/or cleaning procedure; and
- depth of sampling and description (if applicable).

SECTION 10
AIR MONITORING SAFETY EQUIPMENT CALIBRATION PROCEDURES

10.1 General

10.1.1 Introduction

This appendix gives specific procedures to be followed when calibrating air monitoring instrumentation. The calibrations defined in these procedures will result in instrument response accuracy within the capabilities of the instruments. While it is not imperative that the instruments be capable of operating at a high degree of analytical precision and accuracy, it is necessary that calibrations demonstrate proper operation of the monitor and insure that results give an acceptably accurate indication of conditions upon which to base safety decisions and actions.

10.1.2 Calibration Gases

All calibration gasses will be certified by their supplier to be of a specified and known concentration. The concentrations of calibration gases will be within a relevant range of response for the air monitors, but will not exceed any flammability or toxic exposure limits. Calibration mixtures and approximate concentrations for specific air monitors will be as follows:

Monitor	Gas Mixture	Concentration
Combustible Gas	Pentane in Air	0.75%
Flame Ionization Detector	Methane in Air	75 ppm
Photo-Ionization Detector	Toluene in Air	100 ppm

Gas cylinders will not be sent to the field if they contain less than one-fifth of their full capacity. Cylinders below the required volume will be utilized in the warehouse for equipment checkout and maintenance.

10.1.3 Calibration Equipment

All calibrations will consist of introducing a gas of known concentration to the monitor at atmospheric pressure. Under no circumstances will it be acceptable to attempt calibration when the monitor is measuring gas concentrations below or above atmospheric pressure.

To insure stable pressure of the calibration gas, a calibration manifold system will be used. The manifold will consist of a "T" fitting, a Teflon® bag, Teflon® tubing, and fittings. The Teflon® bag is omitted for calibration of the OVA. The calibration gas cylinder will be connected to the "T" fitting with Teflon® tubing so that gas will flow straight through the top of the "T" to a Teflon® bag. The "T" fitting and tubing will be purged with calibration gas prior to connection of the Teflon® bag. The bottom or side port of the "T" will be connected via Teflon® tubing to a stainless steel quick disconnect. Once the Teflon® bag has been filled with gas, the gas cylinder flow will be

turned off. The monitor's probe will be connected to the manifold via the quick disconnect and allowed to sample the contents of the teflon bag.

10.1.4 Calibration Frequency

It is required that monitors be calibrated each time they are turned on. More frequent calibrations are encouraged if samplers feel that field conditions and hazards warrant. Frequent checking of monitor response or proper setting and operation of alarms is encouraged. Prior to turning off the monitor, a post calibration check will be performed. This check will follow the same procedures as the initial calibration except that no adjustments will be made to the monitor. Instead, the response will simple be logged in the field book.

10.1.5 Documentation

Calibrations will be documented in the field log book. The entry needs to include the following information:

Date
Time
Monitor's ID #
Battery Check Response
Alarm Response
Fuel Level (FID)
Calibration Gas Concentration
Instrument Response
Operator's Initials

10.2 Century Model Ova-128 Organic Vapor Analyzer

10.2.1 Introduction

The Century Model OVA-128 Organic Vapor Analyzer is designed to detect organic materials in air. It uses a hydrogen flame ionization detector (FID) as its detection principle. This detector allows the monitor to respond to a wide variety of organic compounds, but limits its sensitivity to around 10 ppm under ideal circumstances.

THE LACK OF A RESPONSE ON THIS METER DOES NOT GUARANTEE THAT THE ENVIRONMENT IS SAFE.

10.2.2 Operational Checks

1. Connect the hand readout unit's electrical and pneumatic fittings to the side pack assembly.

2. Connect probe to the hand readout unit.

3. Place the "PUMP" switch in the ON position. Check the battery's condition by placing the "INSTR" switch to the BATT position and observe the response on the hand readout unit.

4. Place the "INSTR" switch in the ON position.

5. Set the "Calibration Switch" the the "X10" position.

6. Use the "CALIBRATE" knob to set the readout to a reading of 6. Using the Alarm Level Adjustment Knob on the back of the readout, obtain an audible response to the reading of 6.

7. Set the "Calibration Switch" to the "X1" position.

8. Use the "CALIBRATE" knob to set the readout to a reading of 0, and check that the flame-out alarm is audible.

9. Place the "PUMP" switch in the ON position and observe that the "SAMPLE FLOW RATE" indicator shows flow.

10. Open the "H2 TANK VALVE" and the "H2 SUPPLY VALVE" one turn each. Allow fuel to flow for about 1 minute.

11. Press ignitor button and hold until readout unit indicates ignition.

12. Use "CALIBRATE" knob to set readout to a reading of 0. (Note: a small positive offset above 0 may be necessary to prevent activation of the flame-out alarm.)

10.2.3 Calibration

1. Assemble a calibration manifold as described in 10.1.3. using methane as the calibration gas. (Remember to omit the use of a Teflon® bag.)

2. Set the "CALIBRATION SWITCH" to the appropriate position for the concentration of the calibration gas. (Usually X10)

3. Connect the instrument's probe to the calibration manifold and allow it to sample the calibration gas.

4. The readout should indicate close to the concentration of the calibration gas plus any offset which may have been added.

5. Place the "CALIBRATION SWITCH" in the "X1" position before entering the site.

10.3 Photovac Tip Ii Photoionization Detector

10.3.1 Introduction

The Photovac TIP II is designed to detect primarily organic materials in air. It uses a photoionization detector (PID) as its method of operation. The instrument is capable of measuring concentrations down to about 1 ppm sensitivity for certain compounds. It is important to realize that this sensitivity is not achievable for all compounds. Some materials will result in a very low response on the PID

in relation to their actual concentrations, while others well not respond at all to the detector's ionization energy. As a general rule, the PID should not be used to monitor for compounds whose structures contain only single bonds.

THE LACK OF A RESPONSE ON THIS METER DOES NOT GUARANTEE THAT THE ENVIRONMENT IS SAFE.

10.3.2 Operational Checks

1. Press the "POWER" switch to turn the instrument on. After a few seconds, the pump motor should start running.

2. Observe that the "LOBAT" (Low Battery) indication is not displayed on the LCD.

10.3.3 Calibration

1. Unlock the "ZERO" control by turning the locking ring clockwise.

2. In a "Background" type of atmosphere, adjust the "ZERO" potentiometer until the LCD reads approximately zero. Return the locking ring to the locked position.

3. Assemble a calibration manifold as described in 10.1.3 using toluene as the calibration gas.

4. Connect the instrument's probe to the calibration manifold and allow it to sample the calibration gas.

5. The LCD should indicate close to the concentration of the calibration gas. If not, unlock the "SPAN" control by turning the locking ring clockwise. Adjust the "SPAN" control until the LCD reads approximately the concentration of the calibration gas. Return the locking ring to the locked position.

10.4 Hnu Model Pi 101 Photoionization Detector

10.4.1 Introduction

The HNU model PI 101 is designed to detect primarily organic materials in air. It uses a photoionization detector (PID) as its method of operation. The instrument is capable of measuring concentrations down to about 1 ppm sensitivity for certain compounds. It is important to realize that this sensitivity is not achievable for all compounds. Some materials will result in a very low response on the PID in relation to their actual concentrations, while others will not respond at all to the detector's ionization energy. As a general rule, the PID should not be used to monitor for compounds whose structures contain only single bonds.

THE LACK OF A RESPONSE ON THIS METER DOES NOT GUARANTEE THAT THE ENVIRONMENT IS SAFE.

10.4.2 Operational Checks

1. Connect the probe to the meter case of the instrument.

2. Place the function/range switch in the "BATT" position and note the meter's response.

3. Place the function/range switch in any of the three range positions. Listen closely to the probe for a humming sound which indicates that the sample fan is operating.

10.4.3 Calibration

1. Place the function/range switch in the "STANDBY" position. Use the "ZERO" potentiometer to adjust the meter reading to zero.

2. Assemble a calibration train as described in 3.1.3 using toluene as the calibration gas.

3. Place the instrument's function/range switch in the appropriate range for the calibration gas (usually 0-200).

4. Connect the instrument's probe to the calibration manifold and allow it to sample the calibration gas.

5. The readout should indicate close to the concentration of the calibration gas. If not, use the "SPAN" potentiometer to adjust the meter to the appropriate response.

6. Place the function/range switch in the "0-20 ppm" position before entering the site.

APPENDIX E
THEORY OF UVB SYSTEM OPERATION AND TECHNICAL LITERATURE

IN SITU GROUNDWATER REMEDIATION OF STRIPPABLE CONTAMINANTS BY VACUUM VAPORIZER WELLS (UVB): OPERATION OF THE WELL AND REPORT ABOUT CLEANED INDUSTRIAL SITES

by

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INTRODUCTION

The contamination of groundwater by strippable substances is a significant problem in all industrial countries. For remediating aquifers in situ technologies are favored to reduce the investment and operating costs. The paper presents an in situ method that can remove strippable substances, e.g. volatile chlorinated hydrocarbons, and BTEX, from the subsurface (groundwater zone, capillary fringe, and unsaturated zone); it is currently being used at numerous locations in Germany. This technology is an alternative to conventional hydraulic remediation measures (pumping, off-site cleaning, and reinfiltration of groundwater). The contaminated groundwater is stripped in situ by air in a below atmospheric pressure field within a so-called "vacuum vaporizer well" (German: Unterdruck-Verdampfer-Brunnen, UVB). The used air, charged with volatile contaminants, is cleaned using activated carbon.

The UVB technique produces a vertical circulation flow in the area surrounding the well, which catches the total aquifer. The vertical velocity component yields a desired flow through the horizontal structure of a native aquifer. Numerical results demonstrate the size of the sphere of influence and the capture zone of a well or well field; extended field measurements have been and continue to be taken (Herrling et al. 1991a).

The advantages of the UVB technique concerning the vertical circulation system around the wells instigated thought about other applications, even without stripping the groundwater. The realization of in situ biodegradation is such an example and seems to be an appropriate alternative to other existing hydraulic systems. The different nutrients and/or electron acceptors needed for biological activity can be added when the groundwater passes the well casing (Herrling et al. 1991b).

This paper presents the UVB technique for in situ removal of strippable contaminants. The circulation system, sphere of influence, and capture zone of a UVB or UVB field as essential components of the hydraulic flow system are discussed in detail. Further diagrams for dimensioning a UVB or UVB field are presented.

Two extended examples demonstrate the groundwater and soil remediation at different sites located in the Rhine-Ruhr area and in Berlin using different installations of the UVB system. The short remediation period and the low cost niveau for the UVB investment and the well operation are only two among other advantages of the UVB

technology which will be listed.

IN SITU REMEDIATION OF VOLATILE CONTAMINANTS BY TIIE UVB METIIOD

The UVB helps to remove volatile substances from the groundwater, the unsaturated zone, and the capillary fringe. When using the UVB method, a special well with two screen sections is employed, one at the aquifer bottom and one at the groundwater surface (Fig. 1) or below an aquitard in a confined aquifer. The borehole reach between the two screen sections should be made impermeable. One well should be used to remediate only one aquifer (phreatic or confined) and should not connect different aquifers.

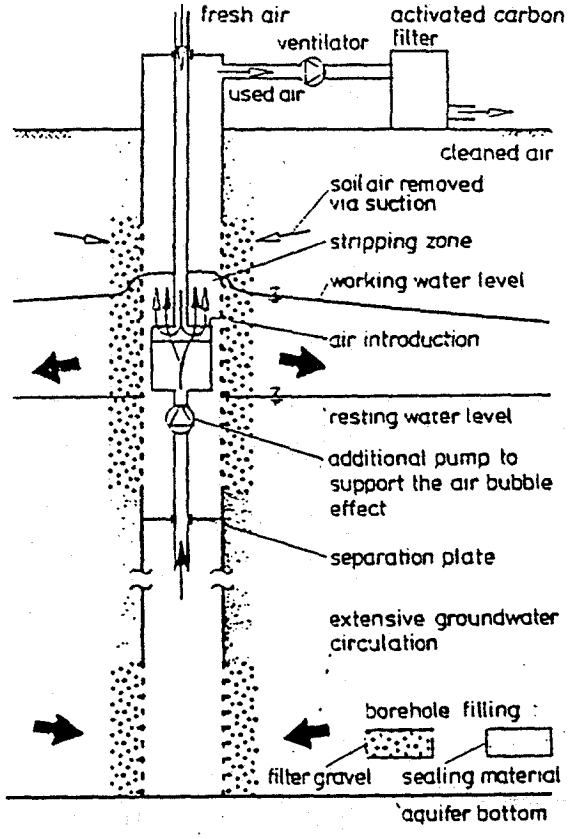

Figure 1: Vacuum vaporizer well (UVB) with additional pump and separating plate.

The upper, closed part of the well is maintained at below atmospheric pressure by a ventilator. This lifts the water level within the well casing. The fresh air for the upper part of the well casing is introduced through a fresh air pipe: the upper end is open to the atmosphere, and the lower end terminates in a pinhole plate. The height of the pinhole plate is adjusted such that the water pressure is lower there than the atmospheric pressure. Therefore, the fresh air is drawn into the system. The reach between the pinhole plate and the water surface in the well casing is the stripping zone, in which an air bubble flow develops. The rising air bubbles produce a pump effect, which moves the water up and causes a suction effect at the well bottom. In recent wells, a separating plate and an additional pump (Fig. 1) are used to reinforce the pumping effect of the air bubbles. Additionally, soil air is drawn from the surrounding

contaminated unsaturated zone at many sites. Stripped air and possibly soil air are transported through the ventilator and across activated carbon, onto which the contamination is adsorbed. Thus, only clean air escapes into the atmosphere.

The cleaning effect of the well is based on reduced pressure, which reinforces the escape of volatile contamination out of the water, and as a result of the air intermixing, onto the considerable surface area of the air bubbles and onto the concentration gradient. In this sense, the permanent vibration caused by the air bubbles is beneficial to the escape process of the contamination. This vibration is transmitted as compression and shear waves into sediment and fluid, and presumably influences the mobility of the contaminants, even outside the well.

The upward-streaming, stripped groundwater leaves the well casing through the upper screen section in the reach of the groundwater surface, which is lifted in a phreatic aquifer by the previously explained pump processes and the below-atmospheric pressure. It then returns in an extensive circulation to the well bottom. In this way, the groundwater surrounding the well is also remediated. The expansion of groundwater circulation is positively influenced by the anisotropy existing in each natural aquifer possessing greater horizontal than vertical hydraulic conductivities. The artificial groundwater circulation determines the sphere of influence of a well and is overlapped with the natural groundwater flow (as described below).

The pinhole plate and all the installations within the well casing are designed as a float so they can adjust automaticly to changing groundwater levels.

For special contaminants of lower density than water, a special installation within the well is available: the contaminated water enters the well through the upper screen, is stripped there, and with help of the additional pump, leaves the well through the lower screen. Both installations can be used within the same well casing.

At many remediation sites, the UVB is used without an additional pump and separating plate (see Fig. 2). In this case, a circulation flow occurs within the well casing, which is produced by the strong pumping effect of the rising air bubbles. For the most part, the stripped water follows the path of least resistance and flows down to the end of the suction pipe. Thus, a water of uniform temperature and oxygen content appears in the entire well casing . The water temperature is influenced by the withdrawn evaporation heat in the stripping zone and by the temperature of the fresh air. Depending on the groundwater temperature around the well, the water leaves the well casing through the upper screen section and contaminated water enters the UVB at the lower screen section. This occurs when the groundwater is colder than the circulation water in the well casing. On the other hand, when the water in the well is colder than the surrounding groundwater, an outer circulation occurs which is opposite to that shown in Figure 2. The water leaves the well at the lower screen section and enters it at the upper. Both cases, influenced by density differences of the involved water bodies, have been observed at different sites.

SPHERE OF INFLUENCE AND CAPTURE ZONE OF A UVB OR UVB FIELD

The extended circulation field outside the well is of special interest. In this paper numerical results of only UVB installations with additional pump and separation plate will be discussed (Fig. 1). The effect of the above-mentioned permanent vibrations, caused by the air bubbles, will not be considered. In principle, two different cases have

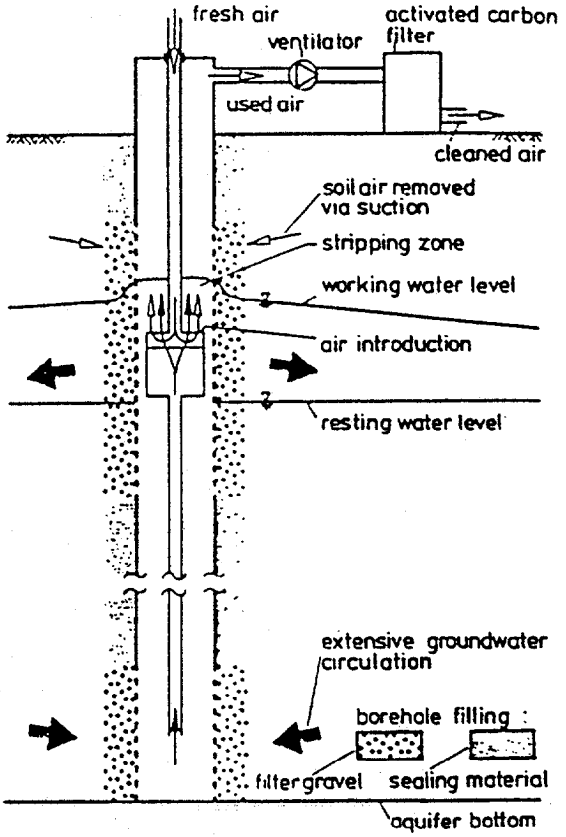

Figure 2. UVB method, driven by the air bubble effect.

been considered:

- When there is no (or negligible) natural groundwater flow, the sphere of influence (or the range, R) of a UVB is of interest.
- When natural groundwater flow is significant, the extent of the capture zone has to be determined for locating the well installations at a remediation site.

The resulting flow field of one or several UVB installations differs from the natural groundwater flow field only in a limited area around the UVB. This is because sinks and sources are located at the bottom and top of the same aquifer, each at places with the same horizontal coordinates. The effected area can, therefore, be limited to the sum of the areas of influence of all the UVBs. When only confined aquifer conditions are considered to reduce the computational effort, the flow field of each UVB can be superimposed onto those of other UVBs and of the natural groundwater flow field.

To estimate the sphere of influence and the capture zone of a UVB, numerical investigations have been performed. To calculate the complex three-dimensional flow field of a single UVB or a UVB field with minimal effort, the following simplifications and assumptions have been used:

- The aquifer thickness is constant.
- Only confined aquifer conditions are considered in the calculation, even if the natural aquifer is phreatic.
- The aquifer structure is assumed radially homogeneous to hydraulic conductivities. Horizontal layers, each with different conductivities, can be used. The hydraulic

conductivities may be anisotropic, but each horizontal layer may have only one vertical and one horizontal conductivity.

- The local below-atmospheric pressure field near the wells is neglected.
- Density effects are neglected.
- The computations assume steady-state conditions.
- For estimating the capture zone, only convective transport is considered.

The three-dimensional flow field in the above-defined, limited aquifer region is obtained by superimposition of a horizontal uniform flow field, computed in a vertical cross section and representing the natural groundwater flow, and of radially symmetric, vertical flow fields for each UVB. The superimposition of the different flow fields with their own discretization is achieved by interpolating and adding the different flow vectors at the various nodes of a simple rectangular grid with variable grid distances that are independently chosen for each Cartesian coordinate. The rectangular grid can be quickly and simply set up and allows for some refinements near the wells and their screen sections. More details of the numerical computations are given in Herrling and Buermann (1990).

Resulting Flow System

Before going into more detail, the complex flow field near an individual UVB is clarified for a vertical longitudinal section in the direction of the natural groundwater flow (symmetry plane of the flow problem). In Figure 3, the streamlines of three case studies are illustrated with Darcy velocities (v) of natural groundwater flow of 0.0 m/day, 0.3 m/day, and 1.0 m/day. All other parameters remain constant: the discharge (Q) through the well casing is 20.16 m^3/hr, the thickness (H) of the aquifer is 10 m, the anisotropic hydraulic conductivities are K_{II} = 0.001 m/sec (horizontal) and K_V = 0.0001 m/sec (vertical), and the lengths of the screen sections are a_B = 1.2 m at the bottom and a_T = 2.1 m at the top.

Figures 3b and 3c show that the groundwater, flowing from the left, dives downward to the lower screen section and is transported upward within the well casing, and that the cleaned water flows out to all sides at the upper screen section. The flow situation can only be calculated and plotted in such a simple way in this longitudinal section, otherwise the complex three-dimensional flow field has to be considered.

For a deep aquifer contaminated only in the upper groundwater zone, a UVB installation can be used at a hydraulically imperfect well. The resulting flow system is demonstrated in Figure 4, clarified for a vertical longitudinal section in the symmetry plane (Fig. 4b). The used parameters are the same as for Figure 3b. The only difference is that the aquifer thickness (H) is 30 m (well length = 10 m, as before).

At most of the UVB installation sites, a natural, nonnegligible groundwater flow will exist. For a normal withdrawal well, a separating streamline can be determined: all the water within this line is captured by the well, and all water outside of it passes the well. In principle, the situation is the same when using a UVB. In contrast to a normal withdrawal well, where the flow can be considered horizontal, the flow around a UVB must be regarded as three-dimensional. Thus, the water body, flowing toward the UVB from upstream and being captured by the lower screen section, cannot be delimited by a simple separating streamline, but by a curved separating stream surface. This can be calculated as described in Herrling and Buermann (1990): on the basis of the three-dimensional flow field, a three-dimensional, particle-tracking method is used. The

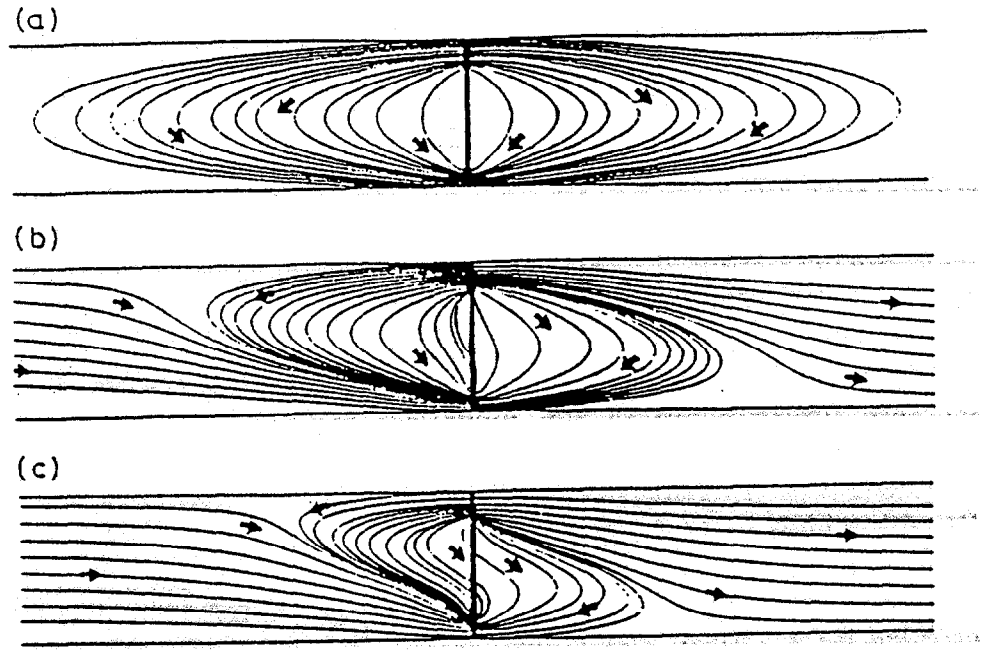

Figure 3. Streamlines clarified for a vertical longitudinal section with natural velocities: (a) 0.0 m/day; (b) 0.3 m/day; (c) 1.0 m/day.

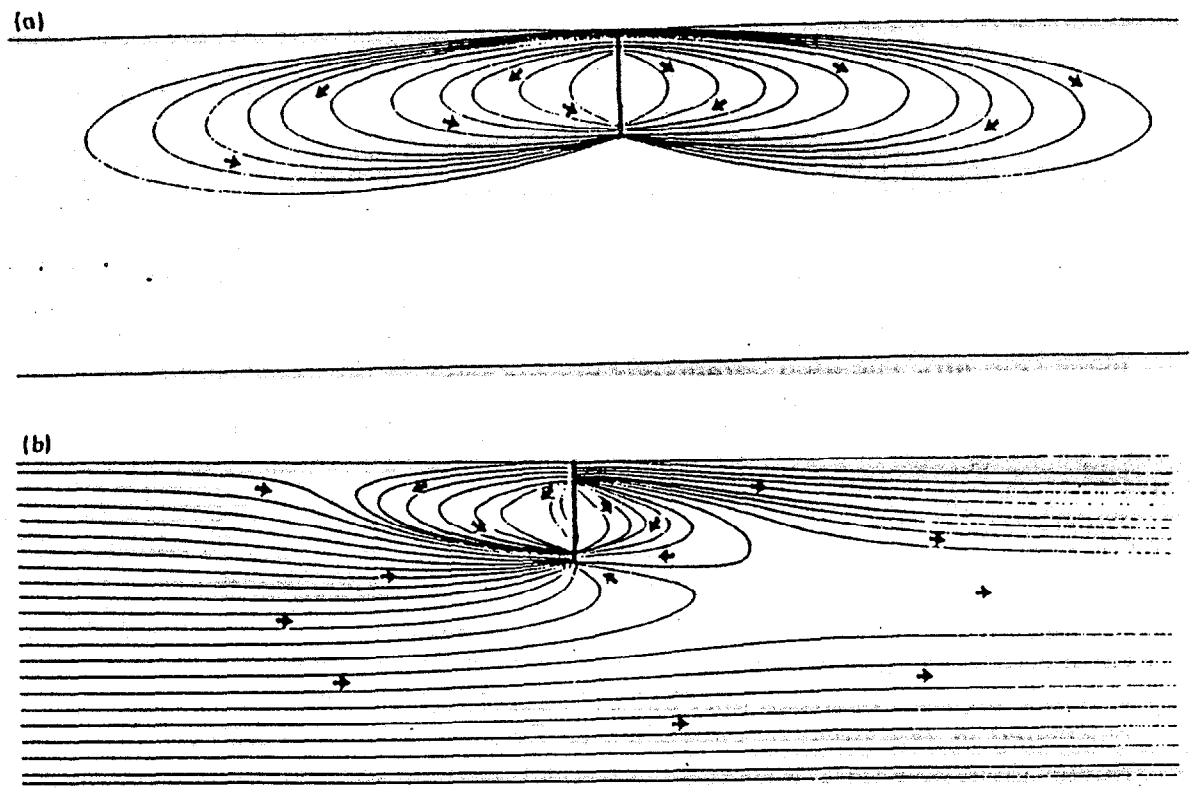

Figure 4. Streamlines at a hydraulically imperfect well clarified for a vertical longitudinal section with natural velocities: (a) 0.0m/day; (b) 0.3 m/day.

water body within the separating stream surface is captured by the UVB, and that outside of it, which flows from upstream, passes the well.

In Figure 5 the outer surface of the capture zone, calculated numerically, and the surrounding horizontal aquifer bottom and aquifer top are plotted for two situations (the natural groundwater flows from the background at the right side to the UVB, as shown by the vectors). Figures 5a and 5b were calculated for the situation described for Figure 3b; the only difference is that for Figure 5a the vertical hydraulic conductivity is K_V = 0.001 m/sec, which means the calculation is performed for isotropic conditions. The figures have a visible basis area of 50 m · 50 m (Fig. 5a) and 100 m · 50 m (Fig. 5b).

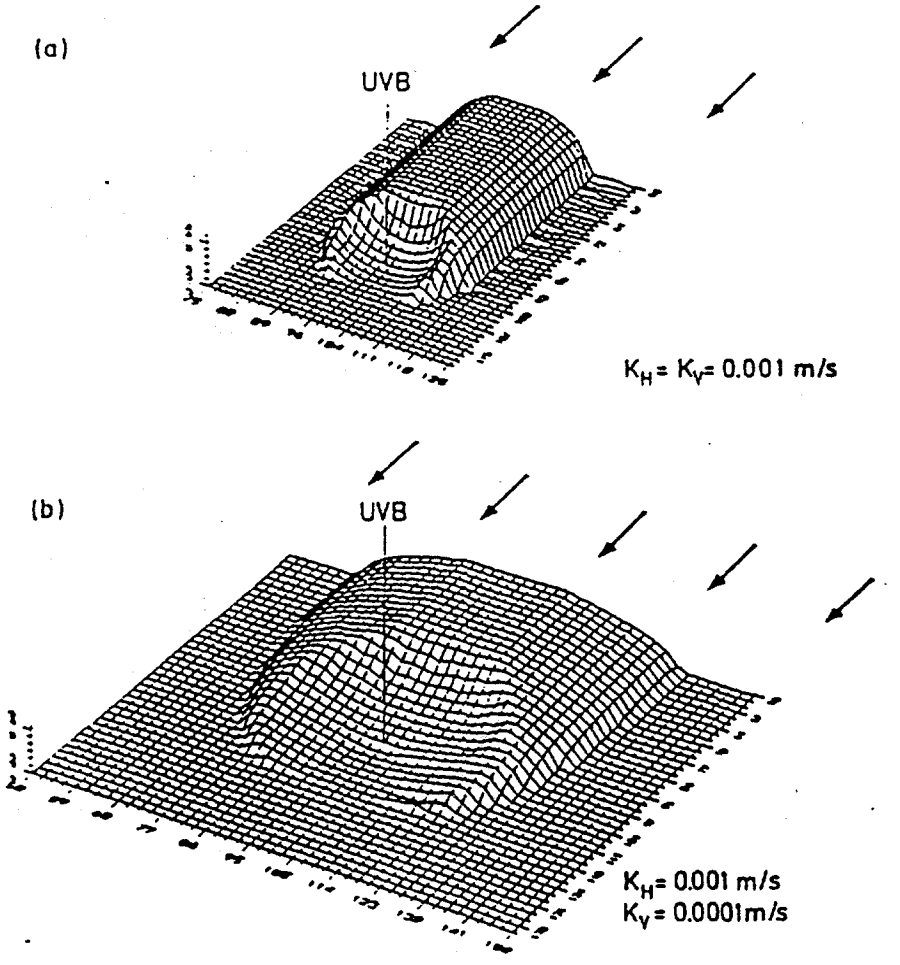

Figure 5. Separating stream surface of the capture zone for the situation of Figure 3b: (a) K_H = 0.001 m/sec (isotropic); (b) anisotropic K_H/K_V = 10.

The captured water is cleaned within the well and leaves it through the upper screen section in all directions (not shown in Fig. 5). Parts of it are again captured by the lower screen section, and the rest flows directly downstream.

If a wide plume of contaminated groundwater is to be cleaned, one UVB might not be enough to capture the whole plume. Different UVB installations can be arranged, for example, in one line normal to the natural flow. An important question concerns the maximum distance that allows no contaminated water to flow between two neighbouring wells without being cleaned. Figure 6 demonstrates such an example for the situation of

Figure 5b where the maximum well distance is 46 m. The visible basis area of Figure 6 is to 150 m · 150 m.

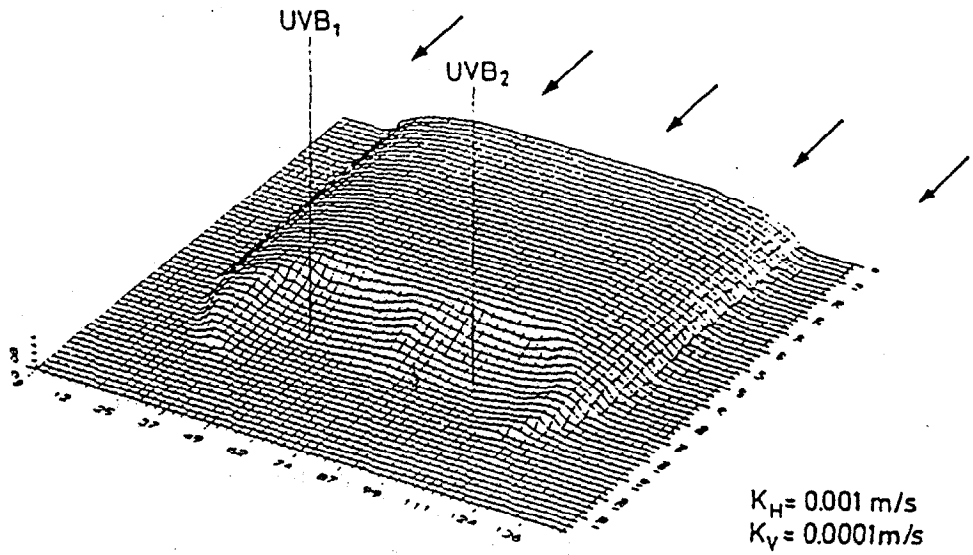

Figure 6. Separating stream surface of the capture zone for the situation of Figure 5b, but for two UVB installations at a maximum distance.

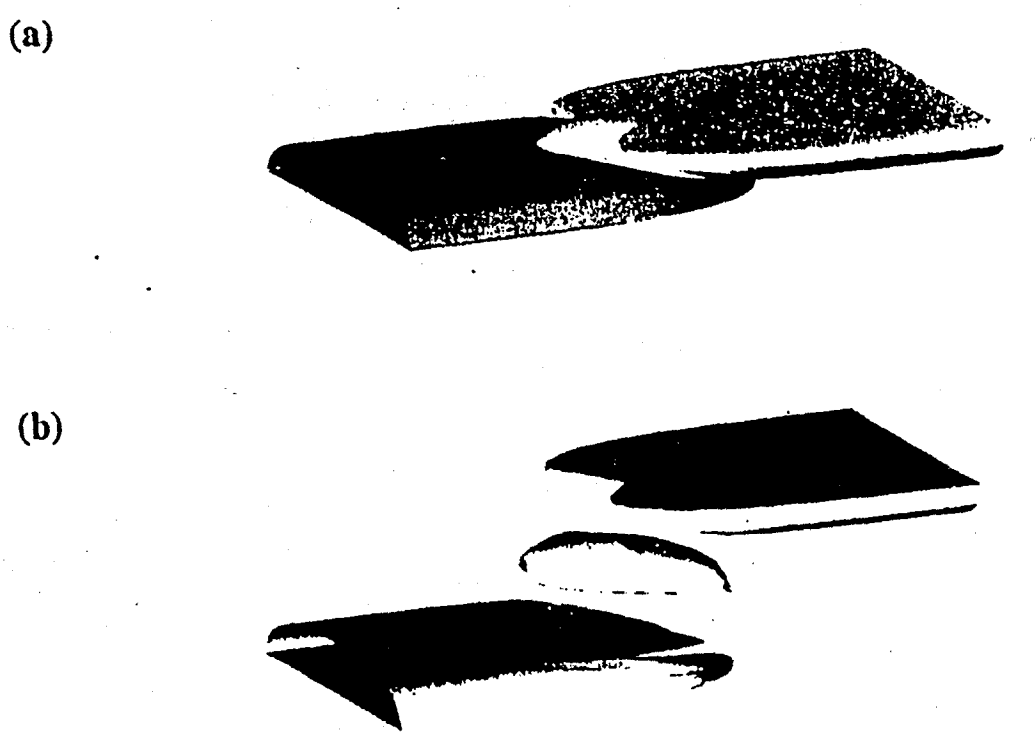

Figure 7. Separating stream surface of the different water bodies in the outside flow of a UVB: captured, circulating and flowing downstream water in (a) a real situation, and (b) water bodies separated for clarification.

Figure 7 presents a view of the separating stream surfaces of all three water bodies in connection with the flow around a UVB. The natural groundwater flow comes from the left side. (In Figure 7b the three water bodies were artificially separated for clarification.)

At the left side of Figure 7, the separating stream surface of the contaminated groundwater captured by the UVB can be seen. In the center a water body is shown which consists of cleaned groundwater and shows the circulation flow around the UVB. At the right side of Figure 7, the separating stream surface of the cleaned groundwater flowing downstream is displayed. The calculation has accounted for the following dimensionless parameters: $Q/(H^2v) = 30$, $a/H = 0.25$, and $K_H/K_V = 5$. The screen lengths at the bottom and top are the same: $a_T = a_B = a$.

Diagrams for the Dimensioning of UVB Installations

Absence of Natural Groundwater Flow. At sites without natural groundwater flow, the sphere of influence (R) of a UVB is of special interest. R is dependent on the anisotropy (horizontal over vertical hydraulic conductivity: K_H/K_V), on the thickness (H) of the aquifer, and on the length of the screen sections a_T and a_B at the top and bottom of the aquifer (see Fig. 8) or the ratio a/H (when the same length of the screen section is used for both, then only a is referred to). Although R is mathematically infinite, it is, in practice, defined as the horizontal distance from the well axis to the farthest point at which circulation flow is still significant. In a dimensionless description, R has been made dependent on the ratio Q_R/Q, where Q_R is that water quantity, which circulates within the distance R from the well. The ratio Q_R/Q, which is prescribed for practical reasons, describes the strength of a circulation flow at the distance R from the well.

In Figure 9a, results are presented for ratios $Q_R/Q = 0.98$ and 0.8 and for $a = a_T = a_B$ in a dimensionless diagram. The sphere of influence (R) is independent of the discharge through the well, but strongly dependent on the anisotropy K_H/K_V. Within usual proportions, the length of the screen sections has only a small influence. For a UVB with separating plate and additional pump, a totally screened well casing should be avoided because of hydraulic shortcircuiting.

Figure 9b presents a dimensionless diagram that describes the differences (Δh) of the hydraulic heads between the top and bottom of a double-screened well through which

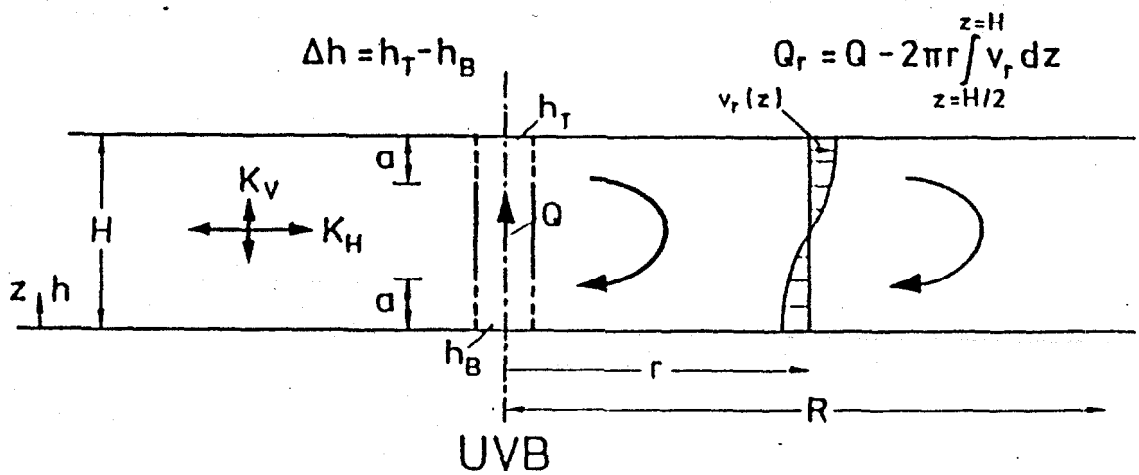

Figure 8. Notation in a vertical cross section.

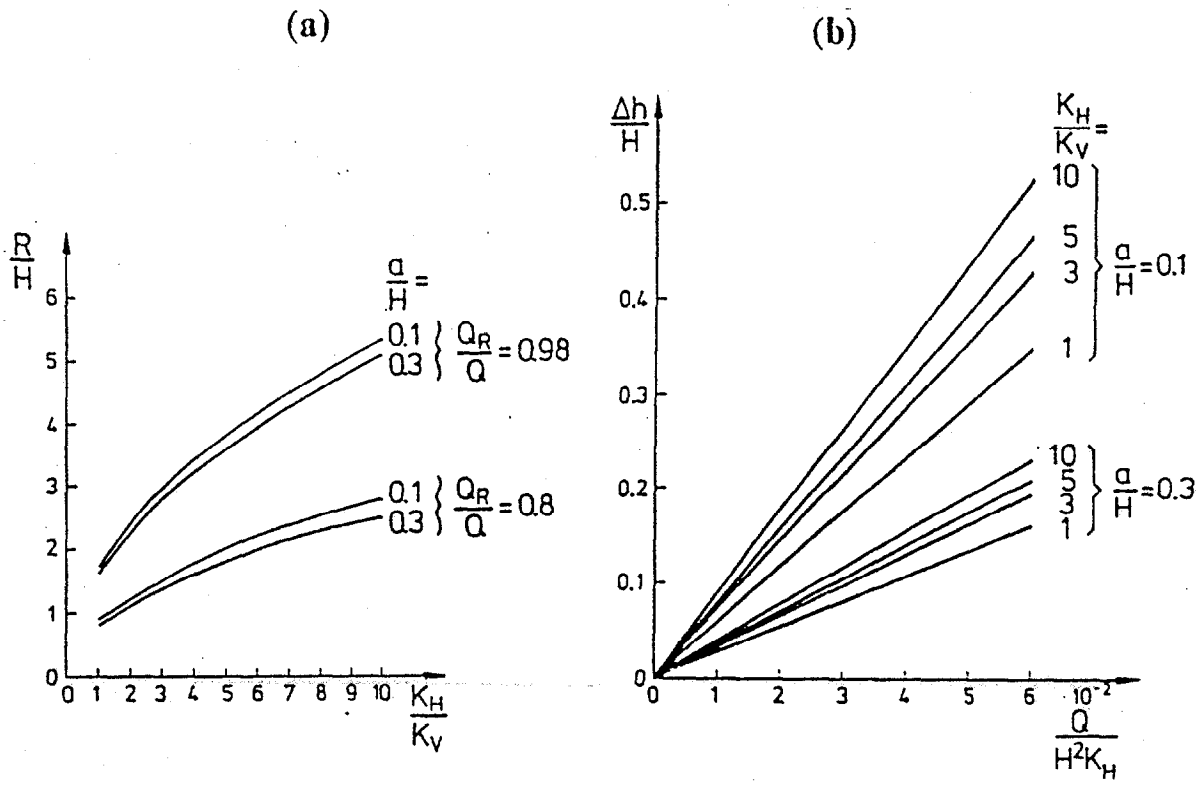

Figure 9. (a) Sphere of influence (R) for a site without natural groundwater flow, (b) differences (Δh) of the hydraulic heads between the top and bottom of a well.

a discharge (Q) is pumped. Δh is dependent on the parameter $Q/(H^2K_{II})$ and the ratios K_{II}/K_V and a/H. Abiding by the above-described assumptions, the rise of the hydraulic head at the top of the well amounts to $\Delta h/2$, and the decrease is $-\Delta h/2$ at the bottom (both referring to the position of rest). When using the UVB for stripping, the falling, stripped water in the reactor causes a dynamic effect that will influence the upper hydraulic head within the well.

For the dimensioning or examination of a site, Figure 9b is a valuable expedient. When K_{II} is known (e.g., by pump test) - along with H, Q, and a - Figure 9b and the measured Δh allow an estimate of the anisotropy at a site.

Presence of Natural Groundwater Flow. At most remediation sites a natural groundwater flow exists. Figure 11 shows numerical results represented in dimensionless form for the dimensioning of UVB installations under these conditions. Figure 10 introduces the notations for an upstream cross section through the capture zone normal to the natural groundwater flow direction (comparable with the open influx region to the left of the capture zone in Figure 7) for one and two UVB installations. It is often the case when remediating a wide contamination plume, that several wells are used in a line normal to the direction of the natural groundwater flow. The length (D) denotes the maximum well distance at which the contaminated groundwater cannot pass between the wells without being cleaned. The results of Figure 11 have been calculated for an upstream distance

of 5H from the well and for a constant ratio of a/H = 0.25 (screen length over aquifer thickness). The results are discussed for wells which pump upward.

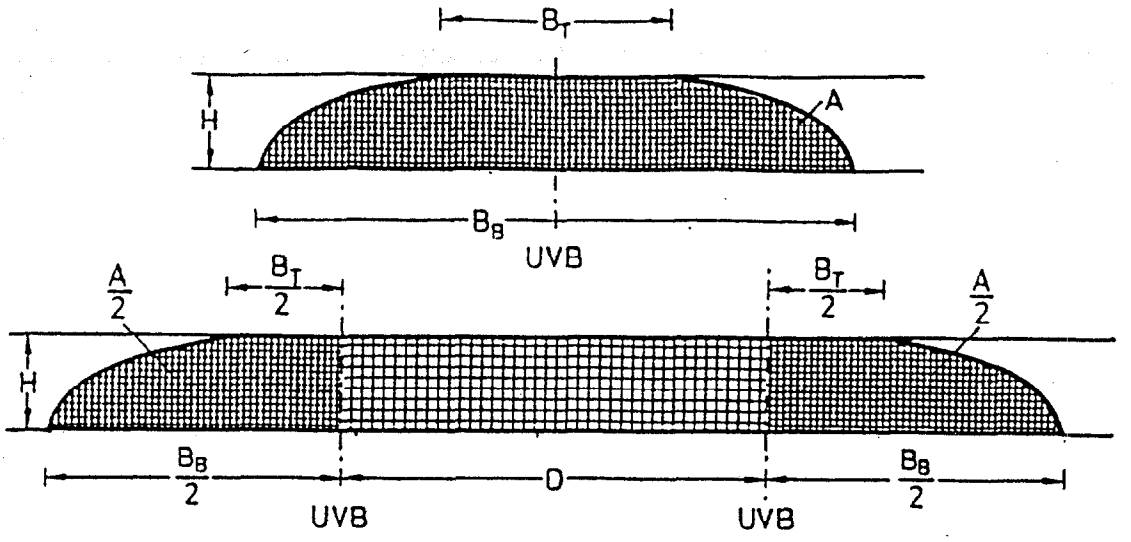

Figure 10. Notations in an upstream cross section through the capture zone for one and two UVB installations (for wells pumping upward).

The widths B_T and B_B of the upstream capture zone, measured at the aquifer top and bottom, are shown in Figure 11a. The ratios B_T/H and B_B/H are dependent on the ratios $Q/(H^2v)$, K_H/K_V, and a/H. v denotes the Darcy velocity of the natural groundwater flow; all other variables are explained above. For small values of $Q/(H^2v)$, the upper part of the capture zone does not reach the top of the aquifer. This implies that for remediating a plume, a minimum well discharge (Q) is required. Again, the results are quite sensitive to the degree of the anisotropy (see Fig. 5, as well).

Figure 11b shows the results for the influx area (A) of the upstream capture zone, and Figure 11c the maximum well distance (D) of two wells between which contaminated groundwater cannot pass without being treated. The ratios A/H^2 as well as D/H are dependent on the same parameters as the widths B_T and B_B. When a plume of width W is to be cleaned, the number (n) of UVB installations can be estimated by $n = (W-B_T)/D+1$.

When a plume is remediated, the contaminated water of quantity Q_o, flowing into the capture zone of a UVB from upstream, is diluted with water that has already flowed through the well and circulates around the UVB. Thus, the contaminant concentration of the water within the well casing will be lower than in the upstream plume; near a contamination source the situation is contrary. Figure 11d illustrates the portion Q_o of the total well discharge Q. The ratio Q_o/Q is again dependent on the same parameters as the widths of the upstream capture zone. Figure 11d can be used to estimate the expected concentration value of the water within the well casing for the dimensioning of a UVB installation. It may help to evaluate the progress of remediation at a site when concentration data of the upstream plume and the water within the well are determined.

In Figure 12 the upstream distance (S) of the stagnation point at the aquifer top from the well axis is described (see Fig. 3b and 3c, as well). The ratio S/H is also dependent on the parameters $Q/(H^2v)$, K_H/K_V, and a/H. The location of the stagnation

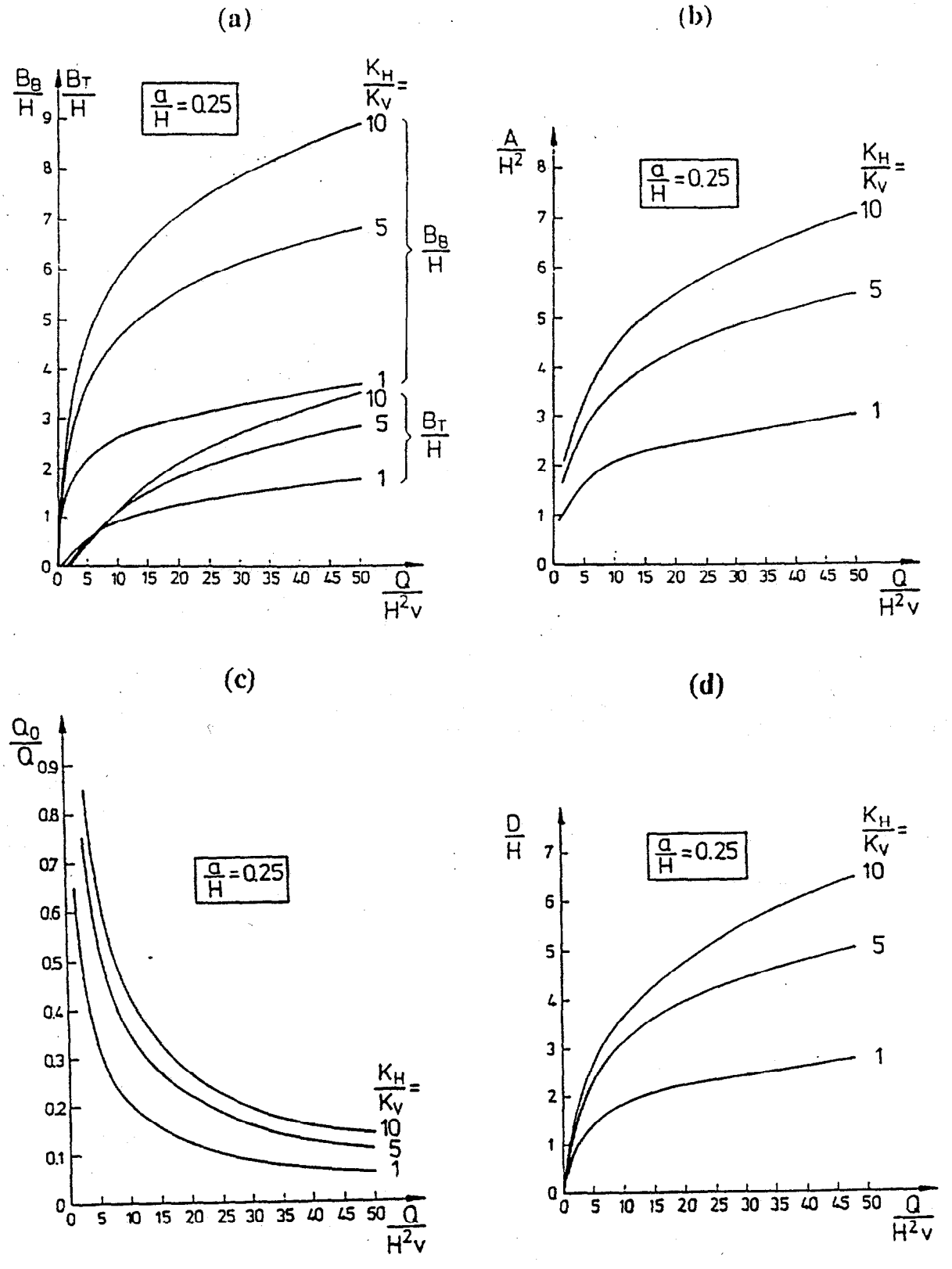

Figure 11. (a) Widths B_T and B_B of the upstream capture zone at the aquifer top and bottom; (b) Influx area A of the upstream capture zone; (c) Maximum well distance (D) at which the contaminated groundwater cannot pass between the wells without being treated; (d) Upstream discharge (Q_o) in the capture zone, which is diluted with the circulating water to the total well discharge (Q).

point is highly sensitive to the anisotropy of the aquifer. The length of the screen section is of small importance within usual proportions (as described above). The knowledge of the distance (S) from the stagnation point can be used to determine the positions of measuring equipment. The operation of a UVB can also be supervised using depth-dependent measurements between the stagnation point and the well.

The sphere of influence of the circulation around a UVB at sites with natural groundwater flow is of special interest. This sphere of circulation is limited in a quite different way than at a site with absence of natural flow (Fig. 9a) as can be seen in Figures 3b, 3c, 4b, and 7. In the direction of natural groundwater flow, this sphere has a maximum expansion of (S) (see Fig. 12) to the upstream and downstream sides. Normal to this direction, the maximum radius of the sphere of circulation is approximated by $(B_n+B_r)/4$ (Fig. 11a), and, in the case of several wells in one line, by D/2 (Fig.11c).

Figures 9, 11, and 12 can be used for the dimensioning of a UVB or UVB field when the parameters K_H/K_V and $Q/(H^2v)$ can be estimated, where Q depends on the well size and on the additional pump. For an irregular well field, a layered aquifer, or special critical cases, numerical calculations can be performed.

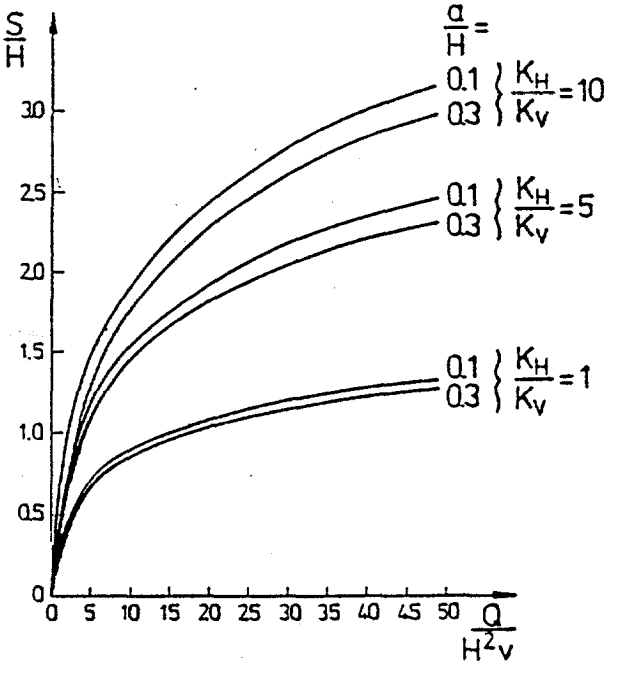

Figure 12. Upstream distance (S) of the stagnation point from the well axis.

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Numerical Results of Calculated 3D Vertical Circulation Flows Around Wells with Two Screen Sections for In Situ or On-Site Aquifer Remediation

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INTRODUCTION

Three-dimensional vertical circulation flows around wells with two screen sections in one aquifer, so called "groundwater circulation wells" (German: Grundwasser-Zirkulations-Brunnen, abbreviation: GZB), are an important subject of numerical investigation. Originally this flow system has been used only for in situ remediation of aquifers from strippable contaminants in so called "vacuum vaporizer wells" (German: Unterdruck-Verdampfer-Brunnen, abbreviation: UVB), but in the meantime the application of this technique has been generalized (Herrling et al. [1,2]). Often these flow systems are situated at several locations beside one another and are located within a natural groundwater flow field. The circulation flow around the wells is initiated by vertical pumping measures within the well casing. Normally, the two screen sections are placed at the bottom and top of an aquifer.

At numerous locations in Germany and recently in the United States, among other countries, this technology is used for physical and/or recently for biological in situ groundwater remediation. This includes in situ stripping of volatile organic compounds, e.g. chlorinated hydrocarbons, and BTEX, in the vacuum zone of the upper well casing of a UVB (see figure 1a) or in situ biodegradation by controlled addition of nutrients and/or electron acceptors as the groundwater passes through the well casing of a GZB (figure 1b) thus using the aquifer as a bioreactor. The same hydraulic circulation system has been utilized for special in situ cleaning treatments of groundwater between the two screen sections while the water passes through the well casing.

When on-site remediation techniques should be used, e.g. for the elimination of dissolved heavy metals from the groundwater, the same technique of a GZB as explained before can be utilized: The groundwater entering the well is pumped above ground, treated, and infiltrated into the same well using the other well screen.

Furthermore, following these ideas, the GZB can be advantageously used as a pump or infiltration well for standard on-site remediations (figure 2). In this case, a partial discharge withdrawal or infiltration is taken from or added to the total discharge through the well casing. There exists the possibility to extract or to infiltrate water without any change of heads at the well top for a special ratio between the extracted or infiltrated and the circulating quantity of water. Of course, at a certain distance from the well a smooth deviation of the groundwater table from the resting position will be found. But in the case

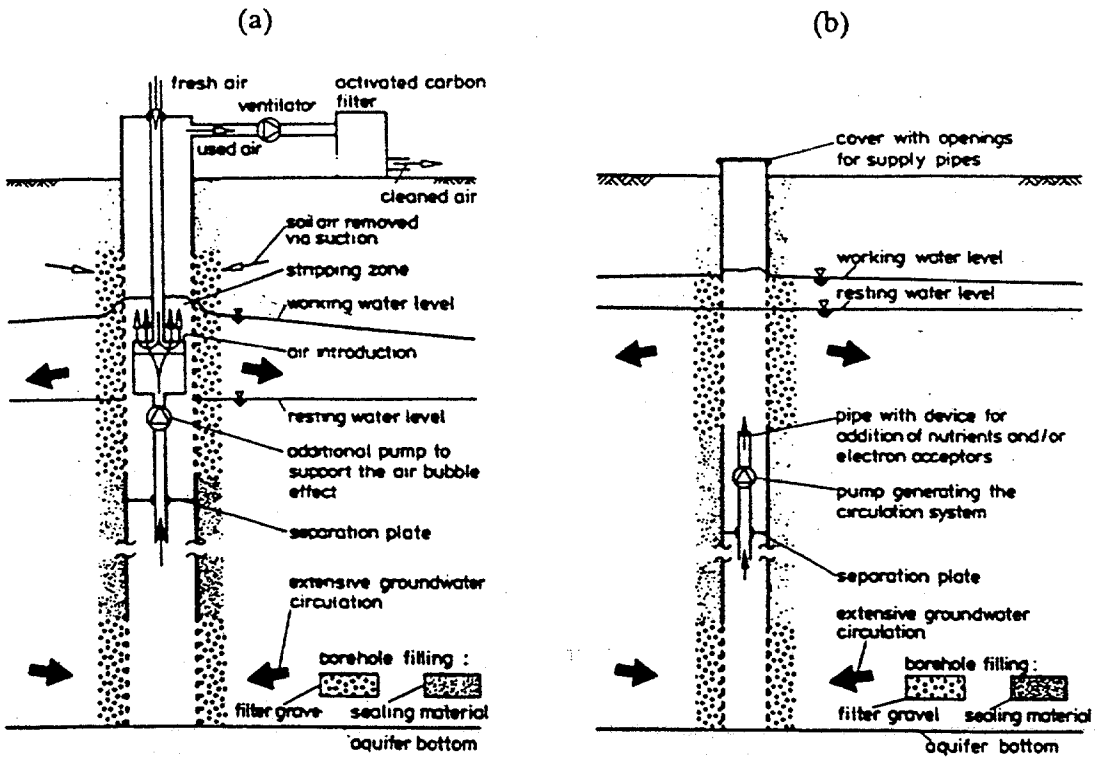


Fig. 1 (a) Vacuum vaporizer well (UVB) for in situ stripping of volatile substances; (b) circulation system for in situ biodegradation using the groundwater circulation well (GZB)

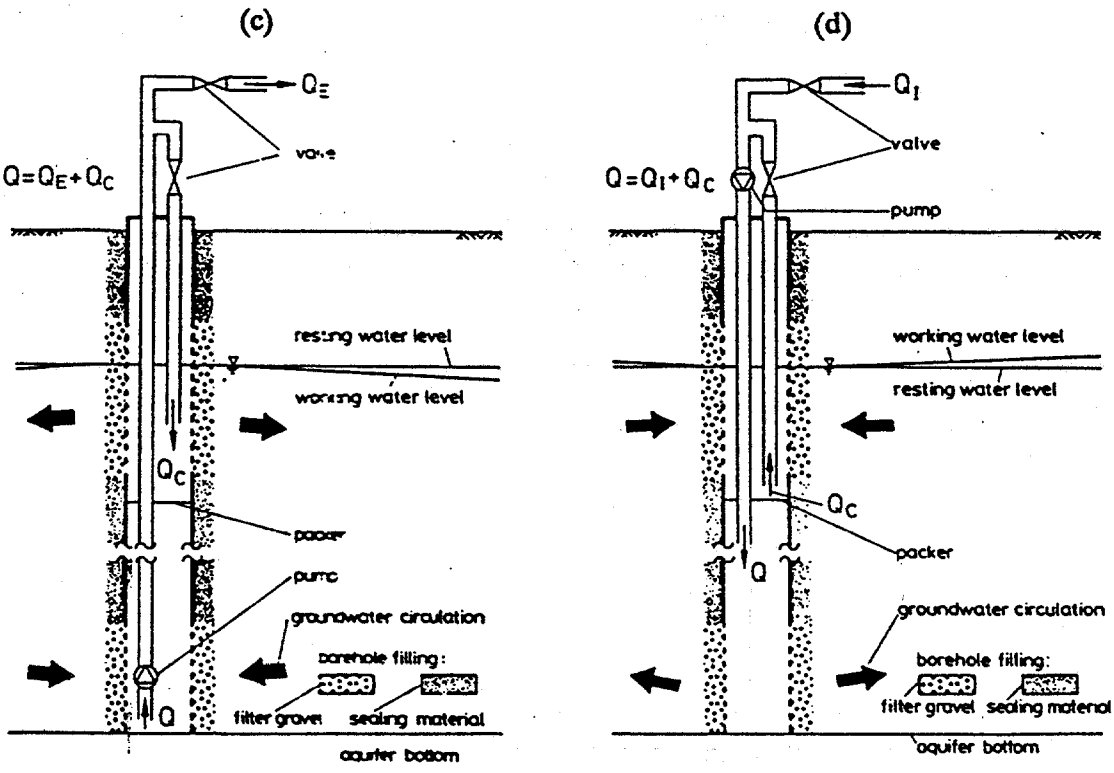


Fig. 2 Groundwater circulation wells (GZB) for (a) extraction and (b) infiltration of water avoiding head changes at the well top

of low well capacity, the pumping operation is continuous for a much higher rate and the infiltration can be realized for a much greater quantity even for a low distance between surface and groundwater table. For pumping wells, being operated as demonstrated in figure 2a, a strongly lowered groundwater table at the well can be avoided and thus the common problem of iron or manganese precipitation or of clogging by calcium carbonate due to the mixing of air and groundwater within the well can be prevented to the greatest extent possible.

All the technologies described above are patented, see acknowledgement.

SCOPE AND CONCEPTION OF THE NUMERICAL INVESTIGATIONS

Around the GZB a vertical circulation flow exists as a result of the vertical pumping in the well casing. The sphere of influence and the capture zone in the presence of a natural groundwater flow at a site are of great interest for describing such flow systems. For the latter, the distance between the well axis and stagnation point, the maximum distance between wells arranged normal to the natural groundwater flow direction such that no groundwater can pass between the wells without having been treated, and the dilution ratio of the upstream discharge in the capture zone and the circulating water are important. Further, the change of heads at the well should be investigated for the case of pumping through the well casing alone or in combination with an additional extraction or infiltration of water. For the latter, the knowledge of the greatest deviation of the heads from the resting position and its distance from the well axis are of significance. Here, the case where the heads at the well top remain unchanged should be investigated.

The great scope of numerical investigations of partial three-dimensional flow systems makes it absolutely essential, as a first step, to use some suitable simplifications and assumptions to reduce the numerical effort. The initial objective consisted of explaining the general features of such circulation systems and of determining universal results using simple dimensionless diagrams.

The most essential simplification is that only confined aquifer conditions have been investigated. In this case, the circulation flow around each well can be calculated radial symmetrically and the total field of different, mutually influenced wells together with the natural horizontal groundwater flow field can be calculated by superposition of the simple starting systems. For this each individual flow system must have the same aquifer thickness and is limited to a radial symmetric description of the hydraulic properties. Anisotropy and horizontal layers can exist. This is not an important restriction because the range of the circulation flow is limited and has a maximum extent of about five times the aquifer thickness around each well. The calculations are carried out for steady state conditions, and only convective transport is considered for estimating the capture zone. Furthermore, for the computation of the flow field around a UVB the assumption is used that the local below atmospheric pressure field can be neglected.

The radial symmetric calculation is based on the equation

$$\frac{\partial}{\partial r}\left(2\pi r k_r \frac{\partial h}{\partial r}\right) + \frac{\partial}{\partial z}\left(2\pi r k_z \frac{\partial h}{\partial z}\right) = 0 \qquad (1)$$

formulated in cylindrical coordinates. h defines the piezometric heads, and k_r and k_z the anisotropic hydraulic conductivities (see fig. 3). Boundary conditions are

$$h - \bar{h} = 0 \quad \text{and} \quad v_i n_i + \bar{v} = 0 \tag{2}$$

The bar denotes prescribed values (see fig. 3), v_i the velocity vector and n_i the unit vector normal to the boundary. For the extraction or infiltration well the boundary condition at the right boundary of figure 3 is described by a flux condition

$$\bar{v} = \lambda\,(\bar{h} - h) \tag{3}$$

(see equation 2). This artificially enlarges the model area to reduce the influence of the boundary on the results. λ defines the quotient of the horizontal hydraulic conductivity and the distance between the required and the real boundary and $\bar{h}$ the groundwater head at the required boundary (resting water level).

The numerical computation of the radial symmetric flow has been performed using a Galerkin finite element method with linear shape functions and triangular elements. The above mentioned superposition of the different flow fields has been realized on a simple rectangular three-dimensional discretization with variable grid distances by interpolating and adding the respective velocity vectors. Thus complex 3D flow fields, e.g. defined on 200,000 grid points, can be computed simply, quickly, and sufficiently exact.

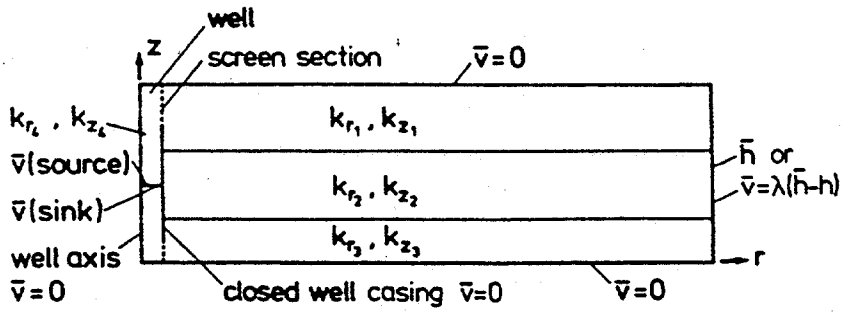


Fig. 3 Radial symmetric flow domain and boundary conditions

A simple particle tracking method has been used to calculate the capture zone, etc. by a large number of streamlines. The curved separating stream surface of the capture zone (see figure.4) is found by an automatic search process starting from the influx boundary. For various heights, the extreme streamlines which barely terminate in the well screen are searched. Each streamline is integrated with an explicit Euler method using small integration steps. A Runge-Kutta method of the fourth order gives the same results but needs much more computer time.

The maximal distance between wells such that no groundwater can pass between them without having been treated is found by an iterative scheme. Corresponding iterations have been realized to find the ratio between extracted or infiltrated and circulating water where no change of heads appears at the well top.

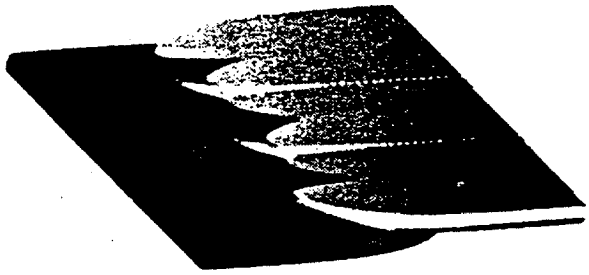
NUMERICAL RESULTS

Resulting flow system of a GZB without extraction or infiltration

The complex flow field around three GZB units is demonstrated by presenting a perspective view on the respective curved separating stream surfaces of all nine water

bodies involved (figure 4). The natural groundwater flow comes from the left side. In figure 4b the downstream water bodies are artificially separated for clarification. At the left side of figure 4, the separating stream surfaces of the contaminated groundwater captured by one of the three wells each can be seen. In the center, the surfaces of three water bodies are shown which contain cleaned or treated groundwater and demonstrate the circulation flow around the wells; the three wells are located in their respective centers (see figure 4b). At the right side of figure 4, the separating stream surfaces of the cleaned or treated groundwater flowing downstream are displayed. The upper and lower surfaces coincide with the aquifer top and bottom. The well distances are maximized so that no water can pass between the wells without having been treated. The calculation was performed using the parameters: $Q/(H^2v) = 16.1$, $a/H = 0.25$, and $K_H/K_V = 10$. Q denotes the vertical discharge through one well, H the aquifer thickness, v the natural Darcy velocity at the site, a the length of the upper or lower screen section, and K_H and K_V the horizontal and vertical hydraulic conductivities.

(a)



(b)

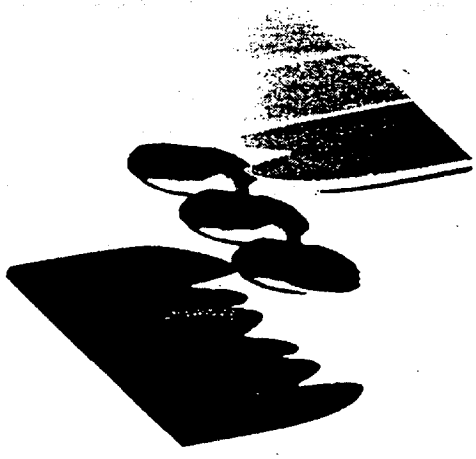


Fig. 4 Separating stream surfaces of the different water bodies in the outside flow around three GZB units: captured, circulating, and flowing downstream water in (a) a real situation and (b) water bodies separated for clarification

Absence of natural groundwater flow. At sites without a natural groundwater flow, the sphere of influence (R) of a GZB is of special interest. The dimensionless parameter R/H is dependent on the anisotropy K_H/K_V and on the dimensionless screen length a/H, see figure 5a. Although R is mathematically infinite, it is, in practice, defined as the horizontal

distance from the well axis to the farthest point at which the circulation flow is still significant. In a dimensionless description, R depends on the ratio Q_R/Q, where Q_R is the circulating water quantity within the range R. The ratio Q_R/Q, which is only defined for practical reasons, describes the strength of a circulation flow at the distance R from the well. In figure 5a, results are presented for the ratios Q_R/Q = 0.98 and 0.8 in a dimensionless diagram. The sphere of influence (R) is independent from the discharge through the well, but strongly dependent on the anisotropy K_H/K_V. Within usual proportions, the length of the screen sections has only a small influence. A totally screened well casing should be avoided because of the possibility of hydraulic short-circuiting.

Figure 5b presents a dimensionless diagram which describes the differences (Δh) of the hydraulic heads between the top and bottom of a GZB through which a discharge (Q) is pumped. Δh or the dimensionless parameter Δh/H is dependent on the parameter $Q/(H^2K_H)$ and the ratios K_H/K_V and a/H. For screens arranged symmetrically, the rise of the hydraulic head at the top of the well amounts to Δh/2, and the decrease is -Δh/2 at the bottom (both referring to the position of rest). When using the GZB for stripping (UVB), the falling, stripped water in the reactor causes a dynamic effect that will influence the upper hydraulic head within the well. For the dimensioning or examination of a specific site, figure 5b is a valuable expedient. When K_H is known (e.g. by pump test) - along with H, Q, and a - figure 5b and the measured Δh allow an estimate of the anisotropy at a specific site.

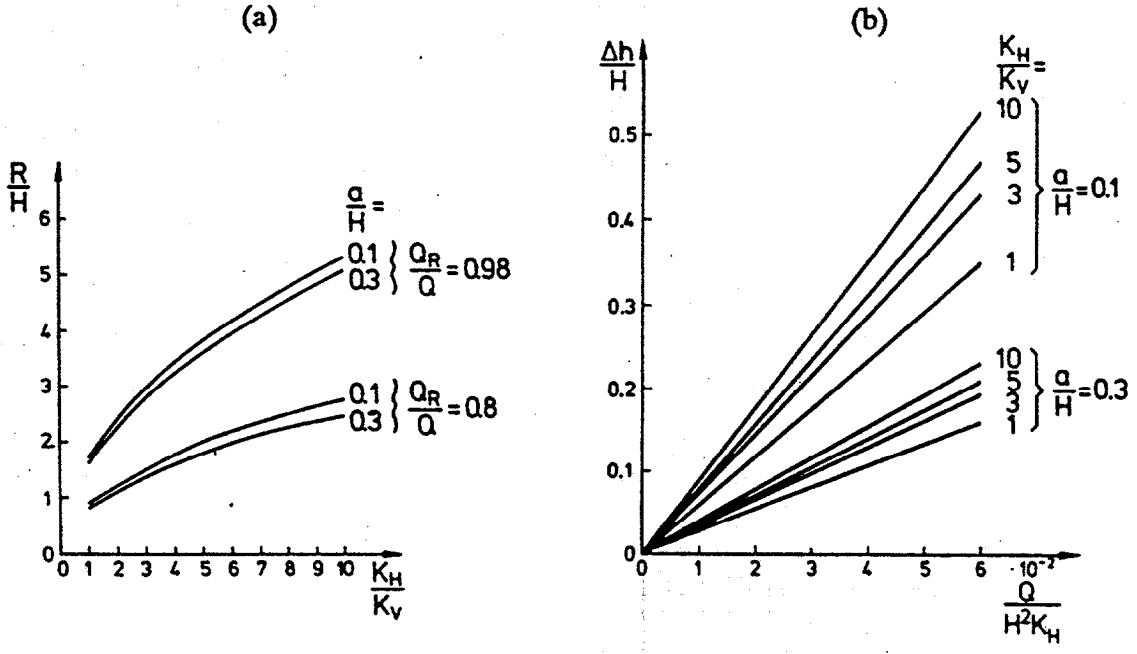


Fig. 5 (a) Sphere of influence (R) for a site without natural groundwater flow, and (b) differences (Δh) of the hydraulic heads between the top and bottom of a GZB

Presence of natural groundwater flow. At most remediation sites, a natural groundwater flow exists. Figure 6 shows numerical results represented in dimensionless form for the dimensioning of GZB installations under these conditions. In figure 6a, the horizontal distance (S) of the stagnation point from the well axis is described. The ratio S/H is

dependent on the parameters $Q/(H^2v)$, K_H/K_V, and a/H (for the definitions of these variables see above). The location of the stagnation point is highly sensitive to the anisotropy of the aquifer. The length of the screen section is of small importance within usual proportions (as described above). The knowledge of the distance (S) from the stagnation point can be used to determine the positioning of the measuring equipment. The operation of a GZB can also be monitored using depth-dependent measurements between the stagnation point and the well.

The results of figure 6b-d have been calculated for an upstream distance of 5H from the well and for a constant ratio of a/H = 0.25. The results are discussed for wells that pump upward. The widths B_T and B_B of the upstream zone, measured at the aquifer top and bottom, are shown in figure 6b. The ratios B_T/H and B_B/H are again dependent on the ratios $Q/(H^2v)$, K_H/K_V, and a/H. For small values of $Q/(H^2v)$, the upper part of the capture zone does not reach the top of the aquifer. This implies that for remediating a plume, a minimum well discharge (Q) is required. Again, the results are quite sensitive to the degree of the anisotropy.

When remediating a wide contamination plume, several wells are used in a line normal to the direction of the natural groundwater flow. The length (D) denotes the maximum well distance at which the contaminated groundwater cannot pass between the wells without being cleaned or treated. The ratio D/H is dependent on the same parameters as before. When a plume of width W is to be cleaned, the number (n) of well installations can be estimated by $n = (W-B_T)/D+1$.

When a plume is remediated, the contaminated water of quantity Q_0, flowing into the capture zone of a single well from upstream, is diluted with water that has already flowed through the well and circulates around it. Thus, the contaminant concentration of the water within the well casing will be lower than in the upstream plume; near a contamination source the situation is reversed. Figure 6d illustrates the portion Q_0 of the total well discharge Q. The ratio Q_0/Q is again dependent on the same parameters as the widths of the upstream capture zone. Figure 6d can be used to estimate the expected concentration value of the water within the well casing for the dimensioning of a well installation. It may help to evaluate the progress of remediation at a site when concentration data of the upstream plume and the water within the well are determined.

The sphere of influence of the circulation around a GZB at sites with natural groundwater flow is of special interest. In the direction of natural groundwater flow, this sphere has a maximum expansion of S (see figure 6a) to the upstream and downstream sides. Normal to this direction, the maximum radius of the sphere of circulation is approximated by $(B_B + B_T)/4$ (figure 6b), and in the case of several wells in one line by D/2 (figure 6c).

Figures 5 and 6 can be used for the dimensioning of one GZB or a GZB field when the parameters K_H/K_V and $Q/(H^2v)$ can be estimated, where Q depends on the well size and on the additional pump. For an irregular well field, a layered aquifer, or special critical cases, additional numerical calculations can be performed.

Groundwater extraction or infiltration using a GZB

Presently, numerical results are only available for the case of absence of natural groundwater flow and for confined aquifer conditions (see above). When a GZB (figure 2a) is used to split the vertical well discharge (Q), pumped from the lower screen section, into a quantity (Q_E) which is extracted and an amount (Q_C) which is infiltrated in the upper screen section and which generates the circulation flow around the well, the

possibility exists to avoid any change of heads at the well top for a special ratio of Q_E/Q_C. This ratio is only dependent on K_H/K_V and a/H. Figure 7a demonstrates for a/H = 0.25, Q_E can be about two to three times of Q_C depending on the aquifer anisotropy. For this special ratio of Q_E/Q_C, the decrease of the head at the well bottom (no change of the

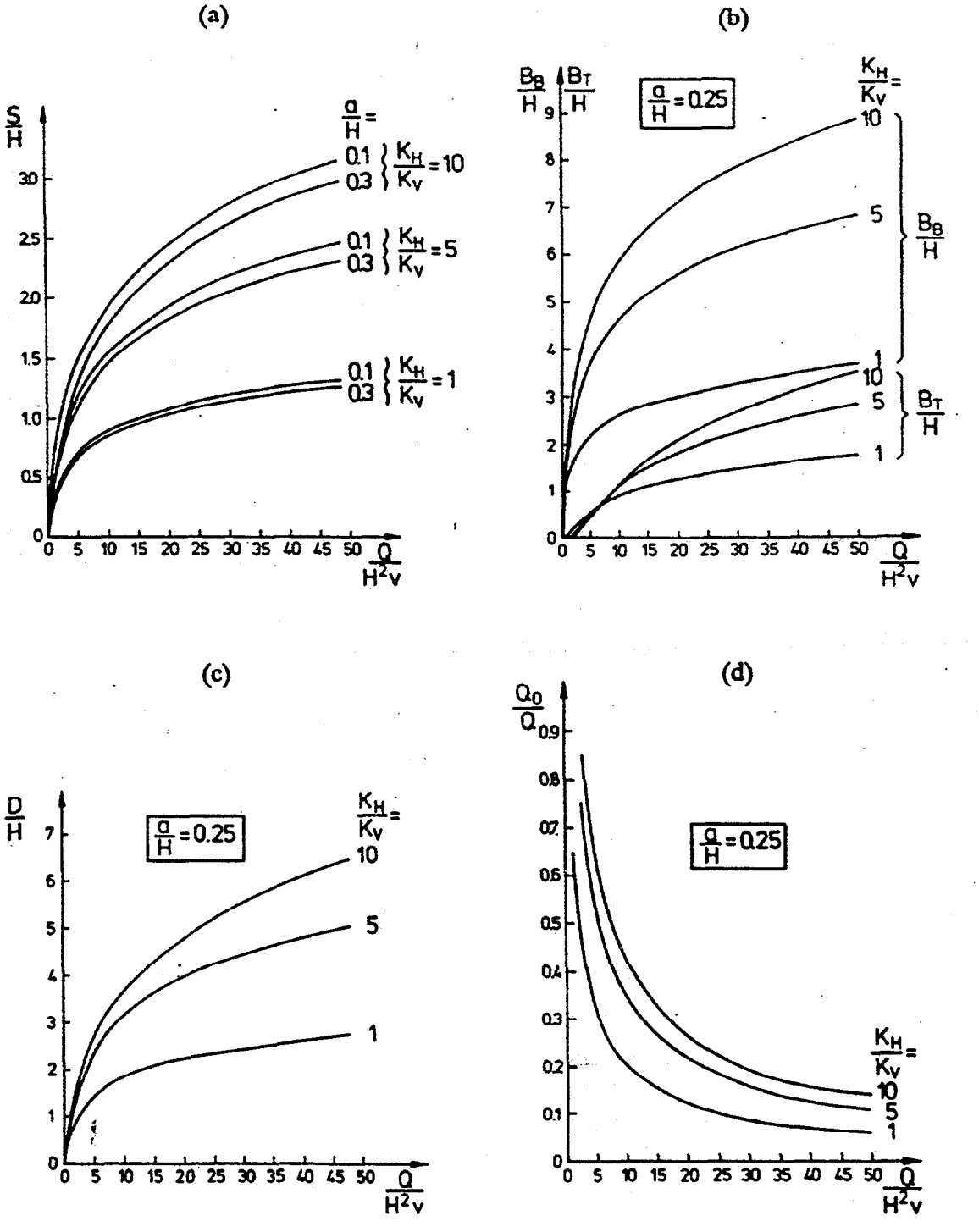


Fig. 6 (a) Distances (S) of the stagnation point from the well axis, (b) widths(B_T) and (B_B) of the upstream capture zone at the aquifer top and bottom, (c) maximum well distance (D) at which the contamintated groundwater cannot pass between the wells without being treated, (d) upstream discharge (Q_0) in the capture zone, which is diluted with the circulating water to the total well discharge (Q)

heads at the well top) is -Δh (figure 7b). In a dimensionless description, Δh/H is dependent on the parameters $Q_E/(H^2K_H)$, K_H/K_V, and a/H (figure 7b: a/H = 0.25). Using this diagram, an important check of whether the danger of cavitation will be existing below the packer can be carried out.

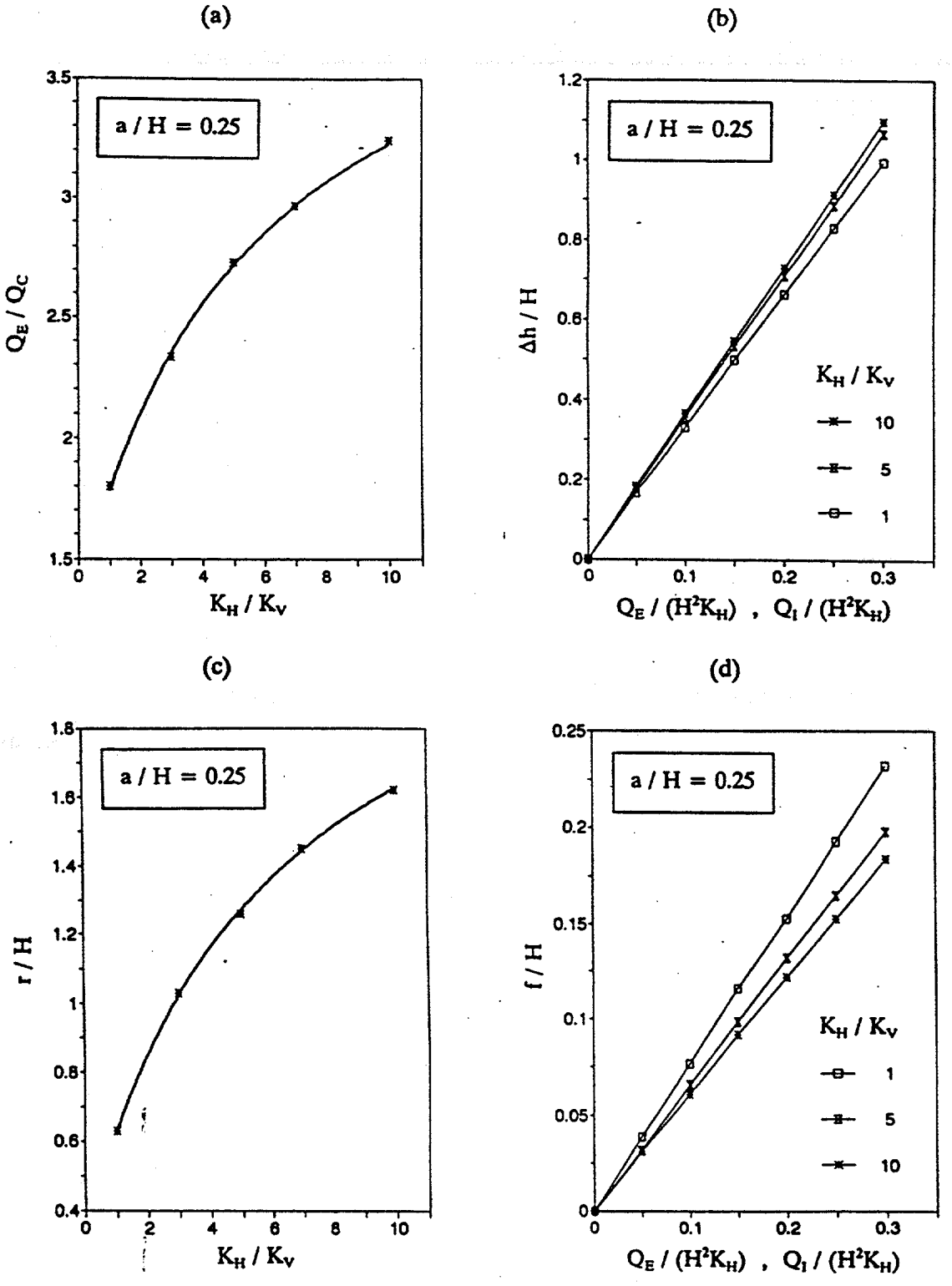


Fig. 7 (a) Ratio Q_E/Q_C and Q_I/Q_C for no head change at the well top, (b) head changes Δh at the well bottom, (c) distance r from the well axis with maximum head deviation f, and (d) maximum head deviation f

In case of infiltration of a quantity (Q_I) in a GZB (figure 2b), the ratio Q_I/Q_C can be taken from the diagram of figure 7a as well, when no change of heads are demanded at the well top. In this case, Q leaves the GZB through the lower screen and Q_C enters the well through the upper screen. The increase of head Δh at the well bottom can be estimated from figure 7b.

In some distance (r) from the well axis, a maximum head deviation (f) from the resting water level will result at the aquifer top. The dimensionless parameter r/H is dependent on K_H/K_V and a/H, and f/H (negative for groundwater extraction and positive for infiltration) depends on $Q_E/(H^2K_H)$, K_H/K_V and a/H. Figures 7c and 7d represent results for a/H = 0.25.

When a groundwater extraction Q_E (or Q_I) is prescribed, the resulting changes of heads at the bottom and top of a GZB can be calculated for any Q by using the diagrams of figure 5b, 7a and 7b as individual results can be superposed. Another case is to prescribe Q_E (or Q_I) and a maximum change of head at the bottom or top of a GZB and to estimate Q. In both cases the values of H, K_H and K_V must be known.

CONCLUSION

The broad applicability of vertical circulation flow systems around groundwater circulation wells (GZB) have been shortly demonstrated for various in situ and on-site remediation techniques. On the basis of confined aquifer conditions the resulting 3D flow systems for one and several GZB units have been characterized (sphere of influence, capture zone, head changes, etc.) by dimensionless diagrams as a result of extended numerical computations. By that, remediation measures can be dimensioned. One of the surprising results is that well extraction or infiltration is possible without head changes at the well top which will have considerable significance in practice. The capture zone of a circulating pumping well in a natural groundwater flow field is going to be investigated.

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REFERENCES

[1] Herrling, B., Stamm, J., Bürmann, W.: "Hydraulic Circulation System for In Situ Bioreclamation and/or In Situ Remediation of Strippable Contamination", in: "In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation", ed. by R.E. Hinchee and R.F. Olfenbuttel, Butterworth - Heinemann, Boston, pp. 173-195, 1991.

[2] Herrling, B., Stamm, J., Alesi, E.J., Brinnel, P.: "Vacuum Vaporizer Wells (UVB) for In Situ Remediation of Volatile and Strippable Contaminants in the Unsaturated and Saturated Zone", Proc. of the Symposium on Soil Venting, April 29 - May 1, 1991, Houston/Texas (USA), published by US EPA, in press, 1992.

Modeling the Free Surface of an Unconfined Aquifer Near a Recirculation Well

by Thomas R. MacDonald and Peter K. Kitanidis[a]

Abstract

We examine flow in an unconfined aquifer near a recirculation well, which consists of a source and a sink of eq discharge, with emphasis on understanding the behavior of the free surface. The well is vertical with a pump located betw an inlet above and an outlet below to induce recirculation of ground water and thus enhance mixing. The boundary elem method is used to model the flow with the free-surface boundary condition. Numerical simulations show that for arrangement there is a critical pumping rate beyond which the free surface becomes unstable and is drawn down to the w The value of this critical rate as well as the maximum drawdown of the phreatic surface were determined for a rang well-screen (inlet and outlet) separations. In addition to the numerical model, we developed an analytical approximation yielded an estimate of the critical pumping rate. The analytical estimate is shown to be in reasonably good agreement with numerical results. We also examined the effect of approximating the free-surface boundary by a horizontal confining la The radius of influence of a single well source-sink pair was only slightly affected by making this approximation, as lon the pumping rate remained below the critical value.

Introduction

In situ ground-water bioremediation is becoming an increasingly popular option for cleanup of various contaminants. It has been applied to cases of hydrocarbon contamination (Raymond et al., 1976; Thomas and Ward, 1989) and more recently, to cases of halogenated organics (Roberts et al., 1989; Vogel et al., 1987). In applications of enhanced in situ remediation, it is necessary to create a flow system to effectively mix nutrient-rich water with the ground water. One such method involves the use of a recirculation unit that consists of a well with two screen sections and a pump located in between. Water flows into one of the screens, nutrients and growth substrates are added, and the enriched ground water is pumped into the aquifer through the second screen (see Figure 1).

An important consideration in modeling the flow around the recirculation unit is the free-surface boundary. In practice, it is convenient to approximate the free surface as a fixed horizontal impermeable boundary because it is simpler to model and faster to compute. Herrling et al. (1991) modeled the flow of a recirculation system as confined, but it is unclear to what extent their results are a cable to unconfined formations. Another important te cal consideration is the possibility of downconing of th surface to the intake screen, when the intake is close t surface, allowing air into the well. This paper provides

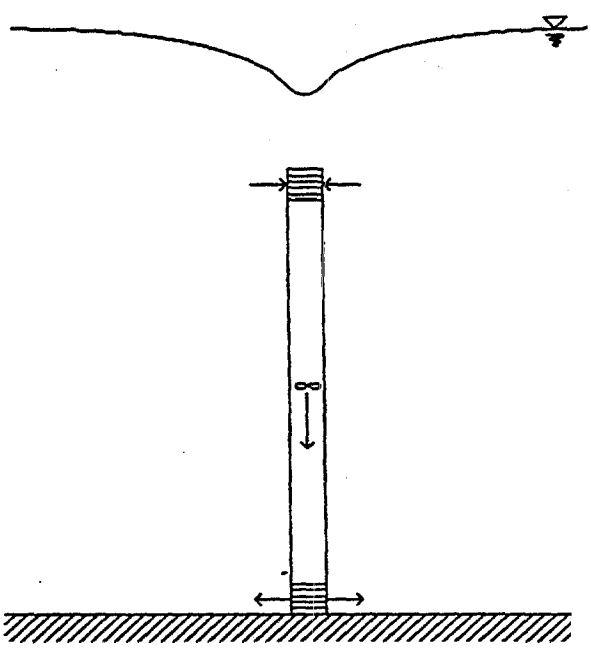

Fig. 1. Schematic of a recirculation unit.

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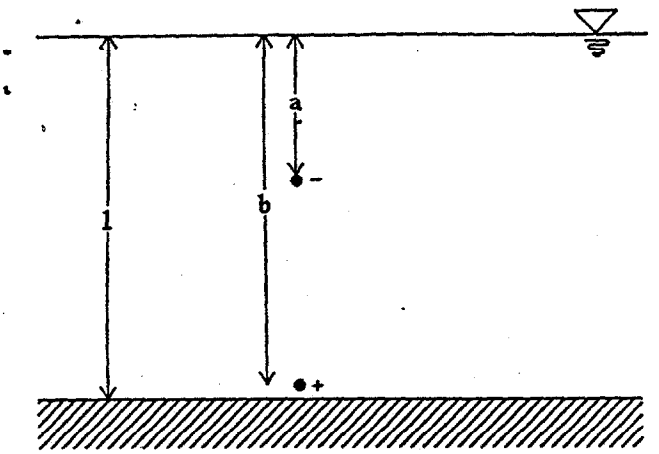

Fig. 2. Source/sink doublet in an unconfined aquifer.

basic guidelines for when the free surface should be modeled as such and when the free surface will be drawn down to the well screen.

Modeling Methodology and Cases

Flow Domain and Nondimensionalization

We can model the flow accounting for the finite lengths and diameters of well screens. However, our experience indicates that in practice the two most important parameters are the intake screen depth and the pumping rate, whereas the screen diameters and lengths have a much less significant effect on the flow, except near the screens. Given that the objective of this paper is to evaluate the free-surface boundary, we will approximate the recirculation unit openings as a point sink and a point source of equal intensity (discharge). In this work, we will consider that the sink is above the source.

A homogeneous, horizontally isotropic aquifer is considered. We note that any horizontal to vertical anisotropy can be handled by the change of variables to an isotropic system with the conversion (Strack, 1989): $Z = \beta Z^*$ where $\beta = \sqrt{K_H/K_V}$ and (X, Y, Z^*) are the actual coordinates, and (X, Y, Z) are the coordinates in the isotropic system; the equivalent conductivity is $K = \sqrt{K_H K_V}$.

The system is nondimensionalized as follows:

$$x = \frac{X}{H} \tag{1a}$$

$$y = \frac{Y}{H} \tag{1b}$$

$$z = \frac{Z}{H} \tag{1c}$$

$$\phi = \frac{\Phi}{H} \tag{1d}$$

$$q = \frac{Q}{KH^2} \tag{1e}$$

where H is the undisturbed saturated thickness of the aquifer, K is the conductivity, Φ is the hydraulic head, and Q is the pumping rate. The nondimensional depth to the sink is a, and the nondimensional depth to the source is b (see Figure 2). The depth to the source was chosen as b = .99 for several reasons. The greater the separation between the source and the sink, the larger the radius of influence (i.e., the radial distance within which most of the flow passes). A large radius of influence is desired in treating an aquifer, so locating the source near the bottom of the aquifer will better approximate most actual remediation setups. Maintaining a consistent source depth also makes the effects of changing the sink depth clearer.

Regional flow is neglected for several reasons: (1) the local flow created by the recirculation unit will dominate most realistic background flows near the well, (2) we can use an axisymmetric model that is less computer intensive than a fully three-dimensional model, and (3) we can focus on the effects of the two most important parameters, q and a.

Test Case

Next, we will describe a test case, for which an analytical solution can be found, that will be useful in validating the results of the numerical model. The equation describing the potential, ϕ, within a domain containing point sources and point sinks is

$$\nabla^2\phi = -\sum_{i=1}^{n} q_i \delta(x - x_i, y - y_i, z - z_i) \tag{2}$$

where n is the number of point sources and sinks in the domain, (x_i, y_i, z_i) is the location of the i^{th} sink, and q_i is the pumping rate (positive for a source, negative for a sink) (Muskat, 1982; Polubarinova-Kochina, 1962). The solution of this equation in an infinite domain is

$$\phi(x, y, z) = \sum_{i=1}^{n} \frac{q_i}{4\pi} \cdot \frac{1}{\sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2}} + \phi_0 \tag{3}$$

While analytical solutions to the confined case can be found by the method of images, solutions for the unconfined case are not available except for cases with very small q. The solution for small q, obtained from a first-order perturbation, is for all practical cases the same as the solution for the confined case. Consider a point sink located at (x_w, y_w, z_w) in an idealized aquifer that is infinite in horizontal extent and in depth. A horizontal confining layer is located at elevation z = 0. To compensate for this impermeable boundary, an image sink is needed at $(x_w, y_w, -z_w)$ to meet the boundary condition, $(\partial\phi/\partial z) = 0$ on z = 0. The hydraulic head is given by superposition as

$$\phi(x, y, z) = \frac{q}{4\pi}\left[\frac{1}{\sqrt{(x - x_w)^2 + (y - y_w)^2 + (z - z_w)^2}} + \frac{1}{\sqrt{(x - x_w)^2 + (y - y_w)^2 + (z + z_w)^2}}\right] + \phi_0 \tag{4}$$

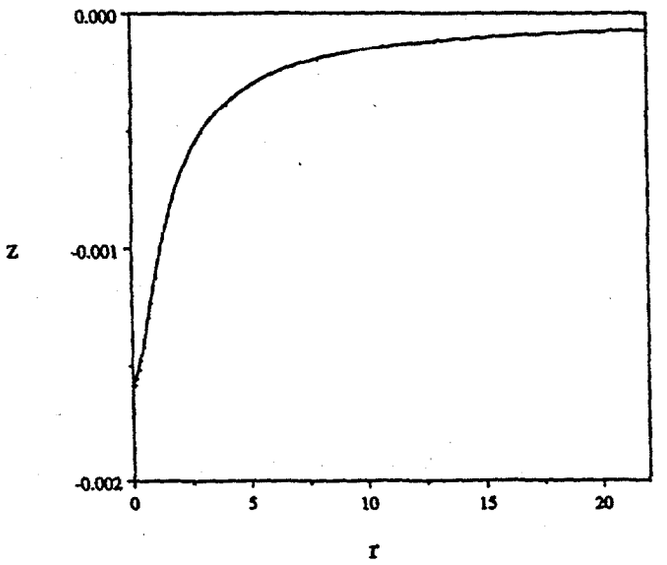

Fig. 3. Analytic approximation to free surface created by a point sink at z = −1, q = −.01, in a semi-infinite aquifer.

ϕ_0 is chosen to equal zero, and the point sink is located at (0, 0, −1). Then

$$\phi(x, y, z) = \frac{q}{4\pi}\left\{\frac{1}{\sqrt{x^2 + y^2 + (z-1)^2}} + \frac{1}{\sqrt{x^2 + y^2 + (z+1)^2}}\right\} \quad (5)$$

This equation is the first term in an expansion of the free-surface solution with a power series in terms of q. If the nondimensional q is much smaller than one (i.e., Q is small, H is large, and/or K is large), then higher order terms can be neglected, and the unconfined aquifer behaves approximately as the confined aquifer since the free surface will be nearly horizontal.

It is important to understand the validity of these approximations to an aquifer that is unconfined. The largest deflection of the horizontal free surface due to the point source will occur right above this point source at x = 0 and y = 0. For this approximation to be truly valid, q → 0, so that $\phi = 0$ at z = 0 on the free surface. For nonzero q, the value of ϕ is

$$\phi = \frac{q}{2\pi} \quad (6)$$

It is evident that for $q \ll 1$, the deflection is insignificant so that the approximation should have a negligible effect on the computed value of ϕ.

The free-surface deflection for a point sink can be calculated from equation (5) by setting $\phi = z$ on the free surface and solving the polynomial for z using a Newton-Raphson routine. The analytic approximation to the free surface created by the presence of a point-sink is shown in Figure 3. This solution will be used later for comparison with the numerical model.

The Axisymmetric Boundary Element Method

Because analytic approximations for unconfined aquifers are limited, the boundary element method (BEM) is used to solve the unconfined cases. The BEM has been used successfully to model ground-water flow for many different situations, including cases with a free surface (Lennon, 1980; Liggett and Liu, 1983; Lennon and Du, 1986). The BEM involves discretizing only the boundary of the domain and is particularly efficient at determining the free surface. Bakr (1986) provides details for the axisymmetric boundary element method. The results in this paper are based on a code written by the authors.

The main advantage of this method is that it effectively reduces the domain that needs to be discretized by one dimension since it uses a boundary rather than a domain approach. This is achieved through the use of Green's second identity:

$$\int_\Omega (\phi\nabla^2 G - G\nabla^2\phi)\, d\Omega = \int_\Gamma \left(\phi \frac{\partial G}{\partial n} - G\frac{\partial \phi}{\partial n}\right) d\Gamma \quad \ldots . (7)$$

where ϕ is the hydraulic head, G is the Green's function, Ω is the domain, and Γ is the boundary of the domain. Since $\nabla^2\phi = 0$ is the governing equation within the domain, and $\nabla^2 G = -\delta(x - x_i, y - y_i, z - z_i)$ by definition, the domain integral can be simplified.

For the axisymmetric case, equation (7) reduces to

$$-\alpha\phi(r_i, z_i, t) + \sum_{s=1}^{n} q_s G(r_s, z_s) = \int_\Gamma \left(\phi \frac{\partial G}{\partial n} - G\frac{\partial \phi}{\partial n}\right) r\, d\Gamma \quad (8$$

where q_s is the strength of a source or sink located at (r_s, z_s), n is the number of sources and sinks, and α is the solid angle. The solid angle can be defined as

$$\alpha = \lim_{\epsilon \to 0} \frac{A_s}{\epsilon^2} \quad (9$$

where A_s is the surface area of the portion of a sphere of radius ϵ centered at (r_i, z_i) that is inside the domain. Thus for (r_i, z_i) inside the domain, $\alpha = 4\pi$, and for points on a smooth part of the boundary, $\alpha = 2\pi$.

The axisymmetric Green's function and its normal derivative are

$$G = \frac{2m}{\sqrt{r_i r_Q}} K\left(m, \frac{\pi}{2}\right) \quad (10$$

$$\frac{\partial G}{\partial n} = \frac{-m}{\sqrt{r_i r_Q}}\left\{\left[\frac{1}{r_Q} K\left(m, \frac{\pi}{2}\right) - \frac{r_i^2 - r_Q^2 + (z_i - z_Q)^2}{r_Q[(r_i - r_Q)^2 + (z_i - z_Q)^2]} E\left(m, \frac{\pi}{2}\right)\right] n_r - \left[\frac{2(z_i - z_Q)}{(r_i - r_Q)^2 + (z_i - z_Q)^2} E\left(m, \frac{\pi}{2}\right)\right] n_z\right\}$$

where (r_i, z_i) is the point at which ϕ is to be determined, (r_Q, z_Q) is the location on the boundary, and n_r and n_z are the r and z components of the unit normal vector (Bakr, 1986). $K[m, (\pi/2)]$ is the complete elliptic integral of the first kind, and $E[m, (\pi/2)]$ is the complete elliptic integral of the second kind, with modulus, m:

$$m = \frac{2\sqrt{r_i r_Q}}{\sqrt{(r_i + r_Q)^2 + (z_i - z_Q)^2}} \qquad (12)$$

The boundary of the axisymmetric domain is one-dimensional. It was discretized into a set of linear elements so that the boundary integral in equation (8) can be evaluated. If both ϕ and $(\partial\phi/\partial n)$ are known on the boundary, then ϕ can be determined anywhere in the domain by use of equation (8). Since ϕ and $(d\phi/dn)$ are generally not both known everywhere on the boundary, they must first be determined. This is done by placing the point (r_i, z_i) at the location of the boundary nodes successively. This produces a set of algebraic equations for each node which can then be solved simultaneously.

As already mentioned, an advantage of the BEM method is its ability to economically determine the free surface. The free-surface elevation is defined by $z = \eta(r)$. The free-surface boundary conditions are

$$\phi = \eta \qquad (13a)$$

$$\frac{\partial \eta}{\partial t} = -\sqrt{1 + (\partial \eta/\partial r)^2}\ \frac{\partial \phi}{\partial n} + W \qquad (13b)$$

where W is the recharge (Lennon, 1980; Ligget and Liu, 1983). The nondimensional time term incorporates the value of the effective porosity, so that $(\partial\eta/\partial t)$ represents the velocity of a fluid particle on the free surface. By using equation (13a) to substitute ϕ for η in equation (13b), a relation between ϕ and $(\partial\phi/\partial n)$ on the free surface is obtained. On the free surface,

$$\frac{\partial \phi}{\partial t} = -\frac{1}{\cos\beta}\ \frac{\partial \phi}{\partial n} \qquad (14a)$$

where β is the angle of the free surface with the horizontal. Put in finite-difference form, this equation becomes

$$\phi^{k+1} = \phi^k - \frac{\Delta t}{\cos\beta}\left[\theta\left(\frac{\partial \phi}{\partial n}\right)^{k+1} + (1-\theta)\left(\frac{\partial \phi}{\partial n}\right)^{k}\right] \qquad \ldots . (14b)$$

where k is the time index, and θ is the weighting factor (usually set to .7). This equation allows stepping forward from an initial estimate of the free surface to the final free surface where the no-flux boundary condition, $(\partial\phi/\partial n) = 0$, is met. This allows for solution of equation (8) as before.

Results

Validation

Ligget and Liu (1983) and Lennon (1980) demonstrated satisfactory agreement between the results of their BEM models and an analytical solution (Dagan, 1967) for the case of small, uniform circular recharge. We provide another comparison for the point sink in a semi-infinite aquifer. For $q = -.01$, Figure 4 shows that there is excellent agreement in the computed free-surface elevation between the boundary element results and the analytic results.

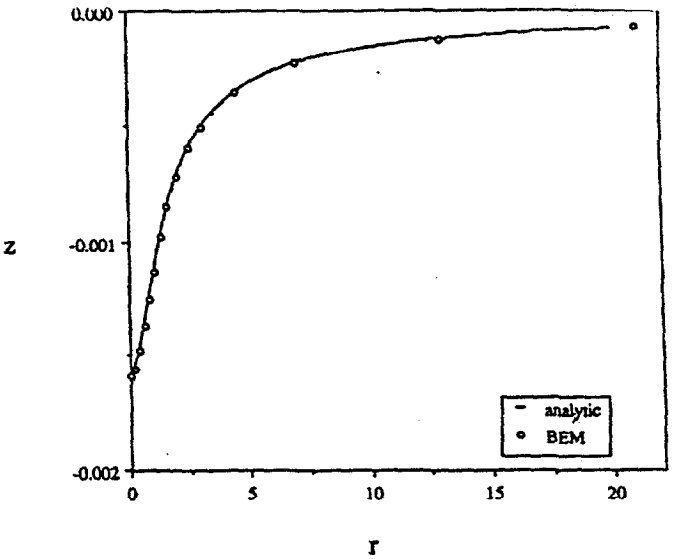

Fig. 4. Comparison of free surface for one sink at $z = -1$, $q = -.01$ using the BEM and the analytic approximation for a semi-infinite aquifer.

Downconing

One major consideration in the design of the recirculation unit is whether the free surface will be drawn down to the upper screen. This could affect the remediation process by drawing in air which could cause gas fouling and damage the pump system. One might have expected that, by increasing q, the free surface would be drawn down gradually until it finally reached the point sink. The results indicate something different. The free surface cannot be drawn down to a stable position below some critical depth which corresponds to a critical pumping rate. When the pumping rate exceeds this critical value, the free surface becomes unstable and drops down to the point sink. This type of instability has been noted (Muskat and Wyckoff, 1935; Wheatley, 1985; Motz, 1992) for other nonlinear boundary condition cases such as upconing of saline water into wells pumping in the fresh water above, or upconing of water into partially penetrating oil wells above.

First-Order Approximation of Critical Drawdown

Consider again the case of the recirculation well shown in Figure 2. To estimate the values of the critical pumping rate and corresponding critical drawdown, we make the following approximations: (1) We neglect the source and the lower confining layer, thus treating the aquifer as semi-infinite with a single sink located at a depth, a, and pumping at a rate q; (2) We make the same first-order approximation as we did above for the free surface (hydraulic head changes linearly with pumping rate). With these approximations, the hydraulic head is:

$$\phi(r, z) = \frac{q}{4\pi}\left\{\frac{1}{\sqrt{r^2 + (a-z)^2}} + \frac{1}{\sqrt{r^2 + (a+z)^2}}\right\} \quad \ldots . (15)$$

On the free surface, $\phi(r, z) = z$, and the maximum drawdown will be at $r = 0$. Equation (15) then becomes

$$z = \frac{q}{4\pi}\left\{\frac{1}{(a-z)} + \frac{1}{(a+z)}\right\} \quad (16)$$

which further reduces to a cubic polynomial expression for z:

$$(a^2 - z^2)\, z = \frac{qa}{2\pi} \quad (17)$$

Mathematically, this equation has three possible solutions for z, but only one of these solutions is physically realistic. That is, for $q = 0$, this solution gives $z = 0$, and as q becomes more negative, this solution suggests that z becomes negative as well. The solution is real only as long as $q > q_{crit}$ so that $z > z_{crit}$, where

$$q_{crit} = \frac{-4\pi a^2}{3\sqrt{3}} \approx -2.42a^2 \quad \text{and} \quad z_{crit} = \frac{-a}{\sqrt{3}} \approx -0.58a \quad \ldots . (18)$$

These are the critical pumping rate and drawdown where unstable downconing occurs. Here is another way to arrive at the same conclusion. If the free surface is stable, then the slope of the free surface should equal zero at $r = 0$, indicating a stagnation point. The derivative of equation (15) with respect to r at $r = 0$ is

$$z'\left\{1 - \frac{q}{4\pi}\left[\frac{1}{(a-z)^2} - \frac{1}{(a+z)^2}\right]\right\} = 0 \quad (19)$$

This solution will be true if $z' = 0$, in which case there is a stable stagnation point, or if $q = q_{crit}$ and $z = z_{crit}$, in which case z' can have any value, thus allowing for unstable drawdown.

Numerical Results for the Source/Sink Pair

The critical drawdown and the critical pumping rate for the source-sink pair were determined numerically for six different sink depths. The undisturbed thickness of the aquifer is maintained at 1, and the source depth is at $b = 0.99$, as shown in Figure 2. The pumping rate was increased from one run to the next if the phreatic surface was stable and was decreased if the phreatic surface was unstable. We continued to make runs until the ratio of the largest pumping rate yielding a stable free surface to the smallest pumping rate for an unstable free surface was equal to or exceeded .999:

$$\frac{q_{stable}}{q_{unstable}} \geq .999 \quad (20)$$

A plot of the fractional drawdown, z_{crit}/a, versus the sink depth, a, is shown in Figure 5. The maximum fractional drawdown decreases with sink depth. This decrease is due to the presence of the point source which becomes increasingly important as the sink is located deeper and thus closer to the source. The values obtained numerically are in reasonable agreement with the value found with the first-order approximation, shown as a dotted line in Figure 5.

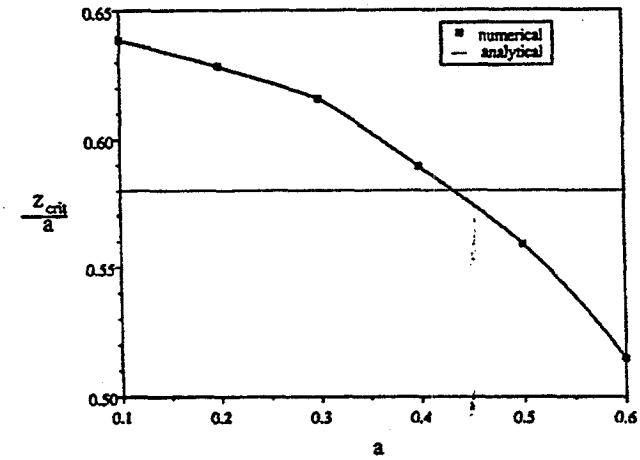

Fig. 5. Maximum fractional drawdown for a given sink depth. The dotted line represents the value obtained from the first-order analytical approximation.

The maximum pumping rate before the free surface is drawn down to the point sink is shown in Figure 6. The critical pumping rate increases with increasing sink depth, as expected. This is because the deeper the sink, the greater the required pumping rate to draw down the free surface to the critical depth. The first-order analytical approximation for a single sink in a semi-infinite aquifer is also shown in Figure 6. For all sink depths, the analytical approximation underestimates q_{crit}. In most practical situations, the value of a is less than 0.2, for which we have satisfactory agreement between the analytical approximation and the numerically computed value of the critical pumping rate. For larger values of a, the discrepancy increases, because of the effect of

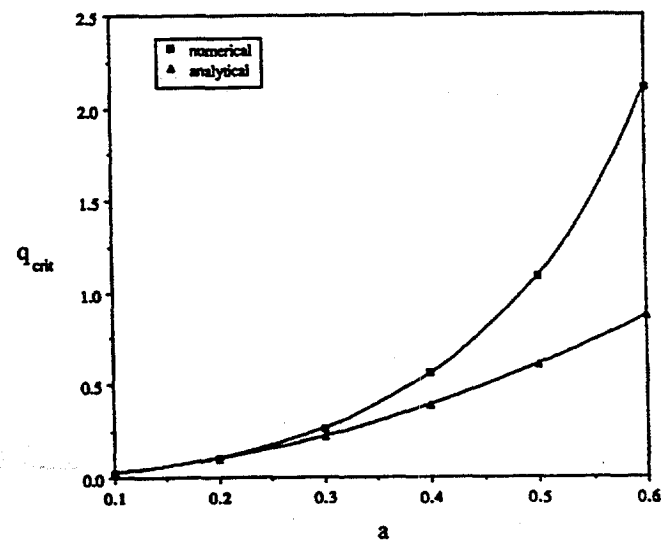

Fig. 6. Maximum pumping rate for different sink depths. The numerical results for the source/sink doublet are shown with the analytical approximation for a single sink in a semi-infinite aquifer.

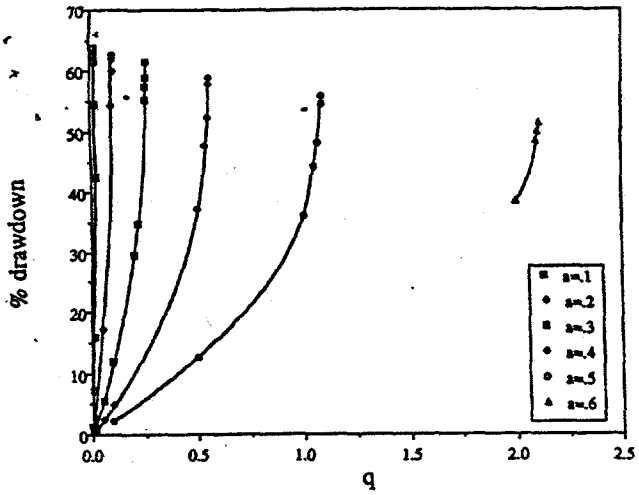

Fig. 7. Drawdown at different pumping rates for six different sink depths.

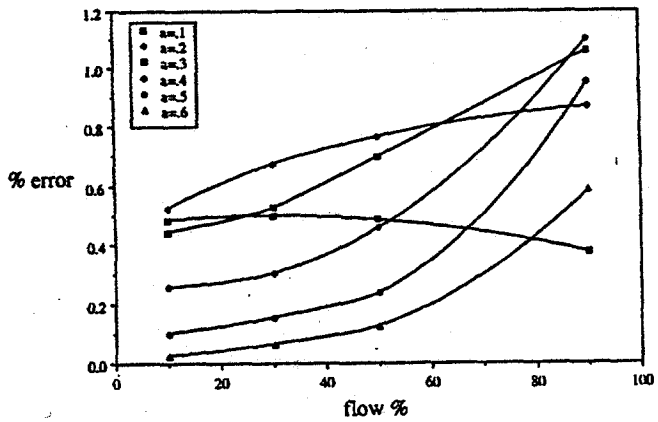

Fig. 8. Percent error versus percent flow for six sink depths.

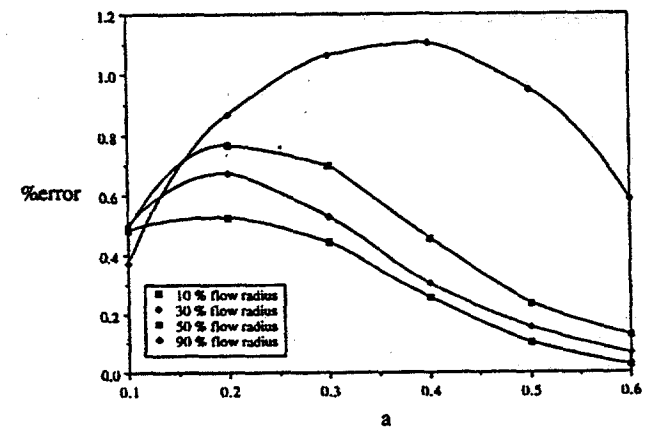

Fig. 9. Percent error versus sink depth for four different flow percents.

the source near the bottom of the aquifer and, to a lesser extent, the presence of the confining lower boundary.

The drawdown resulting from pumping rates smaller than q_{crit} was calculated numerically and is shown in Figure 7. The drawdown versus pumping rate curve is linear for small values of the pumping rate, but curves upward as the pumping rate increases. The slope becomes very large at the critical pumping rate.

Incidentally, note that the results in Figure 7 can be used as an aid in estimating the hydraulic conductivity. A recirculation unit with a known sink depth is operated at a known pumping rate. This creates a drawdown of the free surface which can be measured. The drawdown divided by the sink depth is the percent drawdown on the vertical axis of Figure 7. The value of the nondimensional pumping rate, q, can then be read from the curve corresponding to the sink depth. K can then be found from

$$K = \frac{Q}{H^2 q} \tag{21}$$

Confining Boundary Approximation to the Free Surface

In some cases it is convenient to approximate the free-surface boundary by a horizontal no-flux boundary, assuming that the pumping rate is below the critical value. Here, we discuss the validity of this approximation. The percent of the total flow passing from the source to the sink within a given radial distance was calculated along a horizontal plane midway between the source and sink. The radial distance within which a given percent of the flow (such as 90%) passes is defined as the radius of influence. A comparison of the unconfined with the confined case was made for several different combinations of q and a. The radii at which 10%, 30%, 50%, and 90% of the flow occurs for the critical unconfined case were compared with the confined case.

The percent error in the radii at which these percentages of flow pass caused by approximating the free surface as a confined boundary is

$$\% \text{ error} = \frac{r_{confined} - r_{free}}{r_{free}} 100\% \tag{22}$$

Figures 8 and 9 show how the percent error varies with the flow percent and the sink depth. The confined approximation overestimates the radius within which a given amount of flow passes, especially for the high percent radii of influence. However, this error is small, on the order of one percent. The error is likely to be less than the error introduced in numerical approximations to the flow field and is certainly less than the error due to the uncertainty in parameter values for any actual aquifer. Also, the above percent error is calculated for the extreme case of critical drawdown and will be less for other cases. Therefore, it is believed that approximating the free surface as an impermeable boundary is reasonable for determining the radius of influence for designing remediation schemes.

Conclusions

The effect of a free-surface boundary on the operation of a recirculation unit was examined. The recirculation unit was placed in a horizontally isotropic and homogeneous aquifer without significant background flow. The recirculation unit's intake opening and output opening were modeled as a point sink and point source, respectively. This simplifi-

cation allowed for examination of the two most important parameters affecting the free surface: the sink depth and the pumping rate.

The free-surface boundary for a source sink doublet used in ground-water remediation schemes can be modeled efficiently and accurately with the boundary element method. The BEM is capable of modeling both confined and unconfined aquifers. Analytical approximations of the free surface were found using a first-order perturbation. These analytical solutions are useful for gaining an understanding of the expected shape of the free-surface profile. They also provide validation cases for the numerical model.

The free-surface profile was calculated for six different depths to the sink in the source-sink doublet. An instability in the free surface was found to occur after a critical pumping rate is reached. At that point, the free surface is drawn down to the sink. First-order analytical approximations for the critical pumping rate and drawdown were found. Although the analytical results use a perturbation solution that should only hold for small q, they are still quite accurate. While these analytical approximations help explain the behavior, they do not contain the detail seen in the numerical results. The value of the critical pumping rate can be used in designing a remediation system, and the value of the critical drawdown can be used as a warning check during implementation of such a system. The results in this paper can aid in avoiding unstable drawdown. They can also be used to help estimate the hydraulic conductivity of an aquifer.

Modeling the free-surface boundary is relatively computationally intensive. Therefore, we examined the possibility of simplifying the free surface as an impermeable boundary. We compared the radius of influence modeling the actual free surface with the radius of influence found by approximating the free surface as a horizontal confining boundary. We found that this approximation results in an error on the order of one percent. Therefore, as long as the free surface does not become unstable, the free surface can be modeled as a confining boundary for a recirculation unit. These results demonstrate that the simpler and faster computation of the confined case is a reasonable approximation and will assist in designing remediation setups.

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References

Bakr, A. A. 1986. The Boundary Integral Equation Method in Axisymmetric Stress Analytic Problems. (Edited by C. A. Brebbia and S. A. Orszag.) Springer-Verlag, New York, NY.

Dagan, G. 1967. Linearized solutions of free-surface groundwater flow with uniform recharge. Journal of Geophysical Research. v. 72, no. 4, pp. 1183-1193.

Herrling, B., J. Stamm, and W. Buermann. 1991. Hydraulic circulation system for in situ bioreclamation and/or in situ remediation of strippable contamination. Proceedings of International Symposium on In Situ and On-Site Bioreclamation, San Diego.

Lennon, G. P. 1980. The boundary integral equation method applied to free-surface flow problems in porous media. Ph.D. thesis, Cornell Univ., Ithaca, NY.

Lennon, G. P. and B. L. Du. 1986. Three-dimensional boundary element techniques for moving boundary problems. Proceedings of the Fourth Conference on Computing in Civil Engineering, ASCE, Boston. pp. 79-92.

Liggett, J. A. and P. L-F. Liu. 1983. The Boundary Integral Equation Method for Porous Media Flow. Allen & Unwin Inc., Winchester, MA.

Motz, L. H. 1992. Salt-water upconing in an infinite aquifer overlain by a leaky confining bed. Ground Water. v. 30, no. 2, pp. 192-198.

Muskat, M. and R. D. Wyckoff. 1935. An approximate theory of water-coning in oil production. Transactions, AIME Petroleum Div. v. 114, pp. 144-163.

Muskat, M. 1982. The Flow of Homogeneous Fluids Through Porous Media. International Human Resources Development Corp., Boston, MA.

Polubarinova-Kochina, P. Y. 1962. Theory of Groundwater Movement. (Translated by J.M.R. DeWiest.) Princeton Univ. Press, Princeton, NJ.

Raymond, R. L., J. O. Hudson, and V. W. Jamison. 1976. Oil degradation in soil. Applied and Environmental Microbiology. v. 31, pp. 522-535.

Roberts, P. V. et al. In-situ Aquifer Restoration of Chlorinated Aliphatics by Methanotrophic Bacteria. EPA/600/2-89/033.

Strack, O.D.L. 1989. Groundwater Mechanics. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Thomas, J. M. and C. H. Ward. 1989. In situ biorestoration of organic contaminants in the subsurface. Environmental Science and Technology. v. 23, no. 7, pp. 760-766.

Vogel, T. M., C. S. Criddle, and P. L. McCarty. 1987. Transformations of halogenated organic aliphatic compounds. Environmental Science and Technology. v. 21, no. 8, pp. 722-736.

Wheatley, M. J. 1985. An approximate theory of oil/water coning. 60th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Las Vegas.

Wilson, S. B. and R. A. Brown. 1989. In situ bioreclamation: A cost-effective technology to remediate subsurface organic contamination. Ground Water Monitoring Review. Winter, pp. 173-179.

Prediction of Flow and Hydraulic Head Fields for Vertical Circulation Wells

by Ross D. Philip and Gary R. Walter[a]

Abstract

A vertical circulation well is a well completed in two intervals with extraction induced in one interval and injection induced in the other, generating a circulating flow field near the well. A vertical circulation well may be used to remediate contaminated ground water by air stripping the extracted water and then reinjecting the clean water; by introducing oxygen and/or nutrients to the extracted water before reinjecting it, thereby stimulating the natural bioremediation of the water; or by injecting appropriate chemicals or microbes, effecting remediation of the circulated water. This paper summarizes an analytical technique for predicting the steady-state hydraulic head and flow fields caused by the operation of multiple vertical circulation wells in a confined aquifer with a regional gradient. The method begins with the hydraulic head solution for a point sink in an infinite aquifer. The point sink is then integrated to derive the solution for a line sink. Linear superposition is applied to obtain the hydraulic head resulting from multiple line sinks and sources in a homogeneous confined aquifer. This solution is then differentiated to obtain the hydraulic head gradient and three-dimensional velocity field. The velocity field is numerically integrated by an adaptive Runge-Kutta scheme to obtain the pathlines of three-dimensional flow.

Introduction

The concept of inducing a circulating flow field from a single well was first introduced by petroleum engineers (Burns, 1969) as a technique for measuring vertical permeability in petroleum reservoirs. More recently, hydrologists have applied vertically circulating flow fields as a means of remediating contaminated ground water. The technique is basically one of completing a well in two intervals and inducing extraction from one interval and injection from the other interval, thereby inducing a circulating flow field near the well (Figure 1). The extracted water may then be treated by air stripping within the well (Herrling et al., 1991), or, by introducing oxygen, nutrients, or chemicals to the extracted water before reinjecting it, bioremediation or chemical reaction may be used to treat the extracted water. An important consideration in designing a remediation system based on vertical circulation wells is the extent of the zone of circulation. In the presence of natural ground-water flow or multiple wells, the zone of circulation may be quite complex. In these cases, the circulation pattern is inherently three-dimensional and lacks radial symmetry about the wells. Herrling and Buermann (1990) employed a Galerkin finite-element method to solve for the flow field induced by a single vertical circulation well in a layered confined aquifer with a regional flow gradient and demonstrated its complex three-dimensional nature. In this paper we present an analytical method for simulating the flow field induced by an arbitrary number of vertical circulation wells in a homogeneous anisotropic confined aquifer with a regional gradient. The advantage of the analytical approach presented here is that it may be quickly and easily adapted to solve problems of significant complexity without the tedious processes of generating computational meshes, assigning source and sink rates to specific nodes, etc. associated with a numerical model. Furthermore, the analytical method can predict near-well behavior more efficiently than a numerical model, which would require a very fine mesh spacing in the vicinity of the wells to accurately represent flow near the well. In the following sections, we will describe the theoretical basis for the analytical approach, its actual implementation, and some examples of its use.

Theory

The volumetric flow to a continuous point sink in an infinite homogeneous porous medium may be expressed as (Strack, 1989):

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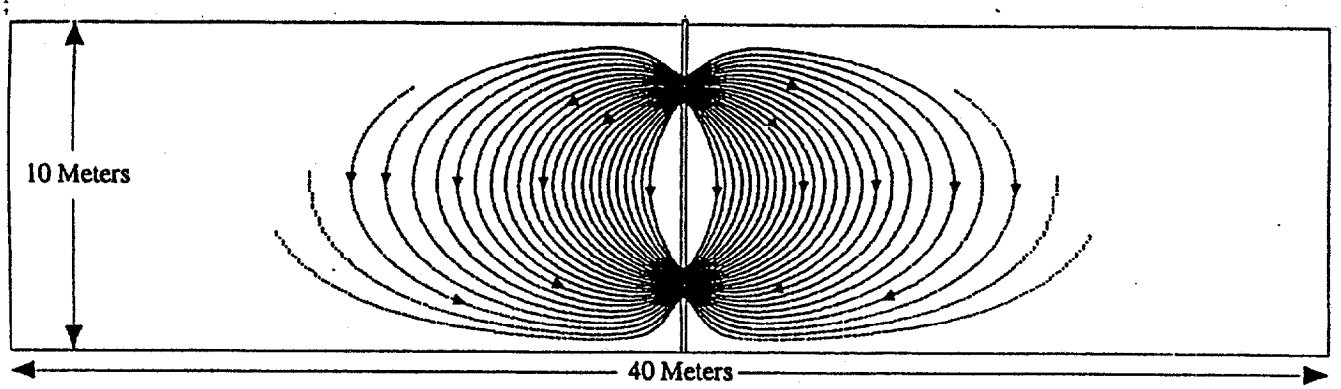


Fig. 1. Pathlines for vertical circulation well in stagnant aquifer.

$$Q = -4\pi r^2 q_r \qquad (1)$$

where Q is the volumetric sink rate [L^3/t]; r is the radial distance from point sink [L]; and q_r is the specific discharge in inward normal radial direction [L/t].

Substituting for q_r using Darcy's Law,

$$q_r = -K \frac{\partial h}{\partial r} \qquad (2)$$

where K is the hydraulic conductivity [L/t]; and h is the hydraulic head [L]. Integrating with respect to r, the solution for the hydraulic head change caused by a point sink in an infinite porous medium of homogeneous conductivity K with boundary condition [h = 0 at r = infinity] is (in spherically symmetric coordinates):

$$h = \frac{-Q}{4\pi K} \cdot \frac{1}{r} \qquad (3)$$

Note that this is the change in head in the porous medium caused by the point sink; so, for Q positive, h will be negative, indicating drawdown in the vicinity of the well. Transforming to cylindrical coordinates, the solution is:

$$h = \frac{-Q}{4\pi K} \cdot \frac{1}{\sqrt{r^2 + (z - z_0)^2}} \qquad (4)$$

where the point sink is centered at $r = 0$, $z = z_0$.

If we assume confined conditions or that the head drop at the wells is small compared with the saturated thickness of the aquifer, the principle of linear superposition may be applied: the solutions for a line of point sinks are integrated to yield the head change caused by a line sink of length 2L centered at $r = 0$, $z = z_0$:

$$h = \int_{z'=-L}^{z'=L} \frac{(-Q/2L)}{4\pi K} \cdot \frac{1}{\sqrt{r^2 + (z - z_0 - z')^2}}\, dz'$$

$$h(r, z) = \frac{-Q}{8\pi KL} \cdot$$

$$\mathrm{Ln}\left[\frac{z - z_0 + L + \sqrt{r^2 + (z - z_0 + L)^2}}{z - z_0 - L + \sqrt{r^2 + (z - z_0 - L)^2}}\right] \qquad (5)$$

Transforming to Cartesian coordinates, the solution is:

$$h(x, y, z) = \frac{-Q}{8\pi KL} \cdot$$

$$\mathrm{Ln}\left[\frac{z - z_0 + L + \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0 + L)^2}}{z - z_0 - L + \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0 - L)^2}}\right] \qquad \ldots . (6)$$

where the line sink is centered at $x = x_0$, $y = y_0$, $z = z_0$. This equation describes the head change at any location in an infinite porous medium caused by a line sink.

To find the velocities at any point in the flow domain, we differentiate the hydraulic head field. Note that, as for the head field, the velocity field may be determined by summing the individual velocity contributions from each well to obtain the net velocities. The velocity of flow induced by a single line sink in an infinite aquifer is given by:

$$V_x = \frac{-K}{n} \frac{\partial h}{\partial x}, \quad V_y = \frac{-K}{n} \frac{\partial h}{\partial y}, \quad V_z = \frac{-K}{n} \frac{\partial h}{\partial z} \qquad \ldots . (7)$$

$$\frac{\partial h}{\partial x} = \frac{-Q(x - x_0)}{8\pi KL} \cdot \left[\frac{1}{W_1} - \frac{1}{W_2}\right] \qquad (8.a)$$

$$\frac{\partial h}{\partial y} = \frac{-Q(y - y_0)}{8\pi KL} \cdot \left[\frac{1}{W_1} - \frac{1}{W_2}\right] \qquad (8.b)$$

$$\frac{\partial h}{\partial z} = \frac{-Q}{8\pi KL} \cdot \frac{1}{\sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0 + L)^2}} - \frac{1}{\sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0 + L)^2}} \qquad (8.c)$$

$$W_1 = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0 + L)^2} \cdot \left(z - z_0 + L + \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0 + L)^2}\right)$$

$$W_2 = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0 - L)^2} \cdot \left(z - z_0 - L + \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0 - L)^2}\right)$$

where V_x = x component of velocity; V_y = y component of velocity; V_z = z component of velocity; and n = effective porosity. The x, y, and z velocities at any point in the flow domain are described by the equations above. These equations, a system of coupled ordinary differential equations, can be integrated to obtain the fluid pathlines. Solution of the coupled equations will yield the (x, y, z) position of a fluid particle advected by the velocity field as a function of time. We performed this integration numerically, using an adaptive fourth-order Runge-Kutta integration scheme (Watts, Shampine, and Davenport, 1975) that takes small time steps in areas of high velocity gradients and large time steps in areas of low velocity gradients.

By employing the principle of linear superposition, a line sink centered at one location may be mated with a line source centered above or below it to simulate the effect of a vertical circulation well. Similarly, the effect of other wells and a regional gradient may be included by simply summing the solutions of the individual components.

The presence of upper and lower confining beds may be accounted for by adding image sources and sinks for each real line source or sink. Bear (1979) and Strack (1989) both provide excellent discussions of the use of image theory to account for boundaries to the flow domain. Because two boundaries are involved, an infinite number of image wells are required, as the images also require their own images to satisfy the boundary conditions (see Figure 2). In practice, however, only a finite number of images is required, since the influence of image wells far distant from the area of interest is small. In our implementation, successive pairs of image wells are added until the percent change in the calculated head or velocity field falls below some small tolerance:

$$\frac{h^{k+1}}{h^k} < \epsilon \qquad (9)$$

where h^k = head calculated after k image well pairs have been employed; h^{k+1} = head calculated after k + 1 image well pairs have been employed; and ϵ = user specified tolerance.

We found that setting ϵ equal to 1.e-6 worked well for most cases. A tighter tolerance may be required for cases with very low regional gradients or when calculating flow path lines at large distances from the wells. If one is unsure whether the tolerance is small enough, one may reduce the tolerance and check for any differences in the predictions. This process is repeated until the predicted values (resulting from the successively more restricted tolerances) no longer change.

The effects of anisotropic hydraulic conductivity are easily incorporated by scaling of coordinates. Essentially, one solves the problem in an isotropic domain and then scales the answer to obtain the solution for the anisotropic domain. Bear (1979) presents a thorough discussion of the relationship between isotropic and anisotropic aquifers; we will only briefly describe the scaling technique here.

The first step is to determine the equivalent isotropic hydraulic conductivity:

$$\bar{K} = (K_x \cdot K_y \cdot K_z)^{1/3} \qquad (10)$$

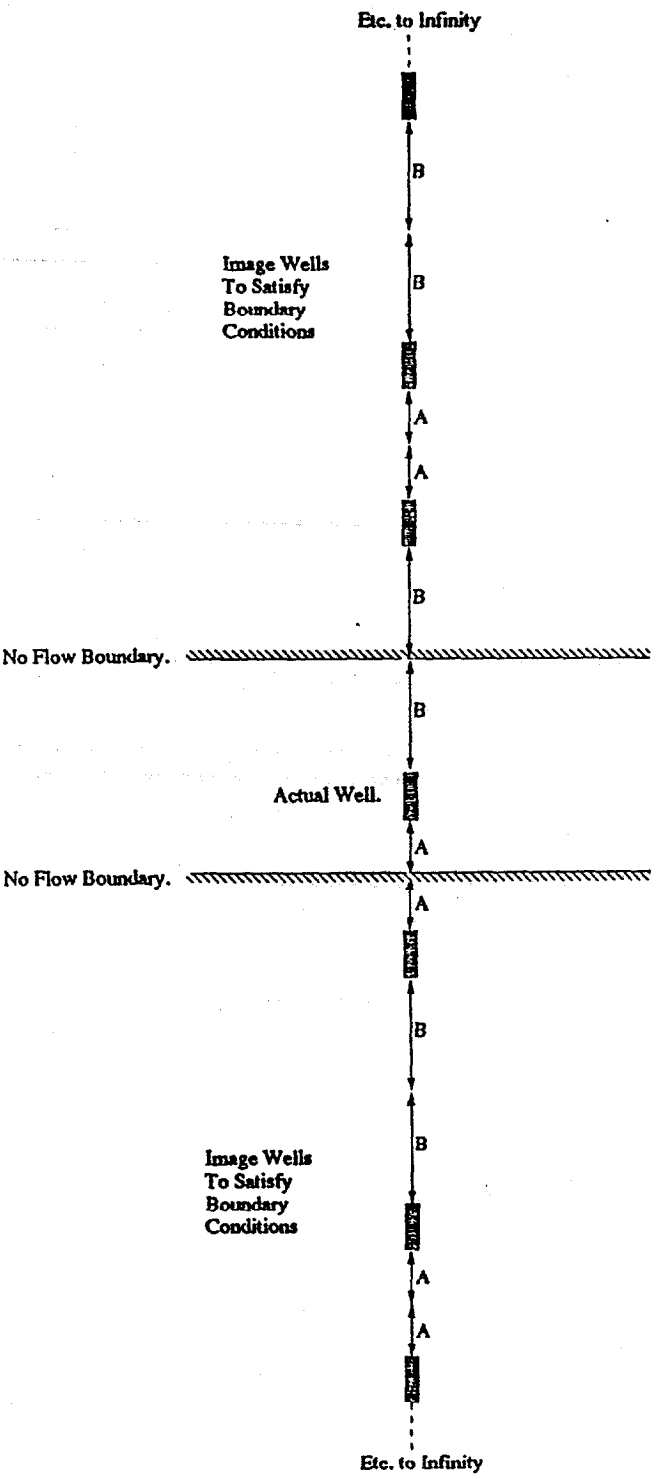


Fig. 2. Image well layout for simulation of upper and lower confining beds.

where $\bar{K}$ = hydraulic conductivity in equivalent isotropic domain; K_x = hydraulic conductivity in x direction; K_y = hydraulic conductivity in y direction; and K_z = hydraulic conductivity in z direction.

Next, determine the scaling factors for the x, y, and z coordinates:

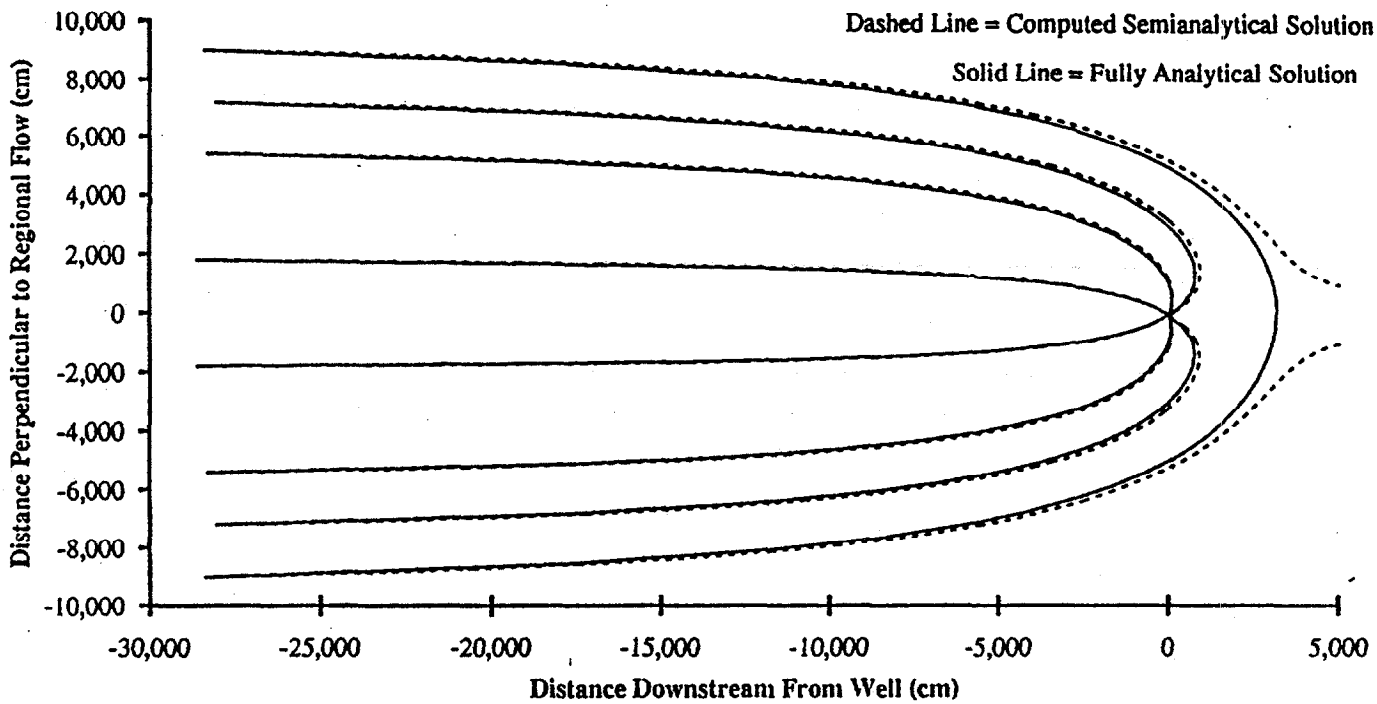


Fig. 3. Comparison of actual vs. computed streamlines for fully penetrating well.

$$F_x = \left(\frac{(K_y \cdot K_z)}{(K_x)^2} \right)^{1/6} \qquad (11.a)$$

$$F_y = \left(\frac{(K_x \cdot K_z)}{(K_y)^2} \right)^{1/6} \qquad (11.b)$$

$$F_z = \left(\frac{(K_x \cdot K_y)}{(K_z)^2} \right)^{1/6} \qquad (11.c)$$

All the dimensional parameters for the problem (length and locations of line sinks, locations of boundaries, regional flow velocities) are scaled into the equivalent isotropic domain by multiplying by the F_x, F_y, and F_z scaling factors. The problem is then solved in the equivalent isotropic domain using the scaled parameters and the equivalent isotropic hydraulic conductivity. Finally, the real (anisotropic) solution is obtained by dividing the calculated isotropic solution by the F_x, F_y, and F_z scaling factors.

Implementation

The theoretical approach described in the previous section was implemented in a FORTRAN 77 computer code. The program allows the placement of an arbitrary number of normal (single injection or extraction) and vertical circulation (simultaneous injection and withdrawal from different intervals of the same bore) wells anywhere in three-dimensional space. An arbitrary uniform regional flow field may be added and the upper and lower confining boundaries can be placed at any desired z locations. Fluid pathlines are generated by forward or reverse tracking the movement of fluid particles from either user-specified locations or from

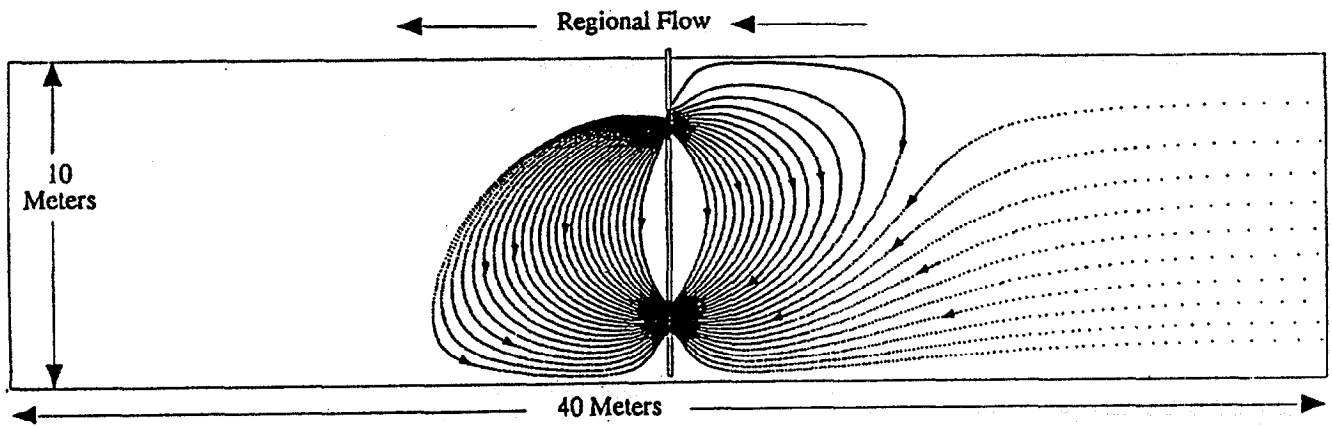
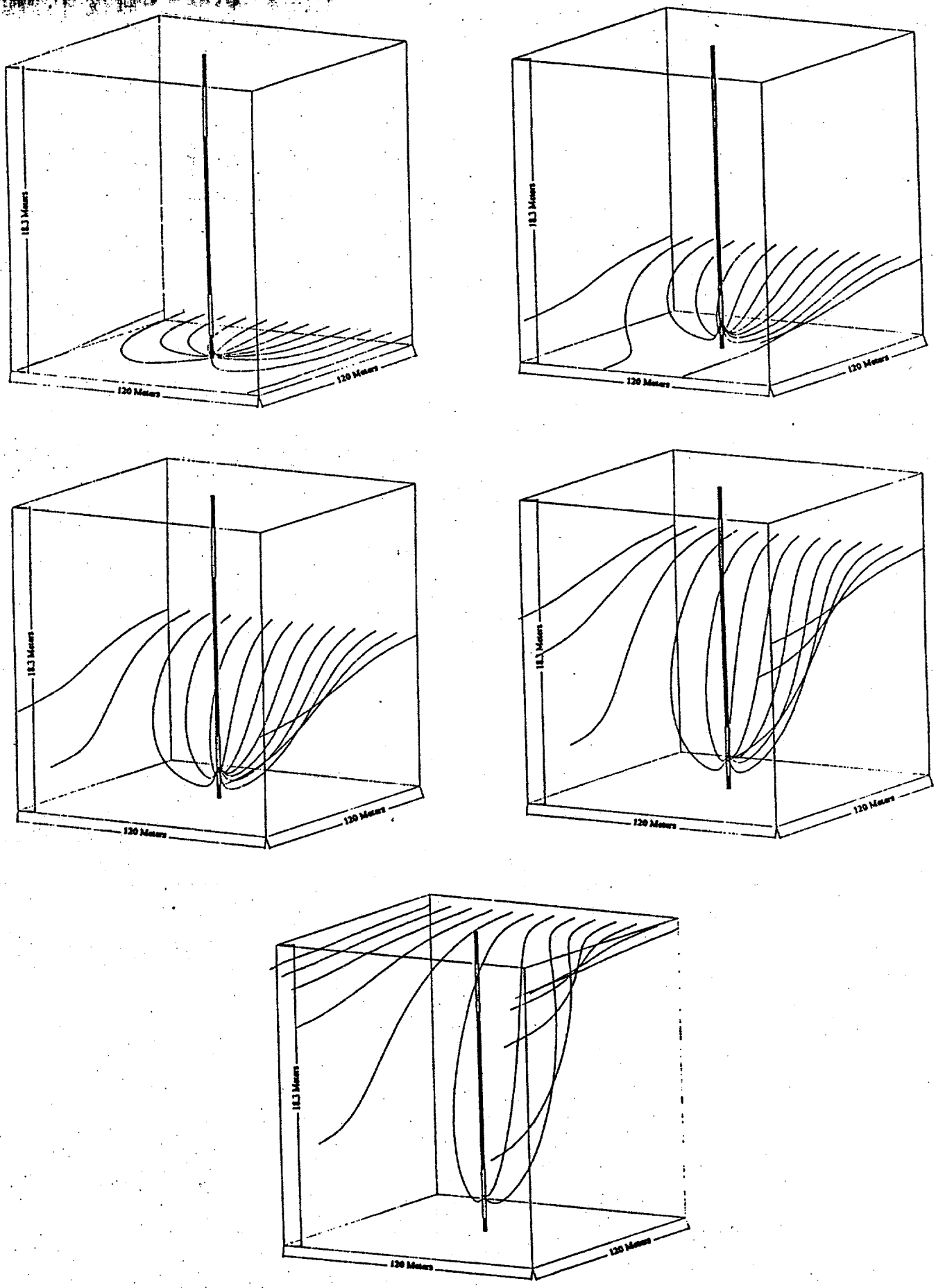


Fig. 4. Pathlines for vertical circulation well in regional flow field.



Figs. 5-9. Isometric view of pathlines for vertical circulation well in regional flow field.

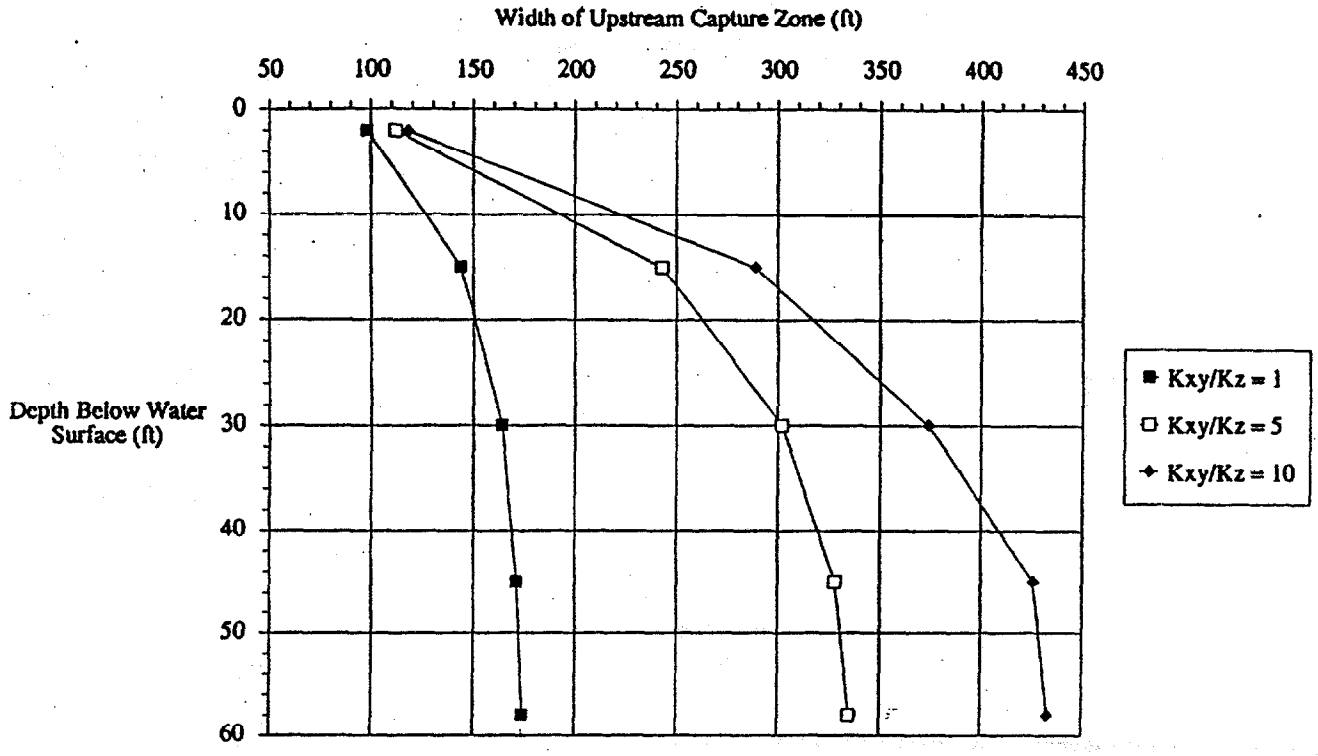


Fig. 10. Variation of capture zone with anisotropic hydraulic conductivity.

default locations generated by the program to most closely represent equal discharge streamtubes.

Figure 3 illustrates a comparison between the fluid pathlines calculated by the computer program and the actual streamlines (obtained from a fully analytical solution) for the case of a fully penetrating well in a confined aquifer with a linear regional flow gradient. The fully analytical solution is given by Strack (1989):

$$x = y \cdot \text{cotangent}\left[2 \cdot \pi \left(\frac{\psi}{Q} + \left(\frac{K \cdot \nabla h \cdot B}{Q}\right) y\right)\right] \quad (12)$$

where x = x coordinate location of streamline; y = y coordinate location of streamline; ψ = value of stream function; Q = pumping rate at well (200 cm^3/sec); K = hydraulic conductivity (1.e-3 cm/sec); ∇h = slope of linear regional hydraulic head field (0.01); and B = thickness of confined aquifer (1000 cm).

The semianalytical solution was obtained by specifying a 1000 cm line sink, bounded above and below by impermeable boundaries. The fluid particles were forward tracked from an upstream distance of 300 meters at a depth of 5 cm below the upper impermeable boundary. The solution obtained by our computer program matches the fully analytical solution quite well, except in the vicinity of the stagnation point at the leading edge of the capture zone. This behavior, however, is to be expected since the stream function is discontinuous along the x axis and the particle tracking method is not designed to integrate the system of ordinary differential equations at discontinuities.

Examples

Figure 1 shows a cross-sectional view of a single vertical circulation well in the absence of a regional flow field. The well is composed of two 1 meter screened intervals with 25 gpm extracted from the lower screened interval and 25 gpm reinjected through the upper screen. The aquifer is 10 meters thick, with a hydraulic conductivity of 1.e-3 cm/s and porosity 0.3. The flow lines represent the paths of particles that have entered the extraction interval of the vertical circulation well over a time period of 30 days. Therefore, fluid pathlines that fully connect between the extraction and injection intervals define a zone for which the residence time of water is less than or equal to 30 days. Note how the fine details of velocity variations very close to the well have been accurately reproduced. If a numerical rather than analytical approach had been employed, it would have required an extremely fine computational mesh in the vicinity of the well to obtain the same accuracy.

Figure 4 shows a cross-sectional view of the same well, but with a superimposed regional flow velocity of 56 cm/day from right to left. Once again, the flow lines represent the paths of particles that have entered the extraction interval of the vertical circulation well over a time period of 30 days. In this case, the vertical circulation well intercepts a significantly larger flow from upstream than from downstream.

Figures 5 through 9 illustrate an isometric view of the fluid pathlines associated with a vertical circulation well in a 60 foot thick confined aquifer with horizontal permeability of 30 darcies and vertical permeability of 6 darcies. A linear regional flow gradient of 17.4 feet per mile is assumed. The

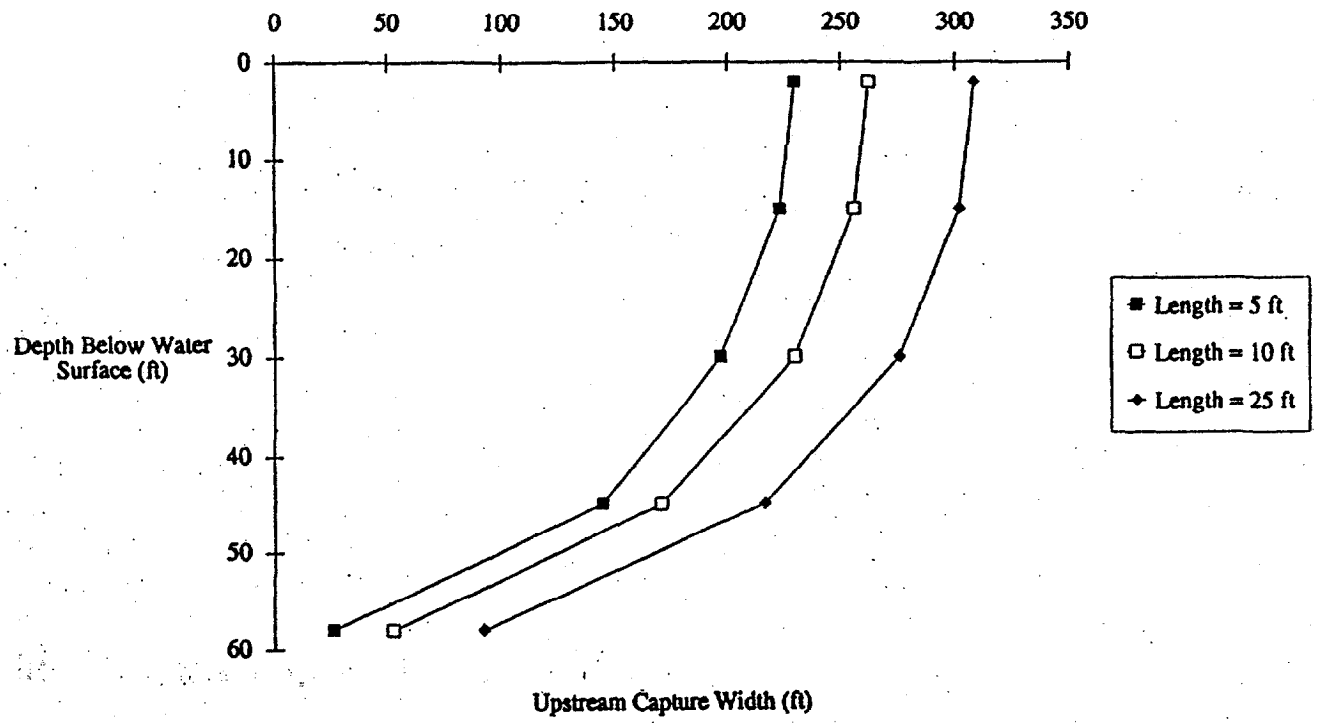


Fig. 11. Variation of capture zone with well screen length.

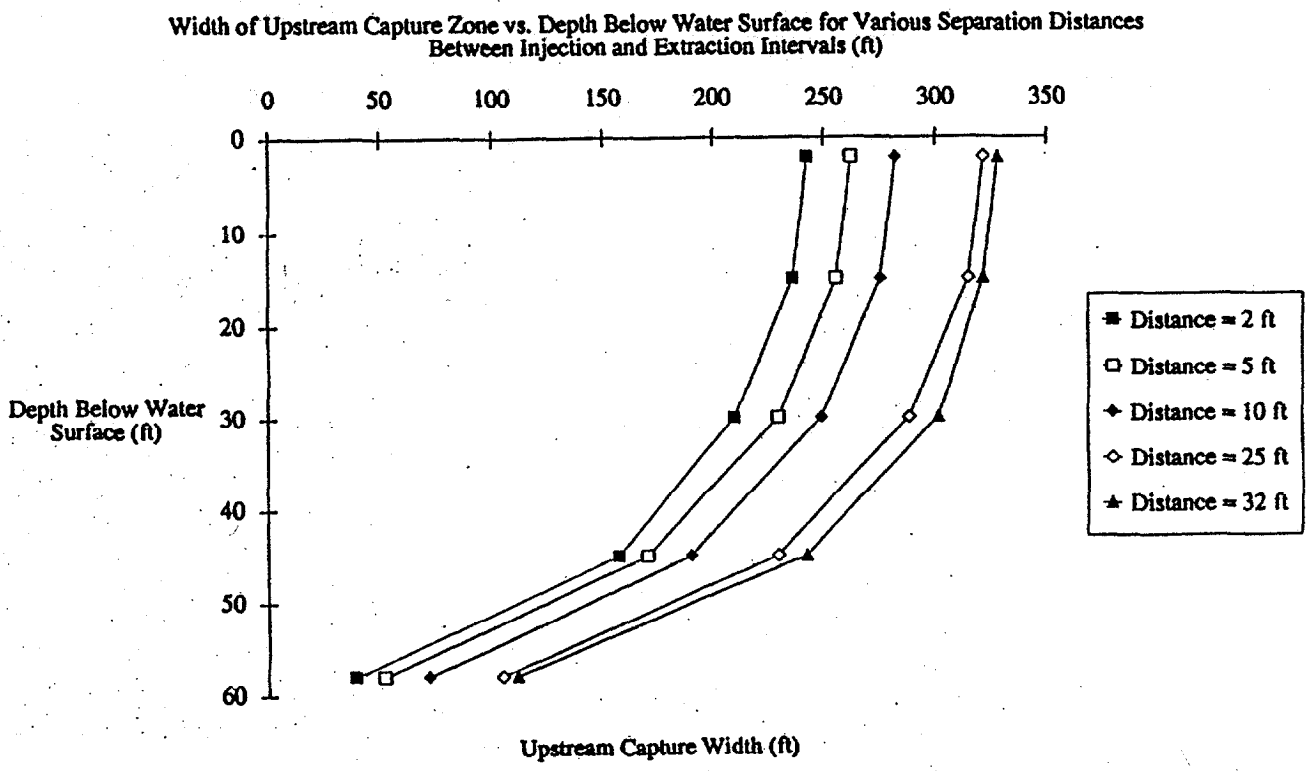


Fig. 12. Variation of capture zone with separation distance between injection and extraction intervals.

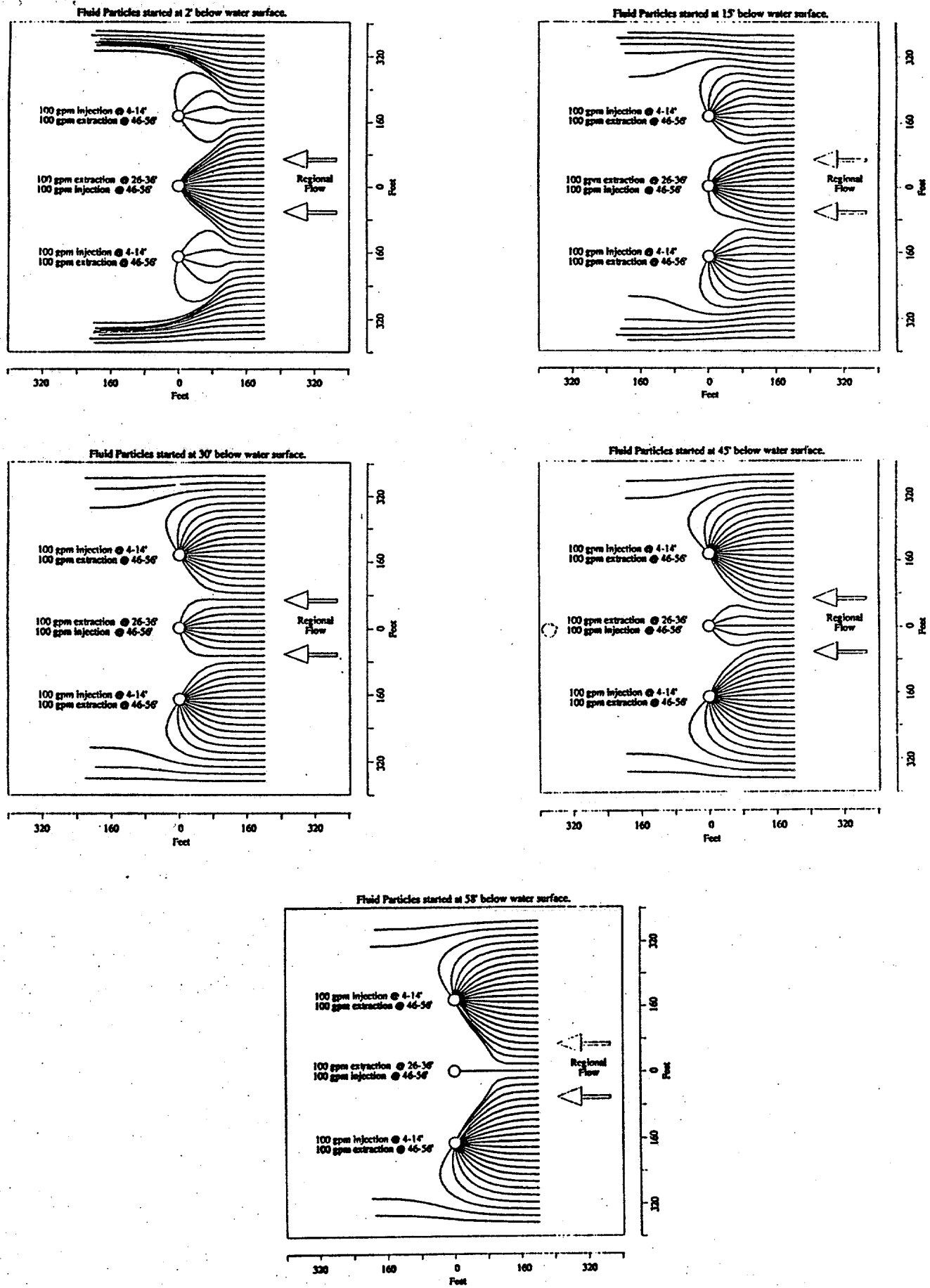


Fig. 13-17. Plan view of capture zones at various depths for alternating vertical circulation well design.

vertical circulation well injects 100 gpm through a 10 foot screen completed from 6.5 to 16.5 feet below the aquifer top and extracts 100 gpm through a 10 foot screen completed from 47.5 to 57.5 feet below the aquifer top. Particles were introduced at five discrete depths (each corresponding to a separate figure) and then forward tracked toward the vertical circulation well. As might be expected, the width of the capture is greatest at depth in the vicinity of the extraction interval of the vertical circulation well and smallest in the vicinity of the injection interval. Note, however, that the well does capture a significant portion of the regional flow above the extraction interval of the well. This effect may be likened to that of a partially penetrating well which, at distance from the well, extracts water from the entire thickness of the aquifer.

Figure 10 illustrates the effect of horizontal to vertical anisotropy in hydraulic conductivity on the capture zones associated with a vertical circulation well. The effective width of the capture zone is greater for greater ratios of horizontal to vertical permeability. Note that the anisotropy most strongly affects the capture width in the extraction interval of the aquifer.

The variation of the capture zone with screen length and screen placement is illustrated in Figures 11 and 12. Figure 11 shows the width of the upstream capture zone vs. depth of flow for vertical circulation wells with 5, 10, and 25 foot long injection and extraction screens placed 5 feet apart from each other. The simulations show that longer screened intervals lead to broader upstream capture zones. Figure 12 shows the width of the upstream capture zone vs. depth of flow for vertical circulation wells with 10 foot long injection and extraction screens placed 2, 5, 10, 25, and 32 feet apart from each other. In this case, increasing the separation distance between injection and extraction intervals increases the width of the capture zone. This is probably because increasing the separation between injection and extraction intervals reduces the short circuiting of flow between extraction and injection zones.

Multiple vertical circulation wells may be required to intercept any ground-water plumes wider than the upstream capture width of a single well. One difficulty in employing multiple vertical circulation wells is the variation of the capture width of such wells with depth. If the wells extract from deep in the formation, the capture width at shallow depths will be narrow and the wells will need to be closely spaced. If, on the other hand, the wells extract from shallow in the formation, the capture width deep in the formation will be narrow, and the wells will still need to be closely spaced. A more desirable design would redistribute the capture zones so that a moderate width could be captured across the entire depth of the aquifer. One possible design that provides a more equally distributed capture zone requires that vertical circulation wells be placed in a line perpendicular to the ground-water flow with the wells extraction screens placed alternately at shallow and deep elevations in the aquifer. This allows the wells with shallow extraction intervals to extend the shallow zone capture width of wells with deep extraction intervals and vice versa. Figures 13 through 17 illustrate the capture zones at various depths from simulations of such a design. The wells employed 10 foot long injection and extraction screens placed at the depths indicated on the figures.

Conclusions

Under certain conditions, the unique hydraulic characteristics of vertical circulation wells may make them desirable as a tool for remediation of contaminated ground water. Vertical circulation wells can be designed to target intense ground-water circulation in a narrow interval of an aquifer, making them advantageous for problems where contaminant velocities are significantly retarded with respect to advective ground-water velocities. Vertical circulation wells may also provide an effective mechanism for adding nutrients and oxygen to a specific zone of an aquifer for use in stimulating bioremediation. The capture zones of vertical circulation wells, however, will be significantly smaller than those associated with traditional capture wells of equivalent discharge.

This paper has described a semianalytical method for estimating the hydraulic performance of vertical circulation wells given some basic aquifer parameters. The method is computationally simple compared to the numerical methods previously employed, yet can be applied easily to complex multiple well problems. We have found the method to be useful in developing insight into the process, evaluating interference effects between multiple wells, and testing well field configurations for efficiency of treating contaminant plumes.

References

Burns, W. A., Jr. 1969. New single-well test for determining vertical permeability. J. Pet. Tech. June, pp. 743-752.

Bear, J. 1979. Hydraulics of Groundwater. McGraw-Hill, New York, NY.

Herrling, B. and W. Buermann. 1990. A new method for in-situ remediation of volatile contaminants in groundwater—Numerical simulation of the flow regime. Computational Methods in Subsurface Hydrology—Proceedings of the Eighth International Conference on Computational Methods in Water Resources, held in Venice, Italy. Computational Mechanics Publications, Southhampton-Boston. Copublished with Springer-Verlag, Berlin.

Herrling, B., J. Stamm, and W. Buermann. 1991. Hydraulic circulation system for in situ bioreclamation and/or in situ remediation of strippable contamination. Proceedings of In Situ and On-Site Bioreclamation, Int. Symp., March 19-21, 1991, San Diego, CA.

Strack, O.D.L. 1989. Groundwater Mechanics. Prentice-Hall, Englewood Cliffs, NJ.

Watts, H. A., L. F. Shampine, and S. Davenport. 1975. Solving non-stiff ordinary differential equations—The state of the art. Sandia Laboratories Report SAND75-0182.

APPENDIX F
EQUIPMENT SPECIFICATIONS

This manual should be available to the operating personnel all the time. The instructions should be read carefully before installation and startin operation. If strict notice is given to these instructions the blower will operate faultlessly for years.

1. General remarks

Elektror high pressure blowers are made of sturdy, light-weight cast aluminium the impellers from sheet aluminium respectively from sheet steel.

They are designed for conveying medium air volumes at high flow resistance.

The use of the units for aggressive and toxid media, for air of extremly high humidity as well as for media temperatures exceeding 80° C is limited only and subject to clarification with the company. Conveying of explosive gases is not permitted.

If the medium to be conveyes contains solid particles or other pollutions, they are to be removed before entering the blower by installing a filter on the intake side. Open discharge or intake ports should be fitted with suitable wire mesh guards. Attention should be given to careful and regular cleaning or replacement of clogged filters as the indicated performance data cannot be guaranteed otherwise.

With blowers the performance curves of which are limited in the higher volume range, care must be taken so as not to exceed the indicated maximum volume flow in order to avoid an overload of the motor. If the resistance of the connected systems is too small a reduction of the volume flow is possible by fitting a throttle flap. The units have to be installed in weather-protected places.

Provisions should be made for sufficient motor cooling. The permitted maximum temperature of conveyed medium and surroundings is 40° C. If equipped with a temperature barrier the maxiumum temperature of the conveyed medium is 180° C. The units should be mounted horizontally only.

2. Technical data

The various blower types as well as their technical data may be taken from our catalogue „Elektror High Pressure Blowers".

3. Installation

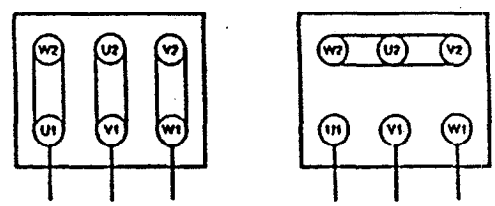
3.1. Check all parts for damage during transportation.

3.2. Elektrical connection is to be carried out according to the wiring diagram in the terminal box by skilled labour only. The respective VDE regulations and the directions of the local power supply company are to be complied with.

3.3. Protection of motor by overload switch; permitted max. current see rating plate.

3.4. Electrical connection diagram

Connection of three phase units



Δ-connection
lower voltage

Y-connection
higher voltage

3.5. Control of the correct rotational direction of the impeller is to be made by the air flow. The direction of the air flow must be in accordance with the arrow on the blower housing.
Reversing of the direction of rotation with three phase a.c. is possible by interchanging two wires (see connection diagram).

3.6. Mechanical connection of the blower.

4. Start of operation

4.1. If the rated current indicated on the rating plate ist being exceeded during operation, it should be checked whether the available supply voltage and frequency are in accordance with the embossed data. Some blowers cannot be operated with free air flow (see catalogue) and if in such a case the system's resistance is too small, current absorption will become too high and an overload of the motor will occur. By fitting a throttle flap on the intake or discharge side of the blower the volume flow will be reduced and an overload avoided.

5. Maintenance

High pressure blowers are equipped with enclosed grooved ball bearings which do not need lubrication. The grease filling is sufficient for the whole service life of the bearings.

Tension control of the V-belts is to be carried out in accordance with the indicated values on the rating plate. They are fixed to the support flange, item 8, to the blower flange, item 6, respectively to the blower base, item 5.

Retightening of the V-belts for models HRD 1/2 - HRD 2/5 is to be carried out as follows:

5.1. Remove cover guard, item 10.
5.2. Loosen hexagonal nut, item 18.
5.3. Increase tension of V-belts by tightening hexagonal nut, item 19 (see rating plate).
5.4. Tighten hexagonal nut, item 18.
5.5. Reassemble cover guard, item 18.

Retightening of the V-belts for models HRD 65/2 - HRD 65/7, HRD 60/3 and HRD 60/5 is to be carried out as follows:

5.6. Remove drive belt guard, item 7.
5.7. Adjust tension of V-belts by loosening or tightening nuts on the threaded bolt, item 10 (see rating plate).
5.8. Retighten hexagonal screw nut item 11.

Retightening of the V-belts for models HRD 7/12 - HRD 7/23 is to be carried out as follows:

5.10. Remove drive belt guard, item 7.
5.11. Loosen hexagonal nut, item 10, adjust tension of V-belts by tightening or loosening the adjusting screw, item 11 (see instruction plate), accordingly.
5.12. Tighten hexagonal nut, item 10.
5.13. Reassemble drive belt guard, item 7.
5.14. Attention should be given to exact alignment of the V-belt pulleys.

6. Repairs

6.1. Repair work on blowers should generally be done in the factory only. Exceptionally repairs may be carried out in a workshop possessing the necessary qualifications and facilities. Units with an explosion-proof motor must be repaired by the manufacture only.

7. Warranty, technical details

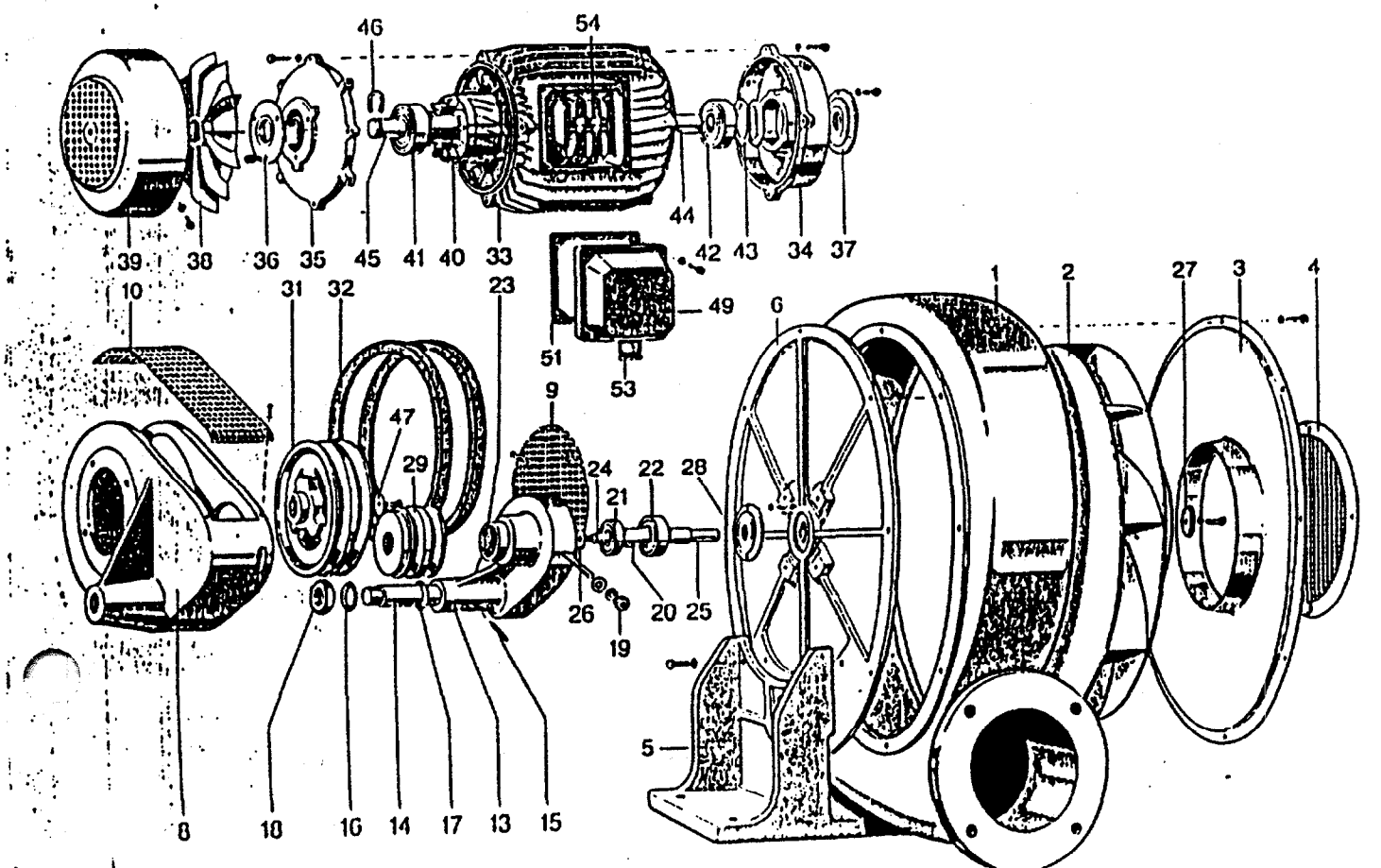
7.1. Legal warranty begins with the day of shipment.
7.2. Our warranty is valid only if the instructions for installation and operation are strictly adhered to.
7.3. Technical details regarding installation, operating conditions and electrical connections may be obtained from the company's experts.

8. Spare parts list

When ordering spare parts please state serial number of the unit, type and part number in accordance with the following lists and drawings.

Elektror High Pressure Blo

HRD2/3—HRD2/5

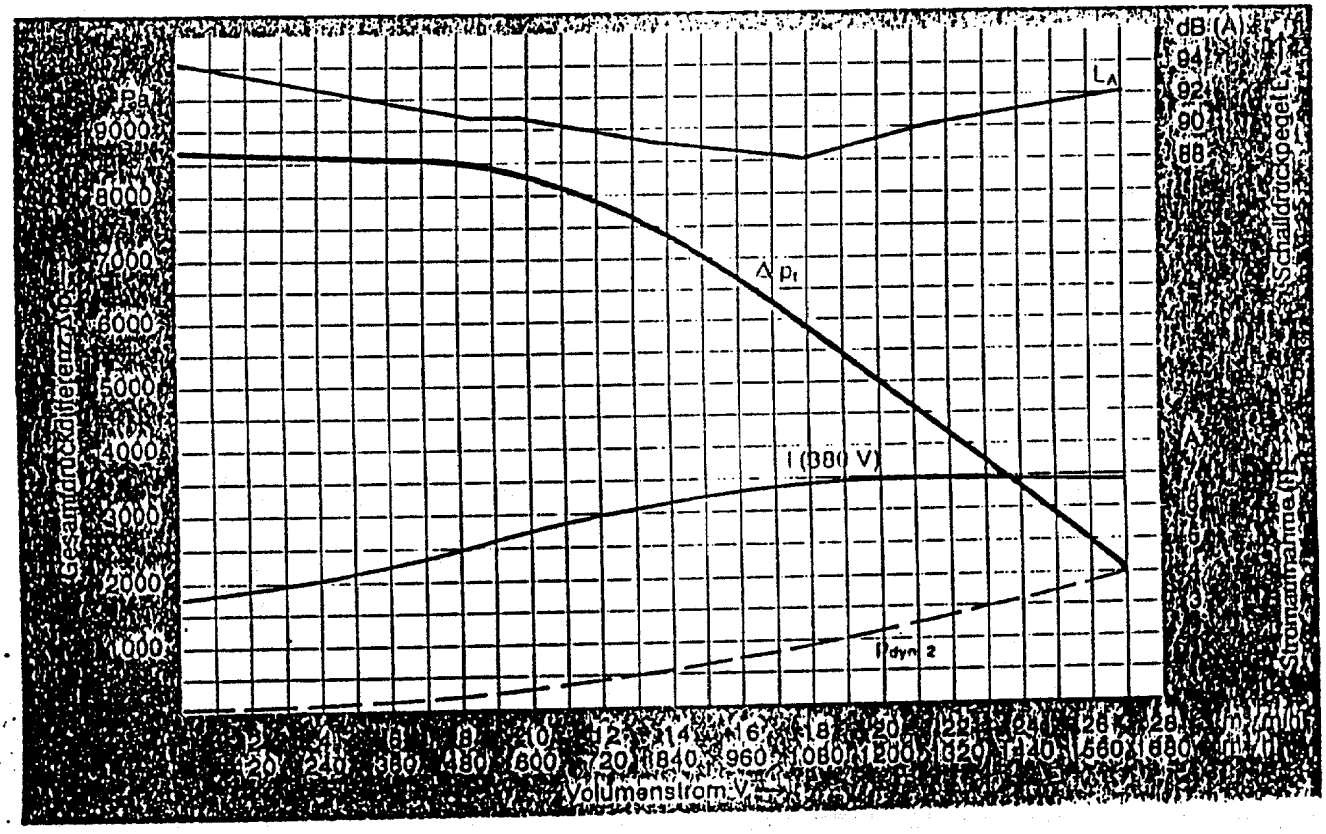


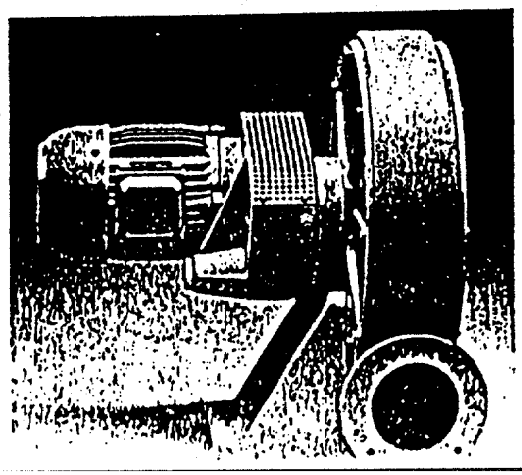
Item	Type Nomenclature	HRD 2/3 Part no.	HRD 2/4 Part no.	HRD2/5 Part no.	
1	blower housing "right"	13075	13075	13075	
or	blower housing "left"	13767	13767	13767	
2	impeller "right"	13768	13768	13768	
or	impeller "left"	13775	13775	13775	
3	housing cover lid	13361	13361	13361	
4	wire mesh guard	13771	13771	13771	
5	blower base	13941	13941	13941	
6	blower flange				
7		11392	11392	11392	
8	support flange Ar, Br, Gl, Hl	11399	11399	11399	
or	support flange Cr, Dr, El, Fl	11429	11429	11429	
9	circular cover guard	11393	11393	11393	
10	belt cover guard				
11		St 2496	St 2496	St 2496	
12	flange housing complete Ar, Br, Gl, Hl	St 2498	St 2498	St 2498	
or	flange housing complete Cr, Dr, El, Fl				
	consisting of items 13–29	11388	11388	11388	
13	flange housing Ar, Br, Gl, Hl	11389	11389	11389	
or	flange housing Cr, Dr, El, Fl	11394	11394	11394	
14	pivot bolt	1424	1424	1424	
15	spiral stud	1418	1418	1418	
16	screw lock washer	1422	1422	1422	
17	screw lock washer	1417	1417	1417	
18	hexagonal nut	3254	3254	3254	
19	hexagonal nut	13942	13942	13942	
20	blower shaft	3060-2z	3060-2z	3060-2z	
21	ball bearing	3019-2z C3	3019-2z C3	3019-2z C3	
22	ball bearing	6349	6349	6349	
23	circlip	3061	3061	3061	
24	key	9606	9606	9606	
25	key	11093	11093	11093	
26	washer	11110	11110	11110	
27	washer	7400	7400	7400	
28	bearing cap	2244	2244	2244	
29	belt pulley				
30		11233	13889	2370	
31	V-belt pulley 50 Hz	13939	13940	11233	
or	V-belt pulley 60 Hz	1395	1394	1394	
32	V-belt 50 Hz	1395	1395	1395	
or	V-belt 60 Hz	10436	10458	10489	
33	cast-in stator complete	10424	10424	10491	
34	flanged bearing endshield	10429	10429	10474	
35	bearing endshield	10433	10433	10476	
36	bearing cap	—	—	10476	
37	bearing cap	10435	10435	10478	
38	cooling fan	10434	10434	10477	
39	fan guard	11432	11395	14463	
40	rotor complete	3201-2z	3201-2z	4067-2z	
41	ball bearing	12487	12487	4067-2z	
42	ball bearing	10439	10439	10483	
43	dished spring	8996	8996	8996	
44	key	6630	6630	6630	
45	key	9506	9506	5172	
46	circlip	11110	11110	11110	
47	washer				
48		14523	14523	14523	
49	terminal box				
50		10442	10442	10442	
51	terminal box gasket				
52		4411	4411	4411	
53	PG cable gland	12794	12794	12794	
54	terminal board				
55					
Design with temperature barrier S 484					
56	spacer ring	2193	2193	2193	
57	ventilating fan	2207	2207	2207	
58	blower shaft	13942/S484	13942/S484	13942/S484	
59	ball bearing	3060-z	3060-z	3060-z	
60	ball bearing	3019 -z C3	3019 -z C3	3019 -z C3	
Design with TMG shaft seal					
61	blower flange				

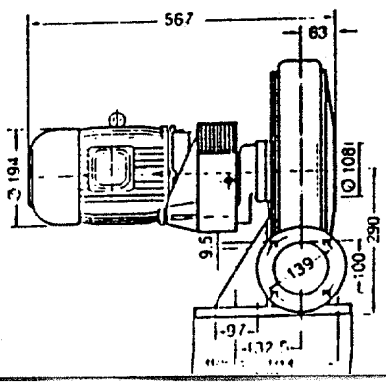
Elektror
Technische Daten

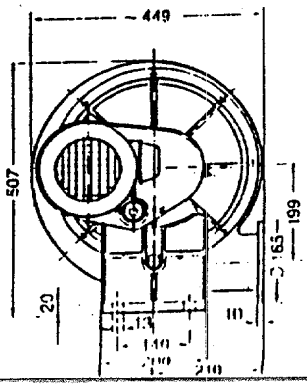
HRD 2/5

Typ	Volumenstrom	Gesamtdruckdifferenz	Spannung	Frequenz	Stromaufnahme	Drehzahl	Motorleistung	Gewicht
	m³/h	Pa	V	Hz	A	1/min	W	kg
HRD 2/5	27	8600	220/380	50	1,1/0,6	2830	3,1	13
HRD 2/5	27	8600	265/440	60	1,0/0,6	3500	3,3	13









Service

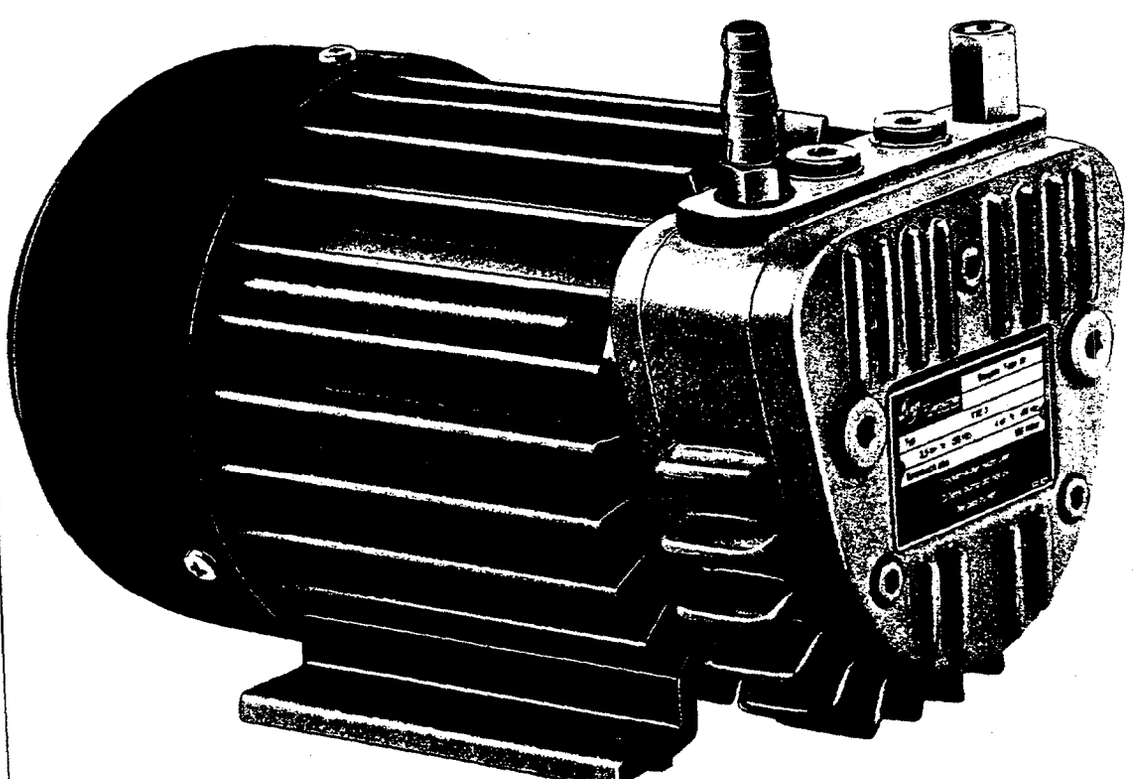
Rietschle

Vakuum-pumpen | Vacuum Pumps | Pompes à vide | Pompe per vuoto

VTE

PICOLINE

VTE 3
VTE 6
VTE 8



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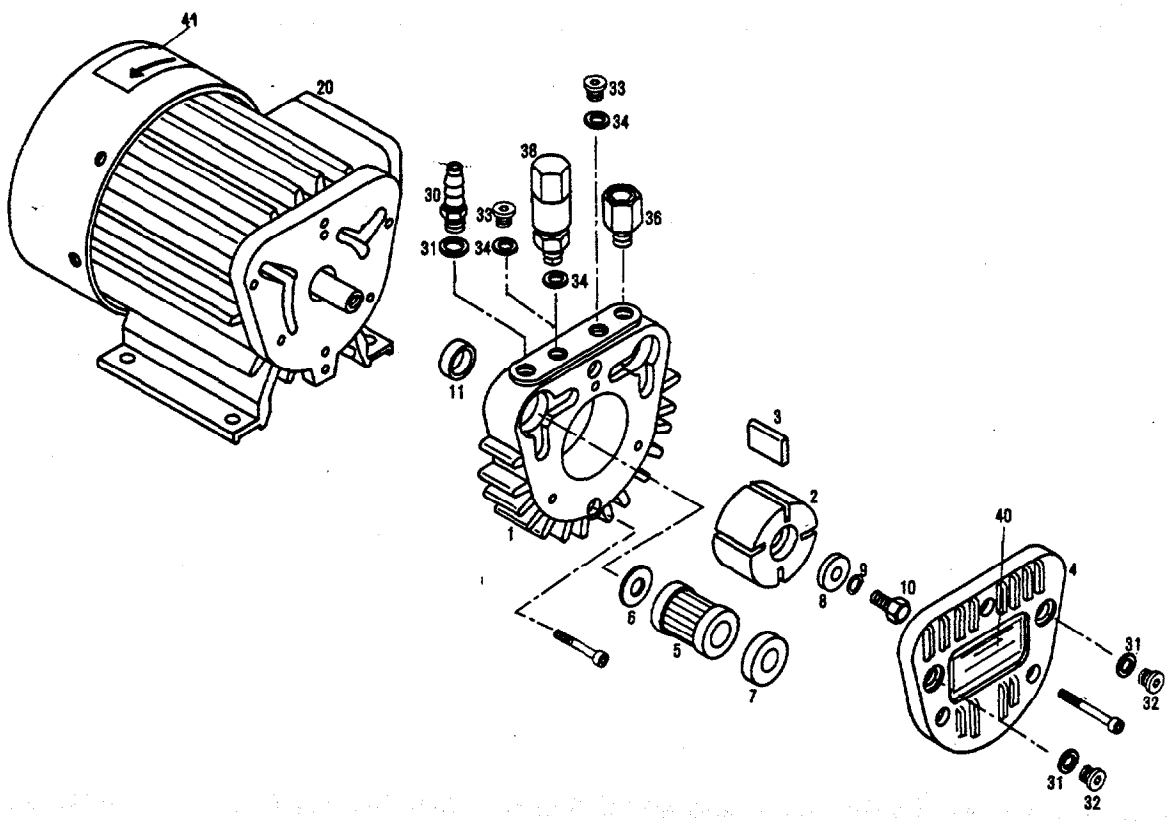
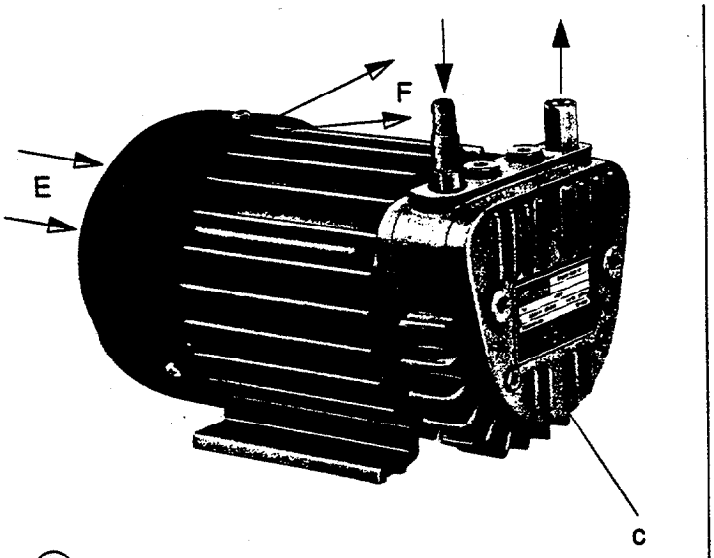


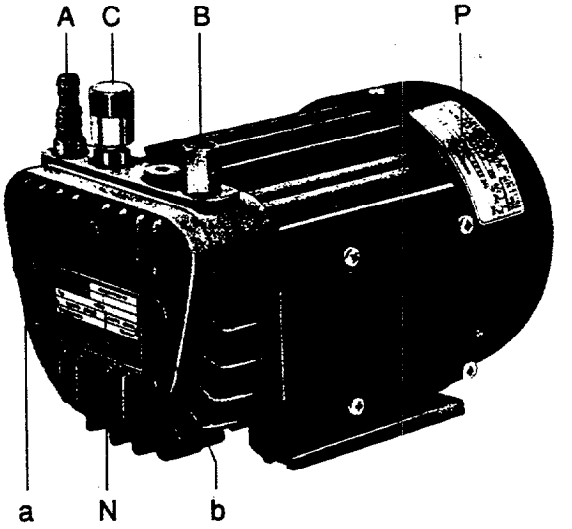
		Grundteile	Parts	Eléments de base	Parti fondamentali
1		Gehäuse	Housing	Corps	Corpo pompa
2		Rotor	Rotor	Rotor	Rotore
3	V	Lamelle	Blade	Palette	Paletta
4		Gehäusedeckel	End cover	Couvercle de corps	Coperchio corpo pompa
5	V	Filterpatrone	Filter cartridge	Cartouche filtre micronique	Cartuccia filtrante microfine
6	D	Dichtring	Sealing ring	Anneau d'étanchéité	Anello guarnizione
7	D	Dichtscheibe	Sealing disc	Disque d'étanchéité	Disco guarnizione
8		Scheibe	Disc	Disque	Disco
9		Federscheibe	Spring shim	Rondelle ressort	Disco elastico
10		Sechskantschraube	Hexagon head screw	Boulon six pans	Vite con testa esagonale
11		Distanzscheibe	Spacer shim	Rondelle entre-toise	Disco distanziatore
20		Motor mit Anschlußdeckel	Motor with connection cover	Moteur avec couvercle raccordement	Motore con coperchio di collegamento
		Anbauteile	**Assembly parts**	**Eléments de montage**	**Elementi di montaggio**
30		Schlauchanschluß	Hose connection	Raccord tuyau	Allacciamento flessibile
31	D	Dichtring	Sealing ring	Anneau d'étanchéité	Anello guarnizione
32		Verschlußschraube	Plug	Bouche obturateur	Vite di chiusura
33		Verschlußschraube G 1/8	Plug G 1/8	Bouche obturateur G 1/8	Vite di chiusura G 1/8
34	D	Dichtring	Sealing ring	Anneau d'étanchéité	Anello guarnizione
36		Ausblasschalldämpfer	Exhaust silencer	Silencieux refoulement	Silenziatore allo scarico
		Zubehör	Optional extra	Accessoires	Accessori
38		Vakuum-Regulierventil ZRV	Vacuum regulating valve ZRV	Valve réglage vide ZRV	Valvola regolazione vuoto ZRV
		Schilder	**Labels**	**Plaque signalétiques**	**Targhette**
40		Datenschild	Data plate	Etiquette caractéristique	Targhetta dati
41		Motordatenschild	Motor data label	Etiquette caractérist: moteur	Targhetta dati del motore

Bei Bestellungen folgendes angeben: Typ, Fabrikations-Nr., Positions-Nr., Motor (kW, V, Hz).
To order please indicate: model, serial-no., item-no., motor (kW, V, Hz).

V = Verschleißteile / **V** = Fast-wearing parts
D = Dichtungen / **D** = Seals



(I)



(II)

Eignung
Die Typen VTE 3, VTE 6 und VTE 8 sind trockenlaufende Vakuumpumpen und eignen sich zum Fördern von Luft mit normaler Feuchtigkeit und trockenen Gasen bis zu einem Enddruck (abs.) von 150 mbar.
Achtung! **Die Umgebungstemperatur darf 40°C nicht überschreiten. Bei höheren Temperaturen bitten wir um Rücksprache.**
Es dürfen keine gefährlichen Beimengungen (z.B. Lösemittel), extrem feuchte Luft, Wasserdampf, aggressive Gase oder Spuren von Öl und Fett angesaugt werden.

Standort
Beim Einbau der Pumpe muß für Wartungsarbeiten vor dem Gehäusedeckel (c) genügend Platz vorhanden sein. Zusätzlich ist zu beachten, daß der Kühlluft. Eintritt (E) und der Kühlluft-Austritt (F) mindestens 8 cm Abstand zur nächsten Wand haben (austretende Kühlluft darf nicht wieder angesaugt werden).

Inbetriebnahme
Bei Aufstellung und Betrieb ist die Unfallverhütungsvorschrift »Verdichter« VBG 16 zu beachten.
1. Motordaten (Motordatenschild (P)) mit vorhandenem Stromnetz vergleichen (Stromart, Spannung, Netzfrequenz, zulässige Stromstärke).
2. Motor über Motorschutzschalter anschließen (zur Absicherung des Motors ist ein Motorschutzschalter und zur Zugentlastung eine PG-Verschraubung vorzusehen).
   Wir empfehlen die Verwendung von Motorschutzschaltern, deren Abschaltung zeitverzögert erfolgt, abhängig von einem evtl. Überstrom. Kurzzeitiger Überstrom kann beim Kaltstart der Maschine auftreten.
   Der Elektroanschluß darf nur von einer Elektrofachkraft unter Beachtung der Unfallverhütungsvorschrift »Elektrische Anlagen und Betriebsmittel« VBG 4 vorgenommen werden.
3. Pumpe zur Drehrichtungs-Überprüfung (Motordatenschild (P)) kurz starten.
   Achtung! Vakuumanschluß muß offen sein, sonst können bei falscher Drehrichtung die Lamellen brechen.
4. Saugleitung an (A) anschließen. Die Abluft wird durch den Ausblasschalldämpfer (B) ausgeblasen.
5. Der Schlauchstutzen (A) und der schalldämpfende Ausblasschalldämpfer (B) können wahlweise auch stirnseitig an den Stellen (a) und (b) eingeschraubt werden.
6. Vakuum-Regulierventil (Zubehör):
   Die Einstellung des Vakuums kann durch Drehen des Regulierknopfes (C) erfolgen.

Application
VTE 3, VTE 6 and VTE 8 models are dry running vacuum pumps and are designed for handling air with normal relative humidity and dry gases up to an ultimate vacuum of 150 mbar.
Please note: **The ambient temperature may not exeed 40°C. At higher temperatures please contact us.**
No dangerous mixtures (i.e. solvent), excessive humid air, water vapour, or aggressive gases or traces of oil or grease in the air can be handled.

Positioning
When the pump is built-in there must be enough space in front of end cover (c) for maintenance. Also cooling air entries (E) and cooling air exits (F) should have at least 8 cm distance from any walls. Do not recirculate heated up cooling air.

Initial start
When fitting and operating the compressor the Health and Safety rules at work should always be applied.
1. Check the incoming voltage and frequency to see that they correspond to the motor (motor data label (P)).
2. Connect the motor to the incoming supply. It is advisable to use a motor starter to protect the motor.
   We recommend that motor starters should be used that are fitted with a time delayed trip resulting from running beyond the amperage setting. When the unit is started cold over amperage may occur for a short time.
   Electrical connections should only be made by a qualified electrician.
3. Check direction of rotation by switching the motor on and off (motor data label (P)).
   Please note: To prevent the rotor blades being damaged do not connect the vacuum pipe until the correct direction of rotation is achieved.
4. Connect vacuum pipe at (A). The air is exhausted through the exhaust silencer (B).
5. The hose connection (A) and exhaust silencer (B) can be fitted alternatively in the front cover in the positions (a) and (b).
6. Vacuum regulating valve (Optional extra): **The vacuum can be regulated by regulating valve (C).**

Application
Les pompes modèles VTE 3, VTE 6 et VTE 8 sont des pompes à vide fonctionnant à sec et qui atteignent un vide limite de 150 mbar absolu. Elles sont conçues pour aspirer et véhiculer de l'air à teneur d'humidité normale ainsi que des gaz secs.
Attention: **La température ambiante ne doit pas dépasser 40°C. Pour les températures plus élevées veuillez nous consulter.**
Des mélanges dangereux (ex. solvants), de l'air à teneur de vapeur d'eau, d'huile ou de gaz corrosifs ne peuvent être aspirés.

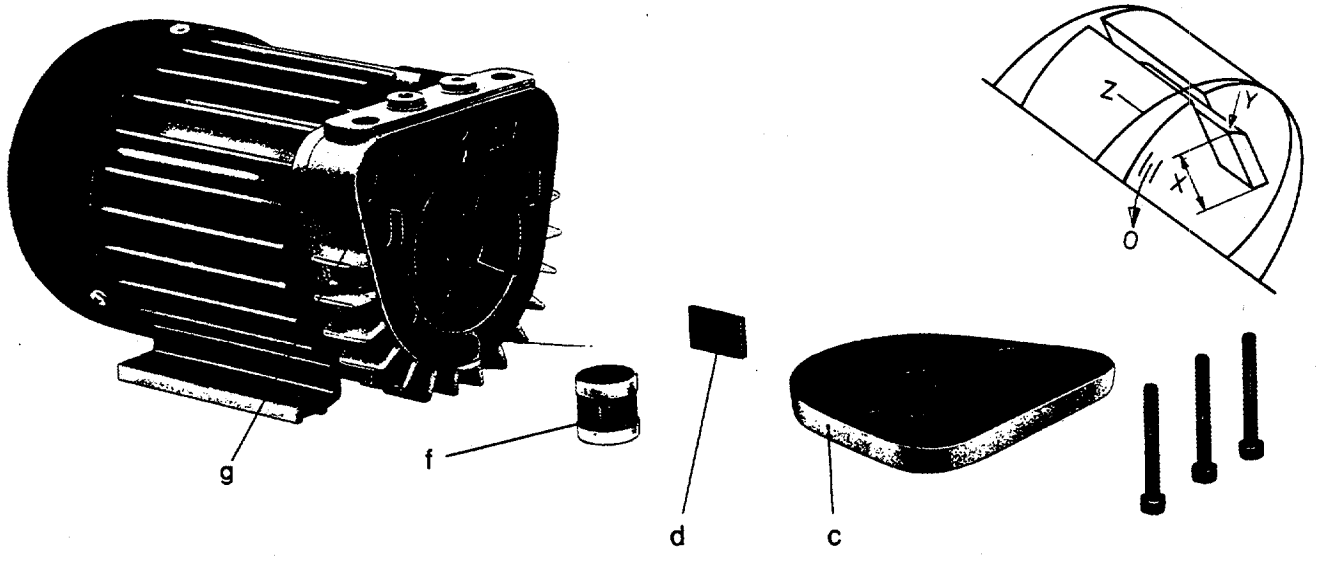
Installation
Pour permettre les opérations de contrôle et de maintenance, le couvercle de corps (c) doit rester facilement accessible.
Lors de l'implantation il y a lieu de faire en sorte que l'entrée (E) et la sortie (F) d'air de refroidissement soient situées au minimum à 8 cm des parois environnantes. (L'air de refroidissement refoulé ne doit pas pouvoir être réaspiré).

Mise en service
Lors de l'installation et utilisation, il faut respecter les conseils d'utilisation et de protection.
1. Vérifier que la tension, la fréquence et l'ampérage de l'installation électrique soient adaptés au moteur (étiquette caractérist. moteur (P)).
2. Les moteurs électriques doivent être protégés à l'aide d'un disjoncteur. Le cable électrique sera bloqué à l'aide d'un presse-étoupe.
   Nous recommandons un disjoncteur à coupure temporisée, indépendament d'une surtension éventuelle. Lors d'un démarrage à froid, peut intervenir une surtension momentanée.
   Les travaux de raccordements électriques doivent être effectués par un électricien agréé.
3. Vérifier le sens rotation (étiquette caractérist. moteur (P)) par une mise en route momentanée.
   Attention! L'orifice d'aspiration doit rester ouvert, car lors d'une inversion de sens de rotation les palettes peuvent être détériorées.
4. Raccorder la tuyauterie d'aspiration en (A). L'air refoulé est évacué par le silencieux (B).
5. Les embouts (A) ainsi que le silencieux de refoulement (B) peuvent également être monter sur la partie avant en position (a) ait (b).
6. Valve de réglage du vide (accessoire): Le réglage du vide se fait à l'aide de la valve (C).

Impiego
Le pompe per vuoto a secco della serie VTE 3, VTE 6 e VTE 8 sono adatte per il convogliamento di aria avente un tasso di umidità normale e gas secchi fino a un vuoto finale (ass.) di 150 mbar.
Attenzione! **La temperatura ambiente non devere superare i 40°C. Nel caso deve di temperature piú alte vi preghiamo di comunicarcelo preventivamente.**
Non devono essere aspirate miscele pericolose (ad. es. solventi), aria molto umida, vapore acqueo, gas aggressivi o tracce di olio o grasso.

Installazione
Installando la pompa bisogna prevedere uno spazio sufficiente davanti al coperchio corpo pompa (c) per la manutenzione. Inoltre le entrate (E) e le uscite (F) dell'aria di raffreddamento devono distare almeno 8 cm. dalla parete più vicina (l'aria servita per il raffreddamento non deve essere riaspirata).

Messa in servizio
Durante il montaggio ed il funzionamento osservare le norme antifortunistische.
1. Verificare che i dati del motore (dati del motore (P)) corrispondano ai valori di rete (tensione, frequenza, corrente nominale).
2. Avviare il motore tramite salvamotore. I cavi di allacciamento vanno ancorati a mezzo di apposite fascette di fissaggio.
   Raccomandiamo l'impiego di salvamotori la cui disinserzione viene ritardata in presenza di una eventuale sovracorrente. Una sovracorrente di breve durata è riscontrabile nell 'avviamento a freddo della macchina.
   L'allaciamento elettrico può esserc eseguito soltanto da elettricisti specializzati.
3. Avviare brevemente la pompa per controllare il senso di rotazione (dati del motore (P)).
   Attenzione: Il collegamento della tubazione aspirante dev'essere aperto, altrimenti, nel caso di rotazione in senso contrario, le palette potrebbero spezzarsi.
4. Collegare la tubazione aspirante al punto (A). L'aria utilizzata viene scaricata al punto (B).
5. Il tronchetto del tubo flessibile (A) ed il silenziatore (B) possono essere avvitati in alternativa anche frontalmente nei punti (a) e (b).
6. Valvola regolazione vuoto (accessorio): La regolazione del vuoto può essere effettuta sull'apposita valvola di regolazione (C).



(III)

Wartung
Bei Maßnahmen zur Instandhaltung, bei denen Personen durch bewegte oder spannungsführende Teile gefährdet werden können, ist die Pumpe durch Ziehen des Netzsteckers oder Betätigen des Hauptschalters vom E-Netz zu trennen und gegen Wiedereinschalten zu sichern.
Schmierung:
Alle Typen haben eine Dauerfettschmierung und brauchen nicht geschmiert werden.
Luftfilterung:
Filterpatrone (f) muß monatlich gereinigt und jährlich ausgewechselt werden (bei extremen Bedingungen müssen diese Wartungsintervalle je nach Notwendigkeit verkürzt werden.
Filterwechsel:
Gehäusedeckel (c) abschrauben, Filterpatrone (f) mit Dichtungen aus Filterraum (g) herausnehmen. Filter reinigen und Dichtungen überprüfen. Der Einbau erfolgt in umgekehrter Reihenfolge.

Die Typen VTE haben vier Kohlelamellen. Die erste Kontrolle soll nach 6000 Betriebsstunden, danach alle 3000 Betriebsstunden erfolgen.
Lamellenwechsel: Gehäusedeckel (c) abschrauben. Lamellen (d) zur Überprüfung herausnehmen. Alle Lamellen müssen eine Höhe (X) von größer als 12 mm haben. Verdichtergehäuse ausblasen und Lamellen in Rotorschlitze einlegen. Beim Einlegen ist darauf zu achten, daß die Lamellen mit der schrägen Seite (Y) nach außen zeigen und diese Schräge in Drehrichtung (O) mit dem Gehäuseradius (Z) übereinstimmt. Gehäusedeckel (c) leicht anschrauben. Pumpe kurz einschalten und den freien Lauf der Lamellen überprüfen. Gehäusedeckelschrauben fest anziehen.

Maintenance
During maintenance, which could endanger personnel because of moving parts or live connections the pump has to be separated from the incoming power supply. The power supply connection should be completely disconnected or turn off the main isolator, making sure that it can not be turned on without the appropriate authority.
Lubrication:
All models are assembled with sealed for life bearings and need no lubrication.
Air Filtration:
The filter cartridge (f) should be checked and cleaned monthly and replaced once a year depending on operating conditions. To change filter remove end cover (c), remove filter cartridge (f) with gasket of filter room (g). The filter can be cleaned by using oil free low pressure compressed air. Check the gasket and reassemble all parts.

VTE models have four carbon blades. Check vanes after the first 6000 operating hours and thereon after every 3000 operating hours.
Changing blades: Remove end cover (c). Take out vanes (d) for control. All vanes must have a height (X) of larger than 12 mm. Clean the cylinder, replace new blades into the rotor slot with the curved side of the blade (Y) in line with the radius of the rotor (Z) and direction of rotation (O). Replace end cover (c) and slightly tighten the screws. Start pump and check for free and smooth running blades. Then firmly tighten end covers screws.

Maintenance
Mesures de Sécurité. Lorsque des personnes peuvent être exposées au contact de parties électrifiées, il faut débrancher la pompe soit en retirant la fiche soit en actionnant le sectionneur et sécuriser tout rebranchement.
Lubrification:
Tous ces appareils sont équipés de roulements à graissage permanent.
Filtration de l'air:
La cartouche filtrante (f) doit être nettoyée mensuellement et remplacée annuellement. Selon le degré d'impureté de l'air aspiré, ces intervalles d'intervention devront être réduits.
Remplacement de la cartouche filtrante: retirer la cartouche (f) avec les joints après avoir retiré le couvercle de corps (c) enlevé la bague (i). Nettoyage par soufflage ou par tapotement.

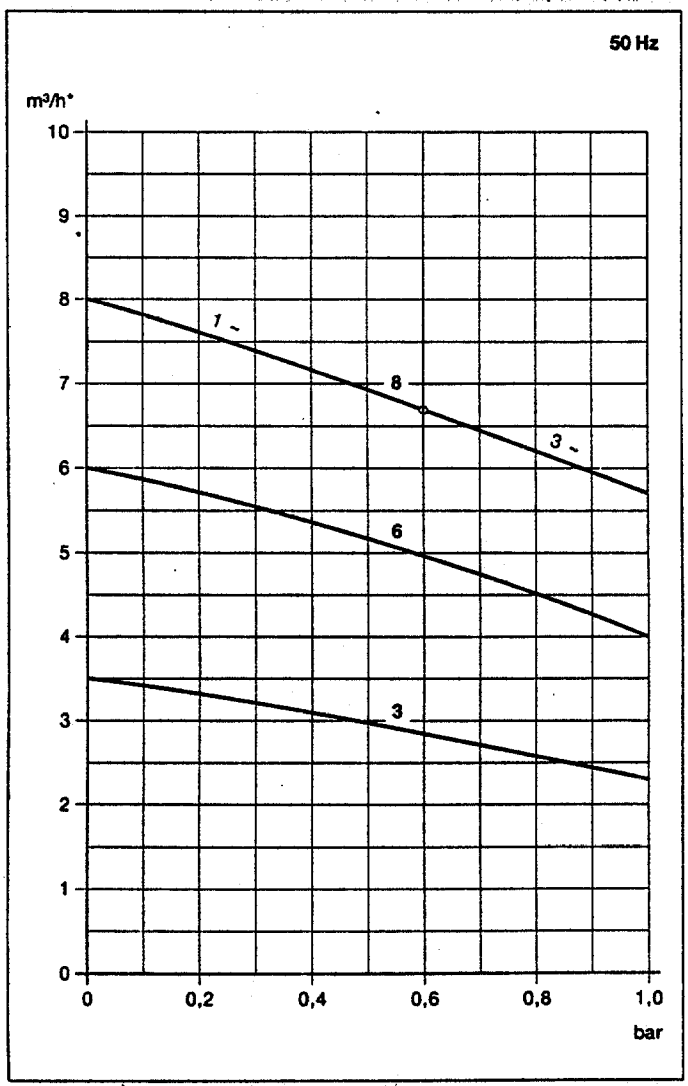
Les modèles VTE comprennent 4 palettes graphites. Leur premier contrôle s'effectue après 6000 h de service puis toutes les 3000 heures de service supplémentaires.
Remplacement de palettes: Enlever le couvercle de corps (c), retirer les palettes (d) pour contrôle. Leur hauteur minimum est de 12 mm. Nettoyer la chambre de compression par soufflage. Les palettes doivent être mises en place dans les rainures du rotor de telle manière que leur côte biseauté (Y) soit orienté vers le haut et que leur chanfrein épouse le rayon du corps (Z) dans le sens de rotation (O). Resserer légèrement le couvercle de corps (c). Mettre la pompe momentanément en marche afin de vérifier le libre mouvement des palettes puis bloquer le couvercle de corps.

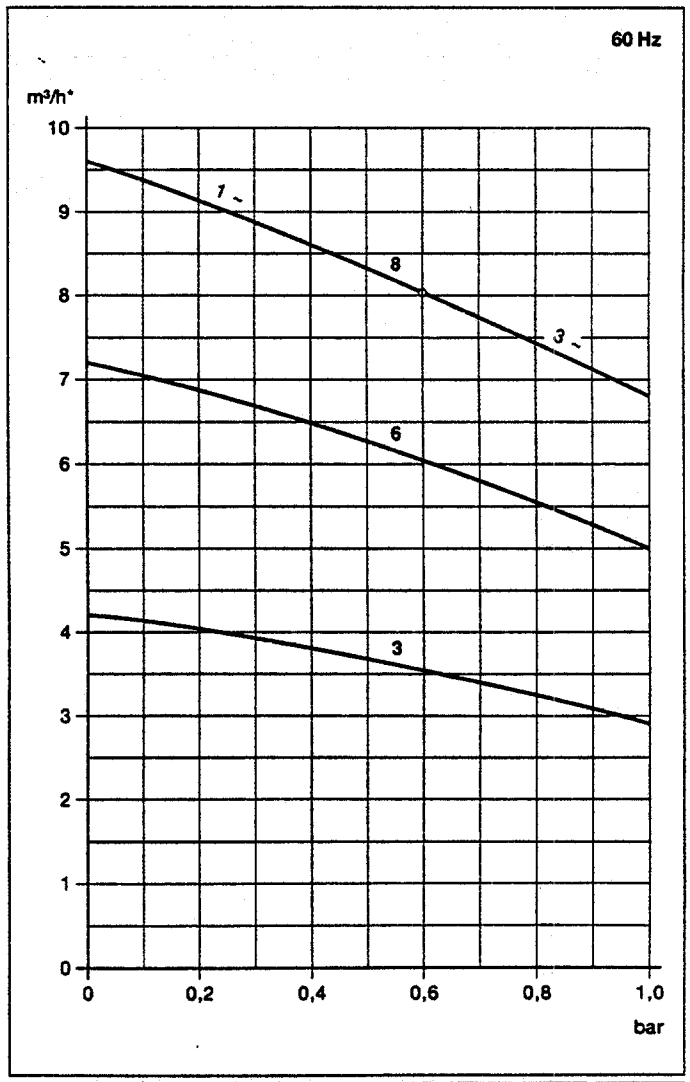
Manutenzione
Si faccia attenzione che qualunque operazione di manutenzione sulle pompe venga effettuata solamente in assenza di tensione!
Lubrificazione:
Tutti questi tipi sono ingrassati a vita e non richiedono pertanto alcun ulteriore ingrassaggio.
Filtri aria:
Le cartucce (f) dei dispositivi filtranti vanno pulite mensilmente e sostituite annualmente, abbreviando comunque opportunamente questi intervalli in condizioni di servizio gravose.
Sostituzione del filtro: Svitare il coperchio corpo pompa (c), la cartuccia (f) con le guarnizioni. Pulire il filtro con un soffio d'aria scuotendolo, e controllare le guarnizioni. Per i montaggio, eseguire queste operazioni in sequenza inversa.

Le pompe per vuoto VTE hanno quattro palette in grafite. Il primo controllo va effettuato dopo 6000 ore di servizio, in seguito ogni 3000 ore.
Sostituzione delle palette: svitare il coperchio corpo pompa (c). Estrarre le palette (d) per il controllo. Tutte le palette della pompa devono avere un'altezza minima di 12 mm. Pulire con un soffio d'aria l'interno del corpo pompa e inserire le palette nelle fessure del rotore facendo attenzione che la smussatura (Y) dello spigolo corrisponda al raggio del rotore (Z). Riavvitare il coperchio (c). Avvitare leggermente il coperchio corpo pompa (c). Avviare brevemente la pompa per verificare che le palette scorrano liberamente. Serrare le viti del corpo pompa.

DTE		3	6	8	
m^3/h	50 Hz	3,5	6,0	8,0	
	60 Hz	4,2	7,2	9,6	
bar		1,0	1,0	0,6 (1~)	1,0 (3~)
3 ~		200–255/346–440 V (50/60 Hz)			
1 ~		230 V ± 10% (50/60 Hz)			
kW (50 Hz)	3 ~	0,12	0,25	0,37	
	1 ~	0,12	0,25	0,35	
kW (60 Hz)	3 ~	0,145	0,30	0,44	
	1 ~	0,145	0,30	0,42	
A (50 Hz)	3 ~	1,1/0,63	1,4/0,81	2,42/1,4	
	1 ~	1,3	2,3	3,9	
A (60 Hz)	3 ~	0,9/0,52	1,44/0,83	2,25/1,3	
	1 ~	1,4	2,5	3,4	
min^{-1}	50 Hz	2750			
	60 Hz	3300			
dB(A)	50 Hz	57	60	64	
	60 Hz	58	61	66	
kg		6,3	7,9	9,1	
ZRD		6	6	12	
ZRK		6 (03)	12 (03)	12 (03)	
ZMS (50 Hz)	3 ~	16/10	16/10	40/16	
	1 ~	16	24	40	
ZMS (60 Hz)	3 ~	10/10	16/10	24/16	
	1 ~	16	40	40	

m^3/h	Volumenstrom	Capacity	Volume engendré	Portata volumetrica
bar	Überdruck	Pressure rating	Surpression	Sovrapressione
3 ~/1 ~	Motorausführung	Motor version	Exécution moteur	Esecuzione motore
kW	Motorleistung	Motor rating	Puissance moteur	Potenza motore
A	Stromaufnahme	Current drawn	Intensité absorbée	Corrente nominale
min^{-1}	Drehzahl	Speed	Vitesse rotation	Numero giri
dB(A)	mittlerer Schallpegel	Average noise level	Niveau sonore moyen	Rumorosità media
kg	max. Gewicht	Weight max.	Poids maxi.	Peso massimo
	Zubehör	Optional extras	Accessoires	Accessori
ZRD	Druck-Regulierventil	Pressure regulating valve	Valve de règlage pression	Valvola regolazione pressione
ZRK	Rückschlagventil	Non return valve	Clapet anti-retour	Valvola di non ritorno
ZMS	Motorschutzschalter	Motor starter	Disjoncteur moteur	Interruttore magnetotermico





*Der Volumenstrom bezieht sich auf freie atmosphärische Luft von 1 bar (abs.) und 20° C. /The capacity refers to free atmospheric air at 1 bar (abs.) and 20° C. / Le débit est mesuré à l'atmosphère de 1 bar (abs.) à 20° C. / La portata si riferisce alla pressione atmosferica di 1 bar (ass.) e 20° C.
Kennlinien und Tabellenangaben beziehen sich auf betriebswarme Verdichter. / Curves and tables refer to compressor at normal operating temperature./Les courbes et tableaux sont établis, compresseur à température de fonctionnement. / Le curve caratteristiche ed i dati riportati nelle tabelle si riferiscono ai compressori con funzionamento a regime.
Technische Änderungen vorbehalten! / We reserve the right to alter technical information! / Sous réserve de modification technique! / Salvo modifiche tecniche!

NIXTOX® Disposable/Refillable

MODULAR ADSORBERS for Flows up to 250 CFM

(U.S. PATENT 4,379,750, CANADA PATENT 1,197,075)

Specifications and Properties 11/15/92

Unit	— Design Maximum — CFM(a)	psig.(b)	°F	Connections NPT	Diameter/ Height, Inches(c)	Adsorbent Pounds(d)	Minimum Contact, Sec.(e)	Shipping Pounds(f)
N20	20	10	350	2"M	16/29	50	5.0	74
N20 XP	20	6	165	3/4"F	14/27	50	5.0	60
N50	50	10	350	2"M	20/30	110	4.3	150
N50 XP	50	6	165	2"F	19/32	110	4.3	135
N100	100	10	350	2"M	24/36	200	3.9	270
N100 XP	100	10	165	2"F	24/39	200	3.9	235
N150	150	10	350	2"M	27/41	300	3.9	395
N250	250	6	350	4"M	33/43	400	3.1	535

(a) Maximum; contact time may require lower flow, see (e).

(b) Per unit. Series pressure additive on upstream unit(s). pressure applies to XP closed-head version.

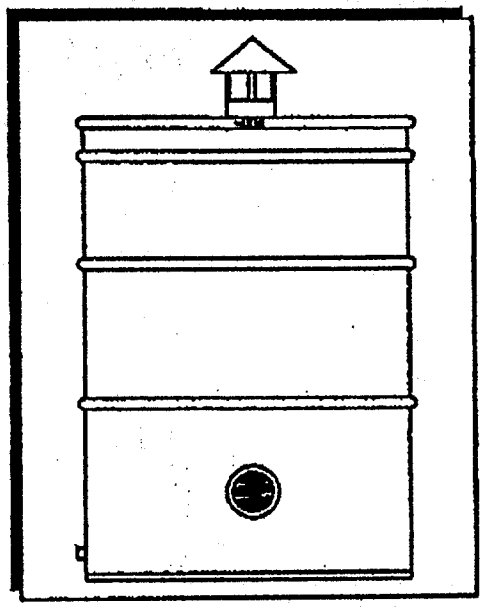
(c) Primary adsorber vessel, including support assembly

(d) Virgin TIGG 5C 0410 Activated Carbon, see (f).

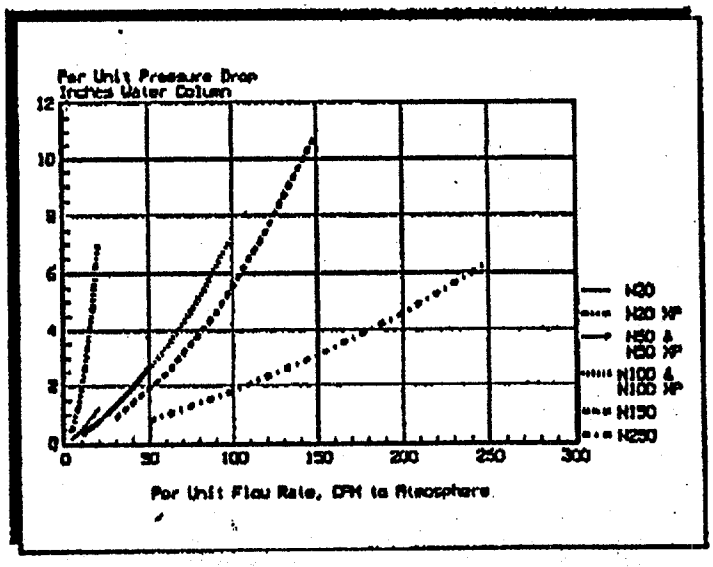
(e) Superficial at maximum flow.

(f) Active carbon basis. Other adsorbents, prewetting will change.

Economical deep bed units may be refilled or discarded with spent adsorbent. Model numbers designate maximum flow in CFM. All feature TIGG's patented vapor distributors to permit full adsorbent utilization and peak removal efficiency, at low pressure drop and low operating cost. Rain shields and condensate drains are standard. Standard construction is corrosion resistant steel with stainless distributor. XP models are built of cross-linked polyethylene for extraordinarily corrosive duty. N50 and N100 are double epoxy/phenolic lined D.O.T 5B drums, N20 is D.O.T. 17H.



FLOW RESISTANCE



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