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Work Implementation Plan for a Demonstration of Intrinsic Remediation of Chlorinated Solvents at Investigation Clusters 17, 19, and 21

McCLELLAN AIR FORCE BASE, CALIFORNIA

Prepared for

McCLELLAN AIR FORCE BASE ENVIRONMENTAL MANAGEMENT

October 1997

Prepared by

PARSONS ENGINEERING SCIENCE, INC.
2101 WEBSTER STREET, SUITE 700, OAKLAND, CA 94612 • 510/891-9085
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WORK IMPLEMENTATION PLAN FOR A DEMONSTRATION OF INTRINSIC REMEDIATION OF CHLORINATED SOLVENTS AT INVESTIGATION CLUSTERS 17, 19, AND 21

at

McCLELLAN AIR FORCE BASE, CALIFORNIA

Prepared for

Environmental Management
McClellan Air Force Base, California

October 1997

Prepared by

PARSONS ENGINEERING SCIENCE, INC.
2101 WEBSTER STREET, SUITE 700, OAKLAND, CA 94612 • 510/891-9085
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LIST OF ACRONYMS

°C	degrees centigrade (Celsius)
°F	degrees Fahrenheit
2-D	two-dimensional
AFB	Air Force Base
ARARs	Applicable or Relevant and Appropriate Requirements
bgs	below ground surface
BOD	biological oxygen demand
BTEX	benzene, toluene, ethylbenzene, and total xylenes
Cal/EPA	California Environmental Protection Agency
$CaCO_3$	calcium carbonate
CAH	chlorinated aliphatic hydrocarbon
COC	contaminants of concern
COPC	contaminants of potential concern
CS	Confirmed Site
CSM	conceptual site model
CPT	cone penetrometer testing
CT	carbon tetrachloride
DCA	dichloroethane
DCE	dichloroethene
DO	dissolved oxygen
DTSC	Department of Toxic Substances Control
EC	electrical conductivity
ES	Engineering-Science, Inc.
EW	Extraction Wells
Fe^{+2}	ferrous iron
FS	Feasibility Study
ft	foot/feet
ft/day	feet per day
ft/ft	foot per foot
ft/s	feet per second
ft^2	square feet
g/cm^3	grams per cubic centimeter
GC/MS	gas chromatograph/mass spectrometer

LIST OF ACRONYMS (continued)

GWOU	Groundwater Operable Unit
GWMP	Groundwater Monitoring Program
GSAP	Groundwater Sampling and Analysis Plan
HASP	Health and Safety Plan
HDPE	high-density polyethylene
IAG	Interagency Agreement
IC	Investigation Cluster
ID	inside diameter
IDW	investigation-derived waste
IROD	Interim Record of Decision
IRP	Installation Restoration Program
IWTP	Industrial Wastewater Treatment Plant
kg	kilogram
L	liter
LTM	long-term monitoring
MCL	Maximum Contaminant Level
mg	milligrams
mg/kg	milligrams per kilogram
µg/kg	micrograms per kilogram
µg	micrograms
µg/L	microgram per liter
mg/L	milligram per liter
MP	monitoring point
msl	mean sea level
mV	millivolts
MW	monitoring well
N	nitrogen
NFI	No Further Investigation
OD	outside diameter
ORD	Office of Research and Development
ORP	Oxidation/reduction potential
OSWER	Office of Solid Waste and Emergency Response
Parsons ES	Parsons Engineering Science, Inc.
PCBs	polychlorinated biphenyls

LIST OF ACRONYMS (continued)

PCE	tetrachloroethene
pH	negative logarithm of the hydrogen ion concentration
POC	point-of-compliance
ppmv	parts per million, by volume
ppbv	parts per billion, by volume
PEL	Permissible Exposure Limit
PID	Photoionization Detector
PRL	Potential Release Location
PVC	polyvinyl chloride
PWS	Performance Work Statement
QA/QC	quality assurance/quality control
redox	reduction/oxidation potential
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RNA	remediation by natural attenuation
ROD	Record of Decision
RWQCB	Regional Water Quality Control Board (California)
s	second
SAP	Sampling and Analysis Plan
SB	soil boring
SOP	Standard Operating Procedure
SVE	soil vapor extraction
SVOC	semivolatile organic compound
SW	surface water
SWRCB	State Water Resources Control Board (California)
TCE	trichloroethene
TEMB	tetramethylbenzene
TMB	trimethylbenzene
TOC	total organic carbon
TO	total organics
TPH	total petroleum hydrocarbons
TPH-d	TPH as diesel fuel
TPH-e	total petroleum hydrocarbons, extractable
TPH-g	TPH as gasoline

LIST OF ACRONYMS (continued)

TS	treatability study
TVH	total volatile hydrocarbons
TVHA	total volatile hydrocarbon analyzer
US	United States
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	underground storage tank
VC	vinyl chloride
VMP	vapor monitoring point
VOC	volatile organic compound
WIP	Work Implementation Plan

SECTION 1

INTRODUCTION AND BACKGROUND

SECTION 1

INTRODUCTION AND BACKGROUND

1.1 PROGRAM OVERVIEW

This work implementation plan (WIP), which was prepared by Parsons Engineering Science, Inc. (Parsons ES) under contract with McClellan Air Force Base (AFB), describes the scope of work required for the collection and analysis of data to evaluate intrinsic remediation (sometimes referred to as natural attenuation, intrinsic bioremediation, or passive bioremediation) of groundwater containing chlorinated solvents beneath Investigation Clusters 17, 19, and 21 (ICs 17/19/21). An important component of the intrinsic remediation evaluation will be to assess the potential for natural biodegradation to reduce the toxicity and mobility of site-related contamination. The term "natural biodegradation" as used in this WIP refers to the biodegradation of chlorinated solvents by indigenous microorganisms without an engineered system. The conditions that allow for the biodegradation processes to occur have been largely determined by the manmade conditions specific to groundwater beneath ICs 17/19/21, namely the co-disposal of fuels with the chlorinated solvents.

Natural attenuation is often listed as an "innovative technology" in published EPA guidance documents to clearly distinguish it from the "No Action" alternative. Although not a technology per se, the word technology is defined as "a manner of accomplishing a task especially using technical processes, methods, or knowledge" (Merriam-Webster Dictionary). Since natural attenuation can potentially accomplish site remediation using technical knowledge about microbial processes and because long-term monitoring methods and knowledge about the progress of remediation are used, the word "technology" is appropriate. An evaluation of natural attenuation requires the actions of process evaluation, contaminant fate and transport modeling, and long-term monitoring. Unlike the "No Action" alternative, a natural attenuation alternative would be expected to attain cleanup levels in a reasonable time frame.

In this WIP, the term "natural attenuation" will be used to refer to the processes (e.g., biodegradation) which are occurring, while "intrinsic remediation" will be used to refer to a management strategy or remedial approach which relies upon natural attenuation processes as the main component of site remediation. Therefore, an intrinsic remediation strategy would include evaluation of natural attenuation processes, fate and transport calculations, long-term monitoring and compliance, and exposure controls.

Data proposed to be collected under this WIP are unique, are not duplicative of any previous efforts, and are necessary to evaluate whether intrinsic remediation can be a cost-effective remedial strategy for the site. Several data analysis techniques will be used after the data

collection phase of this proposed activity to quantitatively evaluate and characterize biodegradation processes for chlorinated solvents.

Documenting the effects of natural attenuation processes, specifically biodegradation, is a critical, but often overlooked, element of completing a quantitative exposure pathways analysis. These data are necessary to assess the need to include engineered remediation techniques into the overall site remedial strategy. The U.S. Air Force Center for Environmental Excellence (AFCEE), in concert with the US Environmental Protection Agency's (USEPA's) National Risk Management Research Laboratory (NRMRL) and Parsons ES, has developed two technical protocols that describe how to scientifically investigate and document natural attenuation of both petroleum hydrocarbons and chlorinated aliphatic hydrocarbons (CAHs) (Wiedemeier *et al.*, 1995; Wiedemeier *et al.*, 1996a and included as Appendix D). If site-specific data indicate that chemical mass-reducing processes, such as biodegradation, are occurring at rates sufficient to minimize transport within the environment and interrupt potential receptor exposure pathways, the Air Force advocates that intrinsic remediation strategies should play a central role in remedial plans for the site. At most sites, including McClellan AFB, long-term monitoring and compliance plans are required to demonstrate that natural attenuation processes continue to occur and exposure controls are required to prevent extraction and use of contaminated groundwater.

Information developed as part of this effort is intended to supplement existing environmental investigation and restoration programs which are already in place at McClellan AFB. Data collected under this demonstration effort can be used to supplement existing site characterization data, risk assessment findings and conclusions, Remedial Investigation/Feasibility Study (RI/FS) recommendations, and the Basewide Groundwater Operable Unit (GWOU) Final Interim Record of Decision (IROD) completed under the Interagency Agreement (IAG) (CH2M Hill, 1995).

1.2 TECHNOLOGY NEED

The GWOU IROD requires that McClellan AFB continue to investigate and evaluate potential remedial solutions. Although not specifically evaluated in the GWOU IROD, intrinsic remediation can be more cost-effective than engineered remedial solutions and an appropriate technology to comply with the statutory determinations of the GWOU IROD if properly evaluated, documented, and monitored. The statutory determinations of GWOU IROD are: overall protection of human health and the environment, compliance with applicable or relevant and appropriate requirements (ARARs), cost-effectiveness, use of permanent solutions or alternative treatment, and preference for treatment solutions that reduce toxicity, mobility, and volume.

In some, but not all, cases, intrinsic remediation may need to be combined with limited source removal technologies (e.g., soil vapor extraction [SVE]) to achieve the desired goals in a reasonable time frame and/or to gain community or state acceptance. At McClellan AFB, SVE is currently being used as a presumptive remedy for sites that meet certain threshold criteria for types of contaminants and concentrations in the vadose zone (MITRE, 1993). These engineered source reduction techniques can be employed to reduce or control any unacceptable risks associated with source area contamination; minimize long-term

compliance costs that can be associated with non-intrusive risk reduction techniques; and/or satisfy other requirements such as regulatory direction, public pressure, or to achieve aesthetic goals.

Intrinsic remediation has gained widespread attention and acceptance as a remedial alternative within the last few years, especially intrinsic remediation of petroleum-hydrocarbons (Hinchee *et al.*, 1995). However, recently the potential for intrinsic remediation of chlorinated solvents has also been recognized (USEPA, 1996). However, Wiedemeier *et al.* (1996a) estimate that while at 80% of sites contaminated with petroleum-hydrocarbons, intrinsic remediation alone may be protective of human health and the environment, this same criteria may only be met at 20% of sites contaminated with chlorinated solvents. Therefore, an accurate assessment of the potential for biodegradation of chlorinated compounds must be made prior to investing in a detailed study.

Based on a preliminary evaluation of the existing site characterization for ICs 17/19/21 using the screening process detailed in the *Technical Protocol For Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater (Draft, Revision 1)* (Wiedemeier *et al.*, 1996a and included as Appendix D), the need for a more complete evaluation of natural attenuation processes at ICs 17/19/21 was considered appropriate. The preliminary evaluation is discuss in detail in Section 2.4 and Section 3.2.

1.3 PURPOSE

The primary purpose of the proposed activities is to collect sufficient site-specific data to assist with remedial design planning for ICs 17/19/21 and incorporate intrinsic remediation into the final remedy for the site, as appropriate. For example, the biodegradation rates and models developed as part of this evaluation could be used to optimally place groundwater extraction wells, manage pumping rates to maximize containment strategies, and estimate remaining time to reach groundwater remediation goals. A secondary purpose will be to incorporate the results of this study into future revisions of the technical protocol document. A mature, field-tested technical protocol document would establish a framework for evaluating intrinsic remediation at other sites at McClellan AFB, other Department of Defense (DoD) facilities, or any other contaminated sites. Objectives of this demonstration study are more fully discussed in Section 4.0.

SECTION 2

SITE DESCRIPTION

SECTION 2

SITE DESCRIPTION

Existing site-specific data were reviewed and used to evaluate the physical characteristics of environmental media, the nature and extent of contamination, and the conceptual models for groundwater flow and contaminant fate and transport at Investigation Clusters (ICs) 17, 19, and 21 in Operable Unit C (OU C). The existing site-specific data were also used to initially screen the site for biodegradation potential, as described in the technical protocol document (Appendix D) and detailed in Section 3.2. Review of available site data aided in defining the additional site characterization data necessary for this demonstration study and to support quantitative modeling efforts (discussed in Sections 4, 5 and 7). Sections 2.1 through 2.4 present a summary of available site data based on review of data from the following sources:

- Installation Restoration Program (IRP), McClellan Air Force Base, Interim Basewide Remedial Investigation: Part 2C: Remedial Investigation Characterization Summary (RICS), Operable Unit C For IC 17, IC 19, and IC 21 (Radian, 1997a);
- Installation Restoration Program (IRP), Stage 7, Preliminary Groundwater Operable Unit Remedial Investigation (Radian, 1992);
- Final, Basewide Groundwater Operable Unit, Interim Record of Decision, McClellan Air Force Base (CH2M Hill, 1995).

2.1 SITE LOCATION AND HISTORY

2.1.1 McClellan Air Force Base

McClellan AFB, an Air Logistics Center for the U.S. Air Force, is located approximately 7 miles northeast of downtown Sacramento and covers approximately 3,000 acres (Figure 2.1). The Base was established in 1936 as the Sacramento Air Depot and is currently the largest industrial employer in Northern California, employing approximately 13,000 civilian and military personnel. As part of its historic and recent mission, the Base provided logistics support for aircraft, weapons systems, communications equipment, and commodity items as well as maintenance, supply, and contracting services. As part of 1995 Base Realignment and Closure (BRAC) activities, the decision was made to close McClellan AFB in 2001 and privatize the mission workload. Past operations have generated various hazardous and toxic wastes, including: industrial solvents, caustic cleaners, electroplating chemicals, heavy metals, polychlorinated biphenyls (PCBs) low-level radioactive wastes, and a variety of fuel oils and lubricants.

Hazardous wastes were disposed of at a variety of burial pits, sludge pits, and miscellaneous disposal trenches and pits. In 1979, groundwater contamination was discovered and

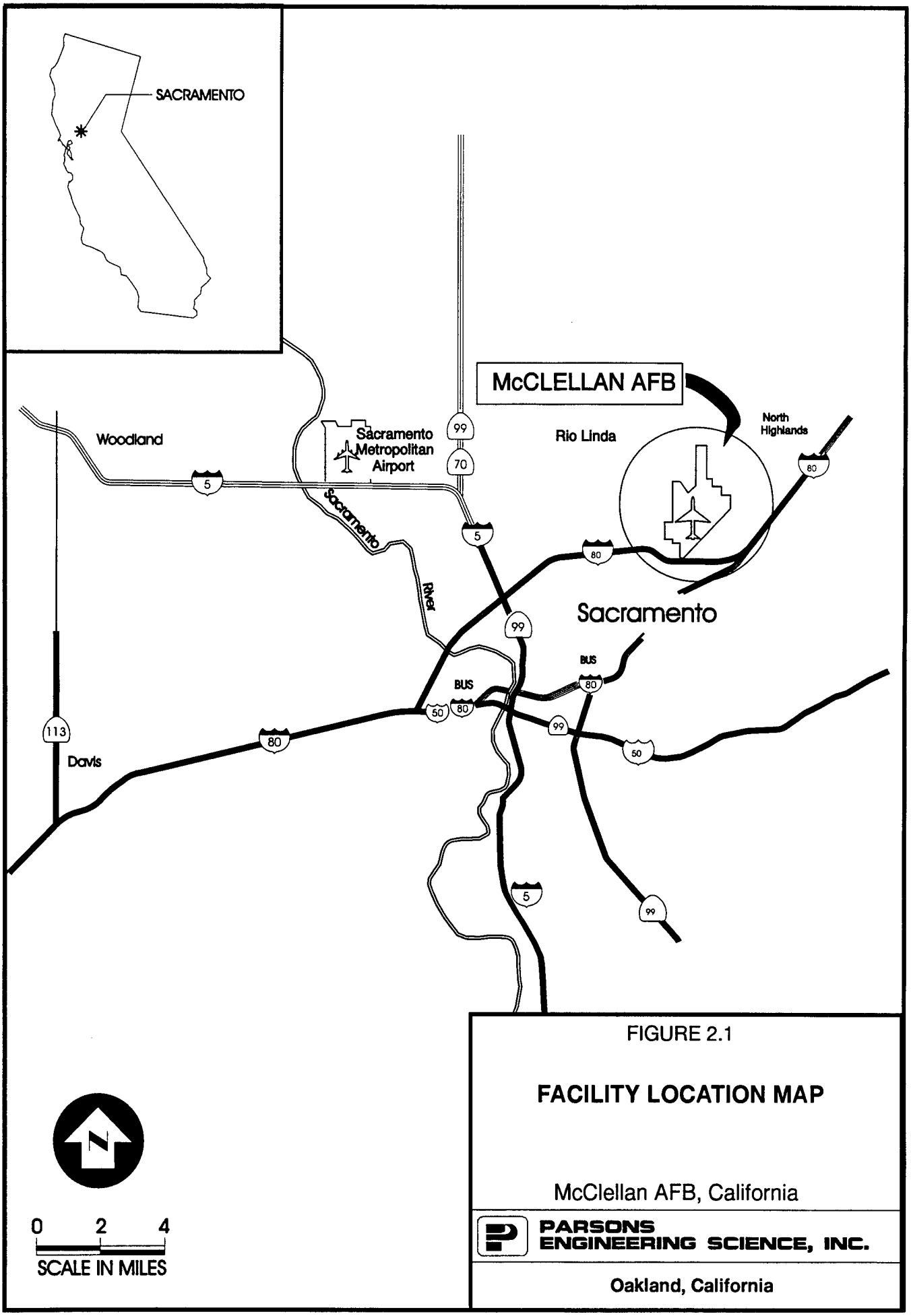


FIGURE 2.1

FACILITY LOCATION MAP

McClellan AFB, California

PARSONS ENGINEERING SCIENCE, INC.

Oakland, California

subsequently base production wells were shut down. Since that time, base production wells have been retrofitted with wellhead treatment systems, numerous monitoring wells (MWs) have been installed, and six groundwater extraction systems have been installed to prevent migration of contaminants.

Numerous environmental investigations have been performed throughout McClellan AFB as part of the U. S. Air Force (USAF) Installation Restoration Program (IRP) and an Interagency Agreement (IAG) between state and federal agencies. Possible sources of contamination at McClellan AFB identified in prior studies are grouped by geographic area, designated as Operable Units (OU) A through H (Figure 2.2). Each OU was further broken down into geographic investigation clusters (IC) comprised of multiple sites. Sites within each IC are generally referred to by their IRP descriptor and number (e.g., CS 10). The most common IRP descriptors used are: SA (Study Area), PRL (potential release locations), SSA (Special Study Areas), CS (Confirmed Sites) and AOC (Area of Concern). An additional OU separately addresses groundwater contamination (GWOU).

2.1.2 Demonstration Study Area

The study area for this demonstration is the contaminated groundwater beneath the source areas within ICs 17, 19, and 21 in OU C (Figures 2.2 and 2.3). However, because this demonstration is evaluating natural attenuation of groundwater contamination, the study area is by definition within the GWOU. The site histories of the source areas within ICs 17, 19, and 21 are discussed in Sections 2.1.2.1 through 2.1.2.3.

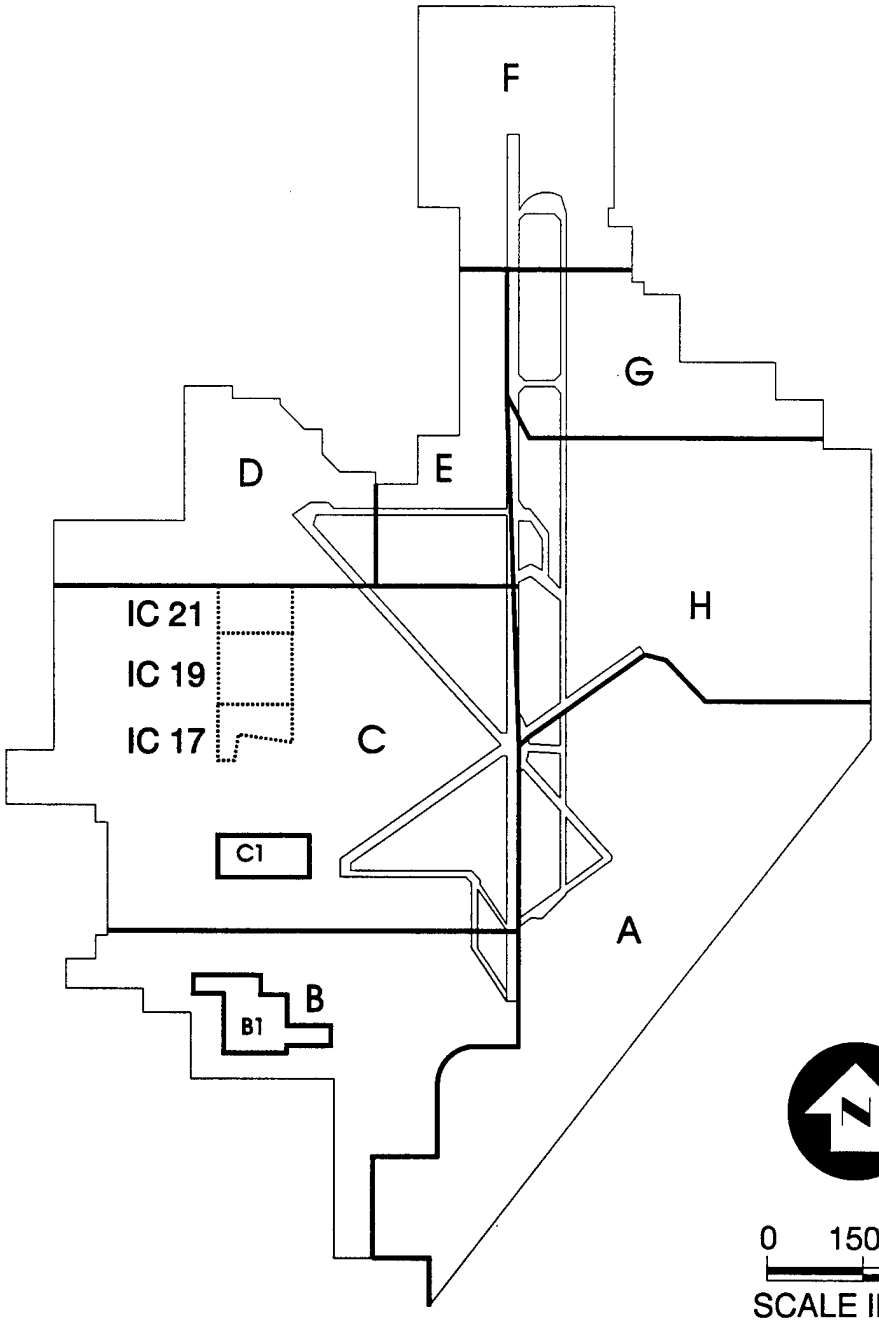
2.1.2.1 Investigation Cluster 21 (IC 21)

IC 21 is located in the north-central area of OU C (Figure 2.3) and is bounded to the north by OU D, by IC 20 to the east, by IC 19 to the south, and by Don Julio Creek to the west. IC 21 includes a former burial pit, the former base landfill, former USTs, and a small arms firing range.

CS 7 was used as a burial pit for disposal of industrial waste and oil, and for waste burning from about 1966 to the mid-1970's. Waste from the Industrial Wastewater Treatment Plant (IWTP), drums of solvents, cyanide, medical supplies, and batteries were also reportedly disposed.

PRL 8 is the former base landfill, a 1.5-acre, unlined Class II-1 landfill that operated from 1974 to 1984. Wastes were placed in a large trench from both the north and the south, leaving a large, unfilled area in the center of the landfill. This unfilled area may have served as a driving force for contaminant migration when rainwater collected in the area. Approximately one-third of the waste material disposed was dewatered industrial sludge.

A 250-gallon diesel underground storage tank (UST) was installed at Building 701 in 1954 and removed in 1990. A 300-gallon diesel UST was installed at Building 712 in 1943 and abandoned in place in 1984 by filling with a cement slurry. No information is available regarding sampling or remedial actions that may have been undertaken during removal or abandonment of these USTs.





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(approx.)

EXPLANATION	
———	BOUNDARIES OF OPERABLE UNITS
.....	BOUNDARIES OF INVESTIGATION CLUSTERS 17, 19, & 21
———	McCLELLAN AFB BOUNDARY

FIGURE 2.2

APPROXIMATE BOUNDARIES OF OPERABLE UNITS AND INVESTIGATION CLUSTERS 17, 19, AND 21

McClellan AFB, California

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Oakland, California

\731010\GRAPHICS\FIGS_P8.CDR 4/7/97

The small arms firing range located northeast of Building 712 was built between 1957 and 1962 and is still in active use. Surface water runoff from the range is discharged to a lined drainage ditch west of IC 21 and soil containing spent ammunition is piled at the southeast end of Building 712.

Previous investigations of IC 21 have identified vadose zone and groundwater contamination (McClaren, 1986; Radian, 1989; CH2M Hill, 1992; Radian, 1997a). COCs include: CAHs (soil gas and groundwater), benzene (groundwater), PCBs (soil), dioxins (soil), metals (soil), and pesticides (soil). A discussion of the groundwater contaminant distribution at IC 21 is presented in Section 2.4.

2.1.2.2 Investigation Cluster 19 (IC 19)

IC 19 is a 20-acre area located south of IC 21. IC 19 is bounded by IC 17 to the south, Don Julio Creek and open grassland to the west, IC 21 to the north, and IC 18 and IC 20 to the east. IC 19 includes former disposal pits, a former fire training area, and a former contaminated soils holding area (Figure 2.3).

CS 10 through 14 were disposal pits that reportedly received industrial waste, ash, and burn residues from waste incinerated elsewhere on the Base. In addition, CS 10 was reportedly used to store low-level radioactive lab waste. These disposal pits were used from approximately 1949 to 1974. The fire training area burn pit was located over the filled and graded disposal pits CS 11 and CS 12 and used from 1977 to 1987. In 1987, the fire training area was regraded, and a high-density polyethylene liner was placed over a clay base. The area was then used to stockpile contaminated soils until 1993. In July 1993, CS 13 and the western portion of CS 14 were graded in preparation for a contractor's staging area. Also in 1993, portions of CS 11 and CS 12 were paved over and this area is currently used to store drums of contaminated soil.

One former UST was located south of CS 14 and used to store sewage waste from portable toilets; it was removed in 1993. An aboveground storage tank used to store fuel for fire training exercises is located near the center of CS 13.

A seasonal creek cuts through the southeast corner of IC 19. Within IC 19 the creek channel is unlined and, historically, washwater contaminated with oil and fuels was discharged into the creek by facilities northeast of IC 19.

Previous investigations of IC 19 have identified vadose zone and groundwater contamination (McClaren, 1985; Radian, 1989; CH2M Hill, 1993; Radian, 1997a). COCs include: CAHs (soil, soil gas, and groundwater), PCBs (soil), dioxin/furan (soil), and radionuclides (soil). A discussion of the groundwater contaminant distribution at IC 19 is presented in Section 2.4.

2.1.2.3 Investigation Cluster 17 (IC 17)

IC 17 is located south of IC 19, near the center of OU C (Figure 2.3). IC 17 is bounded by the IC 19 disposal pits to the north, hush houses and test cells to the east, Building 704 aircraft repair facility to the south, and holding ponds and open fields to the west. Building

702, situated near the center of IC 17, is the only structure within the IC. A lined drainage ditch borders the western boundary and a seasonal creek cuts across the east side of IC 17.

IC 17 is comprised of former waste disposal sites CS 43, CS 52, CS 67, PRL 15, and PRL 16. Another possible contaminant source is a former 250-gallon UST used to store diesel fuel near Building 702.

CS 43 is an inactive burial pit that reportedly received demolition debris and solid and industrial wastes (burned wood, metal, glass, and plastic) from the mid 1940s to 1957 (Radian, 1997a). The total volume of waste and fill is estimated to have been 7,500 cubic yards (yd^3) and may have included solvents and low-level radioactive materials. The dimensions of the disposal pit were approximately 400 feet long by 50 feet wide by 20 feet deep. The pit was covered with soil sometime between 1959 to 1963.

CS 52 is a disturbed soil area located south of CS 43 and was approximately 420 long by 50 feet wide by 25 feet deep. The disturbed area is believed to be a disposal area that received fuel, metal, wood, plastic, paper, and burned materials. The pit was reportedly used between 1956 and 1959; however, waste materials were not found during the OU C RI.

CS 67 is a disposal pit that was located near the northeast corner of IC 17 and was approximately 240 feet long, 160 feet wide, and 10 to 15 feet deep. Solvents, sodium valves, wood, concrete, asphalt, plastic film, burned materials, and other debris were disposed in the pit. It was reportedly used from 1959 to 1963.

PRL 15 and PRL 16 are disturbed soil areas that reportedly were used for disposal of sodium valves from approximately the mid-1940s to the mid-1950s. However, previous investigations have not found any evidence that sodium valves were disposed in these areas and they have been recommended for No Further Investigation (NFI) status.

A 250-gallon diesel UST was installed adjacent to Building 702 in 1959 and removed in 1989. No information is available regarding the removal of the UST or if sampling or remedial actions may have been undertaken during removal.

Previous investigations of IC 17 have identified vadose zone and groundwater contamination (McClaren, 1985; CH2M Hill, 1993; Radian, 1997a). The contaminants include: CAHs (soil, soil gas, and groundwater), total petroleum hydrocarbons (TPH) (soil and soil gas), PCBs (soil and soil gas), dioxin (soil), metals (soil), and radionuclides (soil). However, the only currently identified contaminant of concern (COC) at IC 17 based on a risk assessment is PCB-1260 in soil. A discussion of the groundwater contaminant distribution at IC 17 is presented in Section 2.4.

2.2 GEOLOGY

2.2.1 Regional Geology

McClellan AFB is located in the Sacramento Valley, a deep trough of sediments primarily derived from the erosion of the Sierra Nevada mountains to the east. These alluvial and fluvial sediments were frequently eroded and redeposited by local streams. Meandering and

abandonment of stream channels have produced complex regional and local stratigraphy dominated by lenses of material with little lateral or vertical continuity.

Regionally, soils are mostly fine-grained, but approximately 25 to 30 percent of the deposits are sand and gravel. Soils in the vicinity of the base are extremely variable, but are generally classified as fine, sandy loams. These soils have low shrink-swell potential and generally low soil permeabilities, varying locally. Due to the extreme variability of soils, extrapolation of lithologic units identified from boring logs at horizontal distances greater than 100 feet is difficult.

2.2.2 Site Geology

The following discussion of the geology underlying ICs 17/19/21 was derived from a synthesis of lithologic logs (Radian, 1997a). The subsurface geology is typical of the alluvial and fluvial deposits of this portion of the valley, consisting of interfingering discontinuous lenses of clay, silt, and sand. A representative geologic cross section for OU B and OU C which shows the significant variability in lithologic units, discontinuous lenses, and the difficulty in extrapolating units is shown in Figure 2.4.

Within IC 21, sands with silt lenses occur beneath fill of CS 7 in the western portion of the IC. In the eastern portion of the IC 21, mixtures of silt and clays and sand lenses were encountered below the fill at PRL 8 to a depth of 80 feet bgs. Secondary porosity is evident in most silts below 40 feet bgs.

Within IC 19, the fill from the pits extend to depths as great as 30 feet bgs. Sandy to clayey silt underlie much of IC 19 from 40 to 60 feet bgs. Below 60 feet, sand layers are more abundant. Subsurface lithologies in the western portion of IC 19 tend to be sandier than those in the east. Lithologies in the subsurface to the south also tend to be sandier than lithologies to the north.

Within IC 17, the geology beneath CS 67 consists of high permeability sands with interbedded moderate to low permeability silts from 10 to 30 feet bgs. Below 30 feet bgs silts and clays are the dominant lithologies. In the southern portion of IC 17, silts and clays are the dominant lithologies below the pit material.

2.3 HYDROGEOLOGY

2.3.1 Regional Hydrogeology

The aquifer system in the vicinity of McClellan AFB consists of interfingering lenses of channel, overbank, backwater, sand bars, and flood deposits. The aquifer system is extremely variable over short distances, but broadly interconnected. This aquifer system has been separated into a series of zones for the purposes of groundwater monitoring. These aquifer zones, from shallowest to deepest, are designated A though E (Figure 2.4). The aquifer zones are not hydraulically independent and groundwater can flow vertically between them. Although separate monitoring zones have been designated, the aquifer is generally believed to act as a single hydraulic unit.

General groundwater flow directions have varied greatly over the past 80 years, but have persisted in a south to southwesterly direction during the past decade. This groundwater direction is seen in all of the aquifer zones and is controlled by a regional pumping depression south of Sacramento. South and west of McClellan AFB numerous active private and public water supply wells influence the immediate subregional groundwater flow; therefore, groundwater flow directions on the base can vary locally. The groundwater extraction systems installed at McClellan AFB during the 1980s also exert local hydraulic controls in the shallow aquifer zones. At some locations there appears to be an upward vertical gradient in the lower zones caused by groundwater extraction from the upper zones.

The water table at McClellan AFB is typically between 90 and 110 feet below ground surface (bgs). The water table has declined between 0.09 and 2.0 feet each year between 1955 and 1985. Groundwater levels are expected to continue to decline because of overdrafting of the local groundwater aquifers.

A contaminant smear zone of residual liquid and gaseous phase contaminants (primarily chlorinated aliphatic hydrocarbons) exists in the lower vadose zone due to changes in flow direction and the declining water table (JEG, 1995). As groundwater levels declined, contaminants have re-partitioned to the vadose zone as gases and some contaminants have remained adsorbed onto soil particles.

2.3.2 Site Hydrogeology

The groundwater table in the vicinity of IC 21, IC 19, and IC 17 occurs in the A monitoring zone at an approximate depth of 100 feet bgs. Most of the MWs in the vicinity of these ICs are screened in the A zone and there is little data on the deeper aquifer zones. Based on a plot of relative permeability of the A zone, the deposits in the vicinity of these ICs range from moderate to low permeability. The groundwater flow direction is generally consistent with the regional gradient to the south (Radian, 1992).

To the north of these ICs, extraction wells (EWs) in OU D create a cone of depression which causes the groundwater in the southern portion of OU D to flow generally to the north (groundwater elevations are shown on the contaminant concentrations isopleth figures discussed in Section 2.4). This flow appears to create a groundwater divide within or north of IC 21, although the exact location of the divide is difficult to locate and probably varies both seasonally and with changes in groundwater extraction rates. The proximity of the groundwater divide appears to create a very low to flat gradient in the vicinity of IC 21 and IC 19. The gradient becomes progressively steeper to the south in the vicinity of IC 17. Based on fourth quarter monitoring data for 1996, the average groundwater gradient was 0.0006 ft/ft beneath IC 21, 0.0002 ft/ft beneath IC 19, and 0.0011 ft/ft beneath IC 17 (Radian, 1997a). This general trend in gradient is consistent with data from prior monitoring events. The flow direction for these monitoring periods ranged from southwest to southeast in IC 21 and in the northern portions of IC 19; however, the groundwater flow direction has been historically south-southeast at the southern end of the disposal pits in IC 19 toward IC 17.

2.4 CONTAMINANT DISTRIBUTION

As part of the OU C remedial investigations soil, soil vapor, groundwater, surface water, and sediment samples have been collected at ICs 17/19/21 (Radian, 1997a; 1997b; 1997c). Because the focus of this study is intrinsic remediation of groundwater and will not address remediation of soil, soil vapor, surface water, or sediment contamination, the discussions in this section will focus on contaminants in groundwater.

The contaminants of potential concern (COPCs) in groundwater for ICs 17/19/21 are CAHs and petroleum hydrocarbons. The CAHs which exceed their respective MCLs in groundwater at a minimum of one location include: carbon tetrachloride (CT), tetrachloroethene (PCE), trichloroethene (TCE), 1,1-dichloroethane (1,1-DCA), 1,2-DCA, cis-1,2-dichloroethene (cis-1,2-DCE), 1,1-DCE, chloroform, and vinyl chloride (VC). Petroleum hydrocarbons which have been detected in groundwater at a minimum of one location include: benzene, toluene, and diesel fuel (measured as total petroleum hydrocarbons [TPH]).

A conceptual site model and maximum contaminant concentrations measured during the RI for IC 21, IC 19, and IC 17 are shown in Figures 2.5, 2.6, and 2.7, respectively. As indicated in the conceptual site model diagrams for IC 21 and IC 19, groundwater contamination appears to be a combination of percolation of liquid wastes during higher historic groundwater elevations, infiltration of rainwater through near-surface contaminated soil and deeper soil contaminated by the declining groundwater table, and migration of soil vapor through the vadose zone to groundwater. Groundwater contamination in IC 17 appears to be the result of the upgradient sources at IC 21 and/or IC 19 (Figure 2.3) rather than from sources within IC 17.

Figures 2.8 through 2.14 show the distribution of the most prevalently detected COPCs in groundwater: TPH, PCE, TCE, 1,2-DCE, 1,1-DCE, VC, and Freon 12 (dichloro-difluoromethane). These figures include isopleths drawn using concentrations from both Hydropunch® groundwater samples and samples collected from MWs at different time periods (i.e., from the third quarter of 1994 and the third quarter of 1996). Therefore, these isopleth maps must be interpreted with care. However, the results clearly indicate that both petroleum hydrocarbons (measured as TPH) and CAHs are present in groundwater beneath ICs 17/19/21. The highest concentrations of CAHs were detected at the northern portions of the IC 19 disposal pits, primarily beneath CS 12 and CS 13. The two source areas within IC 21, CS 7 and PRL 8, appear to be source areas of lower concentration and/or have been contaminated due to changes in the groundwater flow direction, as discussed in Section 2.3.2. Although only a limited number of samples were analyzed for TPH, it was detected in 3 out of 4 samples analyzed.

During the RI, screening was performed when non-aqueous phase liquid (NAPL) presence was indicated by wet or damp soil or photoionization detector (PID) readings above 500 parts

per million by volume (ppmv). During this screening, NAPL was indicated at only two locations and confirmed at only one location at 5 to 7 feet below ground surface (out of a total of 54 sampling locations). At this confirmed NAPL location, TCE and toluene were detected at concentrations greater than 100 milligrams per kilogram (mg/kg). Petroleum hydrocarbons and lower concentrations of several other VOCs were also detected. The conclusion drawn in the RI was that the NAPL was a fuel-solvent mixture (the NAPL test does not distinguish between fuels and chlorinated compounds). A subsequent boring drilled adjacent to the same location provided inconclusive results. The GWOU Phase 2 Work Plan (CH2M Hill, 1996b) indicated that the likelihood for subsurface DNAPL is low in OU C, based on partitioning relationships and groundwater concentrations.

The maximum concentrations measured to date in groundwater for each of the CAHs and petroleum hydrocarbons are shown in Table 2.1. Contaminant time series plots for COPCs at IC 17/19/21 are provided in Appendix B.

TABLE 2.1
MAXIMUM DETECTED VOC CONCENTRATIONS IN GROUNDWATER
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Analyte	Concentration (μg/L)	Sampling Location	Sample Type	Date
Benzene	3.1	CS 7, IC 21	Hydropunch	Nov-96
Carbon Tetrachloride	5.0	CS 12, IC 19	Hydropunch	Sep-94
Chloroform	3.4	CS 12, IC 19	Hydropunch	Sep-94
Chlorobenzene	5.2	CS 7, IC 21	Hydropunch	Nov-96
1,2-dichlorobenzene	2.7	CS 13, IC 19	Hydropunch	Sep-94
1,1-DCA	26	CS 7, IC 21	Hydropunch	Oct-94
1,2-DCA	12	FTA, IC 19	Hydropunch	Sep-94
1,1-DCE	550	CS 12, IC 19	Hydropunch	Sep-94
cis-1,2-DCE	284	CS 12, IC 19	MW-354	2Q97
trans-1,2-DCE	11.5	CS 12, IC 19	Hydropunch	Sep-94
Freon 11 (trichlorofluoromethane)	45	CS 14, IC 19	Hydropunch	Sep-94
Freon 12 (dichlorodifluoromethane)	120	CS 14, IC 19	Hydropunch	Sep-94
Methylene Chloride	10	CS 7, IC 21	Hydropunch	Nov-96
PCE	641	CS 12, IC 19	MW-354	2Q97
TCE	628	CS 13, IC 19	MW-355	1Q95
Toluene	5.0	CS 14, IC 19	Hydropunch	Sep-94
Vinyl Chloride	210	CS 12, IC 19	Hydropunch	Sep-94
TPH-d	140	CS 13, IC 19	Hydropunch	Sep-94

FTA = Fire Training Area

SECTION 3

TECHNOLOGY DESCRIPTION

SECTION 3

TECHNOLOGY DESCRIPTION

Intrinsic remediation is a management strategy that relies on natural attenuation mechanisms to remediate contaminants dissolved in groundwater and to control receptor exposure risks associated with contaminants in the subsurface. The USEPA Offices of Research and Development (ORD) and Solid Waste and Emergency Response (OSWER) define natural attenuation as:

> *"The biodegradation, dispersion, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem".*

As suggested by this definition, mechanisms for natural attenuation of CAHs include advection, dispersion, dilution from recharge, sorption, volatilization, abiotic chemical transformation, and biodegradation. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts.

During natural biodegradation, indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the engineered addition of nutrients. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes. Often, the conditions that allow for the biodegradation processes to occur are largely determined by manmade conditions, for example, the co-disposal of fuels with the chlorinated solvents.

3.1 PRINCIPLES OF NATURAL ATTENUATION

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Little *et al.*, 1988; Mayer *et al.*, 1988; Freedman and Gossett, 1989; Alvarez-Cohen and McCarty, 1991a and 1991b; McCarty *et al.*, 1992; McCarty and Semprini, 1994; Vogel, 1994). CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most important.

In a pristine aquifer, native organic carbon is utilized as an electron donor and dissolved oxygen (DO) is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or low-molecular-weight CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed, anaerobic microorganisms typically use native

electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH biodegradation is occurring. In addition, because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of these compounds also can provide evidence on the types of biodegradation processes acting at a site.

As with fuel hydrocarbons, the driving force behind oxidation-reduction (redox) reactions resulting in CAH degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in CAH reduction and oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy.

The following sections describe the biodegradation of those compounds that are most prevalent and whose behavior is best understood.

3.1.1 Electron Acceptor Reactions (Reductive Dechlorination)

The most important process for the natural biodegradation of the more highly chlorinated CAHs is reductive dechlorination. This is the type of process likely to be encountered at ICs 17/19/21. During this process, the CAH is used as an electron acceptor, not as a source of carbon, and a chlorine atom is removed and replaced with a hydrogen atom. Figure 3.1 illustrates the transformation of chlorinated ethenes via reductive dechlorination. In general, reductive dechlorination occurs by sequential dechlorination from PCE to TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dechlorination, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent of the three DCE isomers when they are present as daughter products. Reductive dechlorination of CAHs is associated with the accumulation of daughter products and an increase in the concentration of chloride ions.

Reductive dechlorination affects each of the chlorinated ethenes differently. Of these compounds, PCE is the most susceptible to reductive dechlorination because it is the most oxidized. Conversely, VC is the least susceptible to reductive dechlorination because it is the least oxidized of these compounds. As a result, the rate of reductive dechlorination decreases as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dechlorination. Reductive dechlorination has been demonstrated under nitrate- and iron-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under sulfate-reducing and methanogenic conditions (Bouwer, 1994).

Because CAHs are used as electron acceptors during reductive dechlorination, there must be an appropriate source of carbon for microbial growth in order for this process to occur

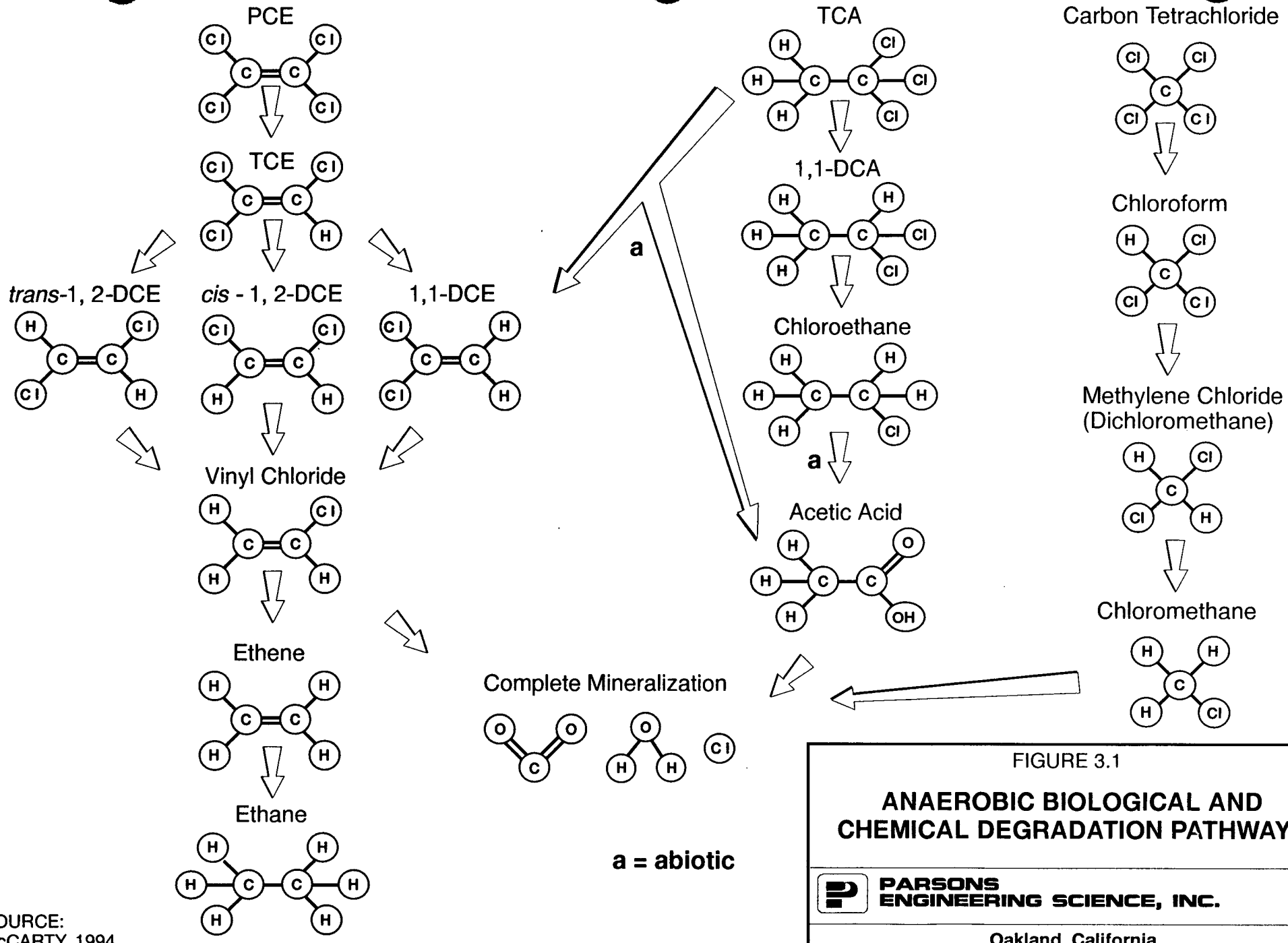


FIGURE 3.1

ANAEROBIC BIOLOGICAL AND CHEMICAL DEGRADATION PATHWAYS

PARSONS ENGINEERING SCIENCE, INC.

Oakland, California

SOURCE:
McCARTY, 1994

(Bouwer, 1994). Potential carbon sources include natural organic matter, fuel hydrocarbons, or other anthropogenic organic compounds such as those found in landfill leachate.

3.1.2 Electron Donor Reactions

Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using PCE and TCE as a primary substrate (i.e., electron donor). However, under aerobic and some anaerobic conditions, the less oxidized CAHs (e.g., VC) can be used as the primary substrate in biologically mediated oxidation-reduction reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAH can be used as electron donors in biologically mediated oxidation-reduction reactions. McCarty and Semprini (1994) describe investigations in which VC and 1,2-dichloroethane (DCA) were shown to serve as primary substrates under aerobic conditions. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Aerobic metabolism of VC may be characterized by a loss of VC mass and a decreasing molar ratio of VC to other CAHs.

Electron donor reactions may be important for three of the COCs at ICs 17/19/21: VC, 1,2-DCA, and chloroform.

3.1.3 Cometabolism

When a CAH is biodegraded via cometabolism, the degradation is catalyzed by an enzyme or cofactor that is fortuitously produced by the organisms for other purposes. The organism receives no known benefit from the degradation of the CAH. Rather, the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the rate of cometabolism increases as the degree of dechlorination decreases.

As an example, consider the cometabolism of TCE. In this cometabolic process, TCE is indirectly transformed by enzymes produced by the bacteria as they use methane and oxygen to meet their energy requirements. In this case, TCE does not enhance the degradation of methane or other carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates may limit cometabolism of CAHs and cometabolic reaction mechanisms are typically engineered.

3.1.4 Abiotic Reactions

Abiotic or chemical transformations of some CAHs can occur within the time frame of interest in groundwater (McCarty, 1997). Trichloroethane (TCA) is the only major chlorinated solvent that can be transformed chemically in groundwater under all likely conditions within the one- to two-decade time span of general interest, although chemical transformation of carbon tetrachloride through reductive processes is a possibility.

TCA chemical transformation occurs by two different pathways, leading to the formation of 1,1-DCE and acetic acid (Figure 3.1). The average reported half-life by various investigators for the abiotic transformation of TCA is approximately 1 year. Almost 80 percent of the TCA is transformed into acetic acid; however, the 20 percent that is converted to 1,1-DCE is of great significance because 1,1-DCE is considered more toxic than TCA. Whenever TCA is present as a contaminant, 1,1-DCE can also be expected. Chloroethane, formed through biological transformation of TCA, can also be chemically transformed with a half-life on the order of months by hydrolysis to ethanol, which can then be biologically converted to acetic acid and harm-less products (Vogel *et al.*, 1987).

3.1.5 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of organic (native and/or anthropogenic) carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being utilized. Individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below. Understanding why a plume behaves in a certain manner is critical to predicting long-term fate and transport and optimizing remedial design.

3.1.5.1 Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX, TPH, or landfill leachate), and this anthropogenic carbon drives reductive dechlorination. When evaluating natural attenuation of a plume exhibiting type 1 behavior, the following questions must be answered:

- Is the electron donor supply adequate to allow microbial reduction of the chlorinated organic compounds? In other words, will the microorganisms "strangle" before they "starve" [i.e., will they run out of CAHs (electron acceptors) before they run out of primary substrate (anthropogenic carbon)]?
- What is the role of competing electron acceptors [e.g., dissolved oxygen, nitrate, iron (III), and sulfate]?
- Is VC oxidized, or is it reduced?

Type 1 behavior results in the rapid and extensive degradation of the highly chlorinated solvents such as PCE, TCE, and DCE.

3.1.5.2 Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high native organic carbon concentrations, and this carbon source drives reductive dechlorination (i.e., the primary substrate for microorganism growth is native organic carbon). When evaluating natural attenuation of a type 2 chlorinated solvent plume, the same questions as those posed in the description of type 1 behavior must be answered.

3.1.5.3 Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low native and/or anthropogenic carbon concentrations, and DO concentrations that are greater than 1.0 mg/L. Under these conditions the plume is aerobic, and reductive dechlorination will not occur. Thus, there is no reductive dechlorination of PCE, TCE, and DCE. Biodegradation may proceed via the much slower process of cometabolism, but will be limited by the low concentrations of native or anthropogenic carbon. The most significant natural attenuation mechanisms for these compounds will be advection, dispersion, and sorption. However, VC could be oxidized under these conditions.

3.1.5.4 Mixed Behavior

As mentioned above, a single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be especially beneficial for biodegradation of CAH plumes. For example, Wiedemeier *et al.* (1996) describe a plume at Plattsburgh AFB, New York that exhibits type 1 behavior in the source area and type 3 behavior downgradient from the source. The best scenario involves a plume in which TCE and DCE are reductively dehalogenated (type 1 or 2 behavior), then VC is oxidized (type 3 behavior), either aerobically or anaerobically (via iron reduction). VC is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in this type of plume:

TCE ⇨ DCE ⇨ VC ⇨ CO_2

In general, the TCE, DCE, and VC attenuate at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this sequence of reactions. VC is removed from the system much faster under these conditions than it is under VC-reducing conditions.

A less desirable scenario involves a plume in which all CAHs are reductively dehalogenated (type 2 or 3 behavior). VC is reduced to ethene, which is further reduced to ethane. The following sequence of reactions occur in this type of plume:

TCE ⇨ DCE ⇨ VC ⇨ Ethene ⇨ Ethane

In this type of plume, DCE and VC degrade more slowly than TCE, and thus they tend to accumulate.

3.2 TECHNOLOGY APPLICABILITY

Intrinsic remediation is a management strategy which is applicable at any site contaminated with CAHs and/or petroleum-hydrocarbons. However, the extent to which it will be successful at reducing the toxicity, mobility, or volume of contaminants to levels that are protective of human health and the environment is dependent on site-specific conditions. Groundwater which is contaminated with CAHs, contains either natural or anthropogenic carbon, and shows evidence of biodegradation daughter products (e.g., 1,2-DCE and VC) is particularly suitable for a detailed evaluation of intrinsic remediation.

As discussed in Section 2.4, groundwater beneath ICs 17/19/21 is contaminated with both CAHs and petroleum hydrocarbons, including benzene and toluene in some locations. The distribution and concentration of CAHs in the groundwater suggest that some degree of anaerobic dechlorination is occurring in both the vadose zone and in the groundwater. The limited extent of the CAH plume and the VC plume also suggest that the plume may be exhibiting mixed behavior (Section 3.1.5.4).

The AFCEE technical protocol document (Appendix D) describes a screening process where existing site characterization data are used to determine if adequate evidence exists that biodegradation of CAHs is occurring and to determine if additional data collection activities are warranted. Using existing site characterization data for ICs 17/19/21 (Section 2.4) and groundwater monitoring program (GWMP) results from the second quarter of 1997 (Radian, 1997d), the screening process was completed for ICs 17/19/21. The screening process resulted in a score of 14 points (Table 3.1). This value is near the score of 15 points used to indicate that "adequate" evidence exists for biodegradation. A score this high is especially noteworthy since the most contaminated MWs (i.e., MW-354 and MW-355) were not sampled for natural attenuation parameters and that many of the required analytes in the technical protocol were not analyzed (e.g., ferrous iron, ORP, alkalinity, carbon dioxide, and ethene/ethane).

Another subcontractor has reported that measured sulfate concentrations in groundwater at OU C are potentially inhibitory to reductive dechlorination (CH2M Hill, 1996). However, the reported sulfate concentrations (8 to 38 mg/L) were from uncontaminated MWs or MWs with lower contaminant concentrations in the southern portion of OU C, not within ICs 17/19/21. Furthermore, the average reported concentration of 13 mg/L sulfate for these MWs and 10 mg/L sulfate across McClellan AFB are below the concentration of 20 mg/L used for site screening in the technical protocol document. Concentrations of sulfate from the most recent groundwater sampling at ICs 17/19/21 in 1996 and 1997 in MW-353, MW-356, and MW-357 (the three wells sampled nearest the source areas) ranged from 2.6 to 31 mg/L. Neither of the most contaminated MWs (MW-354 and MW-355) were sampled for sulfate during these events. This preliminary data can only be considered inconclusive; however, the previous measurements at OU C and ICs 17/19/21 do not necessarily indicate reductive-dechlorinating microorganisms are being significantly inhibited by competition from sulfate-reducing microorganisms at ICs 17/19/21.

Based on the previous site investigation data and the technical protocol screening process, an intrinsic remediation strategy is potentially applicable to ICs 17/19/21. Further study is

TABLE 3.1
NATURAL ATTENUATION SCREENING PROCESS
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Analyte	Concentration in Most Contaminated Zone [1]	Criteria for Points	Points Awarded
Dissolved Oxygen [2]	not analyzed	<0.5 mg/L	3
Nitrate	<1.0 mg/L	<1.0 mg/L	2
Iron (II)	not analyzed	>1.0 mg/L	0
Sulfate	15.8 mg/L	<20 mg/L	2
Sulfide	<0.61 mg/L	>1 mg/L	0
Methane	<0.0010 mg/L	>0.5 mg/L	0
ORP	not analyzed	<50 millivolts	0
TOC	1.8 mg/L	>20 mg/L	0
Temperature	23 °C	>20 °C	1
Carbon Dioxide	not analyzed	>2x background	0
Alkalinity	not analyzed	>2x background	0
Chloride	39 mg/L	>2x background	0
Hydrogen	not analyzed	>1 nM	0
Volatile Fatty Acids	not analyzed	>0.1 mg/L	0
BTEX	not detected	>0.1 mg/L	0
TCE	628 µg/L	not released/daughter prod. of PCE	0
cis-1,2-DCE	284 µg/L	daughter product of TCE	2
Vinyl Chloride	210 µg/L	daughter product of DCE	2
Ethene/Ethane	not analyzed	>0.01 mg/L	0
Chloroethane	not detected	daughter product of VC	0
Chlorobenzene	not detected	daughter product of DCB	0
1,1-DCE	550 µg/L	daughter product of TCA/TCE	2
		TOTAL POINTS	**14**

[1] For the contaminated zone, the average of the most recent sampling results from MW-353, MW-356, and the Hydropunch results from the source areas were used. For background concentrations, the most recent results from MW-359 were used.

[2] Oxygen demand was inferred from elevated BOD (5.6 mg/L) in the source area above background BOD (<3 mg/L).

warranted to evaluate site-specific groundwater geochemistry, plume behavior, and biodegradation rates.

3.3 ADVANTAGES AND LIMITATIONS OF TECHNOLOGY

3.3.1 Advantages and Benefits

An intrinsic remediation management strategy which incorporates natural attenuation processes is advantageous for the following reasons:

- Contaminants are potentially transformed to innocuous byproducts (e.g., carbon dioxide, ethene, or water), not just transferred to another phase or location within the environment;
- Current engineered technologies are generally energy-intensive and, in some cases, are not effective in meeting remedial goals;
- The process is non-intrusive and does not interfere with aboveground operations during remediation; and,
- An intrinsic remediation strategy is potentially less costly than conventional, engineered remedial technologies.

At McClellan AFB, for sites currently undergoing active remediation, the mass removal rates and models used to evaluate natural attenuation processes could be used to optimally place groundwater extraction wells, manage pumping rates to maximize containment strategies, and estimate remaining time to reach groundwater remediation goals. Where engineered solutions are needed for source removal, an evaluation of natural attenuation processes could lead to turning equipment off earlier than anticipated. For sites not undergoing active remediation, demonstrating that natural attenuation processes are occurring and implementing an intrinsic remediation management strategy could avoid installing costly and unnecessary engineered systems. Intrinsic remediation would still be protective of human health and the environment. All of these benefits could potentially result in substantially lower remediation costs.

3.3.2 Limitations

The potential limitations of an intrinsic remediation strategy are technical, economic, and regulatory.

The technical limitations of intrinsic remediation at sites contaminated with chlorinated hydrocarbons include:

- Some chlorinated compounds are biologically recalcitrant under some environmental conditions (e.g., PCE and carbon tetrachloride under aerobic conditions);
- A primary substrate or co-substrate may not be available and reductive dechlorination and cometabolism processes do not occur;
- A limited amount of substrate may be available and the contamination may migrate after the substrate is exhausted; and,

- Biodegradation rates may be too slow to prevent contaminant migration to receptors.

Although an intrinsic remediation strategy that relies upon natural attenuation alone may not be appropriate for such sites, natural attenuation processes may still be important when evaluated in combination with other remedial alternatives, especially source-removal actions.

Because longer remediation times may be required in comparison to other remedial alternatives, the economics of an intrinsic remediation strategy must include the incremental costs for additional long-term monitoring and contingency plans. Site characterization data and frequency of monitoring might exceed that required by regulators for engineered alternatives. These additional costs may impact the cost-competitiveness of intrinsic remediation compared to other alternatives with shorter remediation times.

From a regulatory or public perception perspective, an intrinsic remediation strategy is sometimes confused with the "No Action" alternative. Some regulators and the public may be reluctant to accept intrinsic remediation unless a preponderance of evidence is presented. At some sites, groundwater contamination might still migrate before a steady-state condition is reached and/or the plume begins to shrink. Comprehensive, long-term monitoring plans, including point-of-compliance wells downgradient of a contaminant plume and contingency plans, are likely to be needed as part of an intrinsic remediation strategy in order to demonstrate commitment and confidence in the ability of natural attenuation processes to meet remedial goals.

3.4 DEVELOPMENT STATUS

Recent advances in the science and documentation of natural attenuation processes at petroleum hydrocarbon- and CAH-contaminated sites have clearly shown that biodegradation can play a significant role in remedial plans (Rifai *et al.*, 1995). Recently, numerous case studies have appeared in the literature which document natural attenuation of chlorinated solvents at the field-scale (e.g., Kitanidis *et al.*, 1993; Wiedemeier *et al.*, 1996b; Dupont *et al.* 1996; Ellis *et al.*, 1996).

To date, AFCEE has completed more than 20 separate studies of mixed petroleum/CAH or CAH-only release sites. A summary of published, site-specific information for some of these sites is shown in Table 3.2. Site-specific information for other facilities and sites (e.g., Offutt AFB, NB; Hill AFB, UT; NAS North Island, CA; and, MCB Camp Pendleton, CA) is in preparation (Wiedemeier *et al.*, 1998).

TABLE 3.2
REPRESENTATIVE SITES INVESTIGATED FOR NATURAL ATTENUATION OF CAHs
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Site	Contaminants	Geochemical Processes	Biodegradation Mechanisms	Range of Biodegradation Rate Constants (1/year) TCE	cis-1,2-DCE	Vinyl Chloride	Regulatory Approval as Remedy ?	Reference
Site FT-002 Plattsburgh AFB, NY	Fuels & CAHs	aerobic, denitrification, iron reduction, sulfate reduction, methanogenesis	aerobic and anaerobic	0.23 to 1.3	0.07 to 0.60	0.47 to 1.16	pending	Wiedemeier et al., 1996b
Former Waste Lagoon Sacramento, CA	Septic Wastes & CAHs	aerobic, sulfate reduction, methanogenesis	aerobic and anaerobic	1.10	0.86	3.1	under evaluation	Cox et al., 1995
Site CCFTA-2 Cape Canaveral Air Station, FL	Fuels & CAHs	aerobic, iron reduction, sulfate reduction, methanogenesis	aerobic and anaerobic	0.29	0.22	produced	pending	Swanson et al., 1996
Site 8 NAS Cecil Field, FL	Fuels & CAHs	aerobic, iron reduction, sulfate reduction, methanogenesis	aerobic and anaerobic	3.3 to 7.3	not reported	3.3 to 7.3	not reported	Chappelle, 1996
Building 24 Picatinny Arsenal, NJ	CAHs only	iron reduction, sulfate reduction	anaerobic	1.2	0.5 to 1.6	produced	not reported	Imbrigiotta et al., 1996
Site 45/47 Eielson AFB, AK	Fuels & CAHs	not reported	anaerobic	0.22 to 2.6	not reported	not reported	Yes	Dupont et al., 1996
St. Joseph Superfund Site St. Joseph, MI	CAHs only	sulfate reduction, methanogenesis	anaerobic	0.38 to 1.4	0.50 to 3.1	0.18 to 2.2	not reported	Weaver et al., 1996
Tibbetts Road Superfund Site Barrington, NH	BTEX & TCE	not reported	anaerobic	0.41 to 0.59	0.43 to 0.65	not detected	not reported	Wilson et al., 1996

SECTION 4

OBJECTIVES AND APPROACH

SECTION 4

OBJECTIVES AND APPROACH

4.1 GENERAL OVERVIEW

A good set of objectives become the criteria for evaluating and determining the success of a project. Objectives should be specific, quantifiable, realistic, attainable and time-referenced.

4.2 STATEMENT OF DEMONSTRATION'S OBJECTIVES

The primary objectives of this demonstration are:

1) Collect sufficient information to determine if natural attenuation processes are occurring in groundwater beneath ICs 17/19/21. If natural attenuation processes are occurring, quantify the extent to which contaminant mass can be removed or attenuated under the site-specific field conditions encountered at ICs 17/19/21.

This objective will be achieved upon successful completion of the sampling efforts, contaminant transport modeling, and presentation of results. The results report will include an evaluation of groundwater geochemistry, estimated contaminant mass removal rates, and predictions of future plume migration.

2) Assist McClellan AFB in implementing a practical approach for evaluating the potential for an intrinsic remediation strategy at other sites where groundwater is contaminated with CAHs.

This objective will be achieved upon approval of this WIP, the final results report, and long-term monitoring and compliance plans for groundwater beneath ICs 17/19/21 by McClellan AFB staff and the local regulatory community. Their approval of the technical approach, sampling and analysis methods, results, and long-term monitoring and compliance plans would assist them in evaluating the intrinsic remediation option at other sites.

Simple acceptance of the approach and results is an important and primary objective of this demonstration; however, an additional criteria that would measure success of the intrinsic remediation alternative would be its use in decision documents. If it can be sufficiently demonstrated that natural attenuation processes are occurring in groundwater beneath ICs 17/19/21 and/or other sites, then the use of an intrinsic remediation remedial strategy (alone or in combination with engineered technologies) in the GWOU ROD document would be a significant success. However, this objective would likely have a much longer timeline than anticipated for this demonstration.

4.3 TEST PLAN

To achieve the objectives stated in Section 4.2, the following actions have already been or will be performed:

1) Existing site data have been reviewed (Section 2) and an initial screening assessment of the potential for natural attenuation processes at the site has been conducted (Section 3.2).

2) Based on the review of existing site data and the requirements of the AFCEE technical protocol document for evaluating natural attenuation processes, the following data needs have been identified:

   - Additional groundwater sampling is needed to evaluate the groundwater geochemistry upgradient, cross-gradient, downgradient, and within the contaminant plumes. The geochemical parameters which will be analyzed during the demonstration and their use in evaluating natural attenuation are described in Section 7 and Appendix D.

   - Additional groundwater sampling is needed to evaluate breakdown products and indicators of biodegradation. These additional parameters and their use in evaluating natural attenuation are also described in Section 7 and Appendix D.

   - Additional MWs are needed to estimate site-specific biodegradation rates. The proposed locations and rationale for the additional MWs are provided in Sections 5 and 7. The procedures which will be used to estimate site-specific biodegradation rates are described in Section 4.4.4.

   While the current evidence of daughter products detected in groundwater is not sufficient to determine if biodegradation is occurring in groundwater (because the daughter products may simply have migrated into the groundwater from the vadose zone), the sampling proposed in this demonstration is specifically designed to sufficiently make this determination one way or the other. If geochemical changes are occurring in the groundwater, contaminant mass loss (corrected for non-biological attenuation) is occurring along groundwater flow pathways, and increases in biomass are observed, sufficient evidence would exist to make this determination.

3) A contaminant fate and transport model will be developed to quantify the extent to which contaminant mass can be removed by natural attenuation and to predict future plume migration. Existing site characterization data (Section 2), previous modeling efforts (CH2M Hill, 1994), and data collected during the field activities for this demonstration (Sections 5 and 7) will be used to develop the model. Contaminant fate and transport model development, calibration, and use is described in Section 4.4.

4) A long-term monitoring and compliance plan will be developed to confirm fate and transport model predictions and to provide contingency plans if model predictions are inaccurate or an intrinsic remediation strategy does not meet remedial goals. Long-term monitoring and compliance plan development is described in Section 4.4.7.

4.4 DATA ANALYSIS AND INTERPRETATION

4.4.1 Fate and Transport Modeling Approach

Prediction of the migration and degradation of a dissolved contaminant plume using a solute transport model is an important component of an intrinsic remediation demonstration. Several well-documented and widely-accepted models are available for modeling the fate and transport of contaminants under saturated conditions. Models generally are classified as analytical or numerical, depending on the mathematical formulation and solution of the governing flow and transport equations. Analytical and numerical models are available for modeling the fate and transport of CAHs and fuel hydrocarbons under the influence of advection, dispersion, sorption, and aerobic and anaerobic biodegradation. Because subsurface contaminant transport models incorporate a number of theoretical assumptions about the processes governing the transport and fate of contaminants, all modeling involves simplifying assumptions concerning parameters of the physical and chemical system that is being simulated.

Because numerical models can be used to incorporate spatial variability in groundwater flow and contaminant transport, the modeling approach for this demonstration will be to use a numerical groundwater flow model and a numerical contaminant transport model. MODFLOW, a modular, three-dimensional finite-difference model developed by the U.S. Geological Survey, will be used to model groundwater flow in the vicinity of ICs 17/19/21. Although many numerical contaminant transport models (both public domain and proprietary) are available, MT3D has been used successfully to simulate the effects of both non-destructive and destructive attenuation processes on contaminant mass over time. Therefore, MT3D is planned for use as the numerical contaminant transport model for this demonstration.

This proposed modeling approach may be revised based on geochemical conditions measured during this demonstration. For example, the BIOPLUME II model could be used to model the anaerobic and aerobic biodegradation of VC if groundwater geochemical results indicate the potential for VC to accumulate and migrate beyond the source area (i.e., if groundwater throughout the study area is highly-reducing). In addition, numerical fate and transport models which can incorporate changes in biodegradation rates and changes in parent and daughter compound concentrations (so-called multi-species, reactive transport models) are not currently available but are under development. One such model, RT3D, is near completion but is currently only available in a beta test version. Although, the current beta test version of RT3D is not mature enough to be used for this demonstration, a reevaluation of any future revisions to RT3D will be made at the time the modeling is actually performed. The decision to use MT3D is partially based on the fact that implementing RT3D in the future will be facilitated by the use of MT3D since they are both based on the same basic code, design, and input file structure.

With all currently available contaminant transport models, including MT3D, only one contaminant can be modeled at a time and mass transport which includes the formation of daughter products is not possible. Therefore, the approach for this demonstration will be to

model total VOCs and use the transport parameters for the contaminant with the most conservative transport characteristics (i.e., the most mobile contaminant). For this demonstration, the transport characteristics of cis-1,2-DCE, which is slightly more mobile than TCE and 1,1-DCE, will be used. Although vinyl chloride (VC) is even more mobile and may drive risk at the site (based on the use of source area concentrations), VC has a limited impact on groundwater beyond the source area (Section 2). It is likely that the VC in the source area is being rapidly degraded either aerobically or under iron-reducing conditions in the downgradient portions of the plume. If this conceptual model is correct, using the transport characteristics of VC would be overly conservative and lead to difficulties in calibrating the model to the existing plume geometry.

The groundwater flow and contaminant transport models will be run, and the results will be compared against a known (observed) condition. This process is known as model calibration. Changes to model inputs and boundary conditions, such as the spatial distribution of hydraulic conductivities and source term concentrations, are typically necessary to achieve satisfactory model calibration. Details of the calibration procedures are contained in Section 4.4.5.

Following calibration, model simulations will be run to predict future contaminant distributions at ICs 17/19/21 under different remedial options. Because any groundwater flow and contaminant transport model is influenced by uncertainty related to the inability to define the exact spatial and temporal distribution of aquifer and chemical parameter values at the site, a quantitative sensitivity analysis will be performed. Procedures for conducting the sensitivity analysis are outlined in Section 4.4.6.

4.4.2 Model Input Needs and Data Sources

Data used to model groundwater flow and contaminant transport will consist of data collected during the field work phase of this demonstration study and data generated during previous investigations (i.e., site-specific RI documents, basewide RI reports). The data needs and data sources for MODFLOW, MT3D/BIOPLUME II, and the vadose zone analytical model are provided in Table 4.1.

Data needs include:

- Groundwater heads, gradients, and flow direction for the time periods being modeled;
- Definition of physical and chemical boundary conditions;
- Hydraulic conductivity/transmissivity for hydrogeologic units in model domain;
- Effective porosity for hydrogeologic units in model domain;
- Groundwater recharge (precipitation, infiltration);
- Coefficient(s) of hydrodynamic dispersion;
- Coefficient(s) of retardation;

TABLE 4.1
MODEL INPUT NEEDS AND DATA SOURCES
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Model Input Parameter	Representative Value(s)	Basis or Reference
Time Period of Model (years)	75	IC19 pits' use started in 1950; model prediction typically made at least 25 years into the future
Width of finite difference cell in the x-direction (feet)	50 to 100	dimensions of the IC19 pits and the recommended dimension from semi variogram analyses of contaminant distribution [1]
Width of finite difference cell in the y-direction (feet)	50 to 100	same as above
Number of nodes in the X direction	20 to 40	Current plume transverse length (800 ft), transverse dimension of ICs 17/19/21 (1,500 ft), room for predictions of future plume length, and width of finite difference cell in x-direction
Number of nodes in the Y direction	40 to 80	Current plume longitudinal length (2,000 ft), longitudinal dimension of ICs 17/19/21 (2,500 ft), room for predictions of future plume length, and width of finite difference cell in y-direction
Number of cells used for source terms	60	Extent of soil gas contamination contributing to groundwater contamination (Figure 2.3)
Effective porosity (dimensionless)	0.15 to 0.30	Site geology (Section 2), Table C.3.2 from Wiedemeier et al., 1996a, and CH2M Hill, 1996b
Approx. thickness of the A monitoring zone	35	GW elevations at ICs 17/19/21 (-40 ft msl), base of A zone at OU C of -60 ft msl (Radian, 1992), and Table 4-1 from CH2M Hill, 1994
Transmissivity (ft^2/day)	200 to 1000	Figure 4-7, Figure A-6, Table A-1 from CH2M Hill, 1994 and Table 2.5.2-9 from CH2M Hill, 1996b
Storage Coefficient (dimensionless)	0.18	Table A-1 from CH2M Hill, 1994
Longitudinal dispersivity (feet)	15 to 200	Figure B.2.7 from Wiedemeier et al, 1996a
Ratio of transverse to longitudinal dispersivity	0.10	Section B.2.2.3 from Wiedemeier et al, 1996a
Octanol-water partition coeff. of contaminant being modeled (L/kg)	49	for cis-1,2-DCE (Wiedemeier et al. 1996a); see discussion in Section 4.4.1 of this WIP
Fraction of organic carbon [f_{oc}], (%)	0.003	Table 2.5.2-9 from CH2M Hill, 1996b
Dry bulk density of the soil (g/cm^3)	1.4	Appendix F from CH2M Hill, 1996b
Biodegradation rate (yr^{-1})	TBD	as discussed in Section 4.4.2 of this WIP
Recharge/Infiltration (inches/year)	3 to 5	Section 2.4 from CH2M Hill, 1994
Average percolation rate of liquid through vadose zone (feet/day)	5.6×10^{-4}	Radian, 1997a: Part 1: Appendix B - Fate and Transport Modeling Procedures
Average water-filled porosity of vadose zone, q_w (dimensionless)	0.25	Appendix on Analytical Modeling for IC19 (Radian, 1997a)
Thickness of the vadose zone (feet)	100	GW elevations at ICs 17/19/21 (approx. -40 ft msl) and ground surface elevation (approx. 60 ft msl)
Estimated current and future contaminant concentrations in soil, soil gas, and groundwater	-	RICS for ICs 17/19/21 (Radian, 1997a); Mass removal estimates from operation of SVE system at IC 19
Solubility and Henry's Law constants for contaminants of concern	-	Table B.2.1 from Wiedemeier et al, 1996a
Groundwater elevations (historical and current)	-	measurements in MWs from proposed field work and GSAP; estimated past historical water levels provided in CH2M Hill, 1994.

[1] The minimum semi-variogram range of influence was 300 feet for cis-1,2-DCE (Appendix on Analytical Modeling for IC19 [Radian, 1997a]). The recommended grid spacing for McClellan AFB is one-third to one-half of the range of influence (Radian, 1997a: Part 1: Appendix A - Distributive Modeling and Mass Calculation Procedures).

TBD: to be determined

- Contaminant source concentration and rate of removal;
- Physical constants for contaminants (e.g., sorption, solubility, Henry's constant);
- Distribution and continuity of aquifer and aquitards (e.g., thickness, areal extent);
- Initial solute concentrations; and,
- Biodegradation rate.

Data sources include:

- Lithologic descriptions from soil borings;
- Lithologic cross-sections;
- Aquifer test results;
- Monitoring well coordinates (northing, easting, elevation);
- Soil, soil gas, and groundwater concentrations for all COPCs for all sampling events;
- Recent historical groundwater elevations for all MWs in IC 17/19/21;
- Long-term historical groundwater elevations from public records;
- Total organic carbon (TOC) fraction in uncontaminated, saturated zone soil;
- Estimates of infiltration/percolation rates; and,
- Physical constants provided in the AFCEE technical protocol document or other references.

All previously collected data have been evaluated in terms of quality and usability. The data review included a review of the analytical methods, quantitation limits, and other factors important in determining the precision, accuracy, completeness, and representativeness of the final data set. The outcome of this data evaluation was both a data set appropriate to support quantitative fate and transport analyses and the recommendations for additional data collection provided in Section 4.3. By using the analytical methods and quantitation limits defined in this WIP (Section 7 and Section 8), the data collected during the field work phase of this demonstration study are also designed to satisfy the data requirements of quantitative fate and transport modeling.

4.4.3 Estimation of the Contaminant Sources

An important input into the fate and transport modeling of contaminated groundwater is the estimation of the rate at which contaminants are continuing to migrate to groundwater, typically referred to as the source term. In the case of ICs 17/19/21, an estimate of the mass flux of contaminants migrating from the contaminated soil and soil vapor in the vadose zone to the saturated zone will be required. The vadose zone analytical model described in Section

4.0 of Appendix B (Fate and Transport Modeling Procedures) from the McClellan AFB Interim Basewide RI Report (Radian, 1994) and/or the numerical VAPOUR-T model described in Section 3.0 of the same reference will be used to estimate source inputs to groundwater. The groundwater mixing model described in Section 5.0 of the same reference will be used to estimate the groundwater concentrations from the source inputs.

The vadose zone analytical model is conservative; therefore, it will be used first as a screening step for the source term estimate. This model uses equilibrium partitioning relationships and average percolation rates to provide a conservative estimate of contaminant mass flux from the vadose zone to groundwater. To overcome the limitation that some contaminants and daughter products are found in soil gas but not in soil (e.g., 1,1-DCE; vinyl chloride), equilibrium partitioning between soil gas and soil pore water will be added to the equilibrium relationship currently included for soil and soil pore water. The analytical model may be successful in providing accurate source term estimates if equilibrium and steady-state conditions were reached relatively quickly as the contaminated groundwater decreased in elevation over time.

If the contaminant transport model can be successfully calibrated using the source term estimate from the analytical model, then the VAPOUR-T numerical model will not be used. However, if the contaminant transport model cannot be adequately calibration with the source term estimate from the analytical model, then the VAPOUR-T numerical model will be used.

While it would be useful to quantify the decreases in source concentrations due to vadose zone biodegradation, such estimates are not a requirement for fate and transport modeling, (i.e., not including vadose zone biodegradation makes the source term and model conservative). More importantly, although some vadose zone models allow for a biodegradation term (e.g. SESOIL), there are no techniques for estimating vadose zone biodegradation rates of chlorinated compounds with any level of confidence.

It is probable that the recently implemented SVE removal action in the vadose zone at IC 19 has significantly impacted equilibrium and biodegradation processes in the vadose zone for those source areas within the influence of the extraction well. Enhancements or evaluation of biodegradation processes within these areas are now a moot point. For those areas that are determined not to be under the SVE system influence but still considered sources of groundwater contamination, an evaluation of biodegradation processes in the vadose zone may be warranted prior to expanding the SVE system. However, quantification and enhancement of biodegradation processes in the vadose zone is beyond the current scope of this demonstration.

The changes in source area concentrations as a result of operating the SVE system and the future impacts to groundwater will be simulated during fate and transport modeling. Future source impacts will be estimated using SVE system operational data (e.g., area influenced by the SVE system, total mass removed, changes in soil gas concentrations) available at the time the modeling is performed. If the VAPOUR-T model is used for the source term estimate, then the soil vapor extraction option of the VAPOUR-T model will be used to estimate future source term estimates.

4.4.4 Estimation of Biodegradation Rates

At a site undergoing evaluation of intrinsic remediation potential, successful application of fate and transport modeling, and future prediction of contaminant concentrations require an estimation of the rate of mass loss due to biodegradation. Several methodologies may be used to estimate the rate of reductive dechlorination of CAH compounds. Both first-order and second-order approximation of CAH degradation rates can be useful in predicting CAH plume behavior.

Use of the first-order approximation is appropriate to estimate rates of dechlorination of CAH compounds if it is assumed that the utilization of the primary substrate (electron donor or petroleum hydrocarbon) is not dependent on the presence of the CAH compounds (electron acceptors). This assumption is reasonable if sufficient electron donor mass is available (i.e., significant petroleum hydrocarbon concentrations) or if the microbial population capable of facilitating redox reactions between electron donor and acceptor is small and is exhibiting low growth rates relative to other microbial populations. Use of first-order kinetics may not be appropriate when more than one substrate is limiting microbial degradation rates or when microbial mass is increasing or decreasing significantly. First-order kinetics greatly simplifies numerical modeling and is therefore most commonly assumed in contaminant fate and transport models. With appropriately calculated rate constants, fate and transport models which use first-order rate constants can be successfully used to simulate fate and transport of CAHs dissolved in groundwater.

Buscheck and Alcantar (1995) derive a relationship that allows calculation of first-order biodegradation rate constants for steady-state plumes. This method involves coupling the regression of contaminant concentration (plotted on a logarithmic scale) versus distance downgradient along a groundwater flow path (plotted on a linear scale) to an analytical solution for one-dimensional, steady-state, contaminant transport that includes advection, dispersion, sorption, and biodegradation. For an expanding plume, this method provides an upper bound on the biodegradation rate.

Moutoux *et al.* (1996) describe an additional method to estimate first-order biodegradation rates at sites where dechlorination of CAH is occurring. Their method involves tracking the "carbon core" of the chlorinated compounds in relation to the remaining chlorine mass. During reductive dechlorination, the source chlorinated solvent undergoes successive transformations involving replacement of the chlorine atom with a hydrogen atom; however, the carbon core of the parent and daughter compounds remains unchanged. The carbon core is subject to the same non-destructive attenuation mechanisms that act on the larger chlorinated molecule, but it is unaffected by biologically mediated reductive dechlorination. Therefore, it can serve as a theoretically perfect "tracer". Measured contaminant concentrations from a minimum of three points along a groundwater flow path are used to estimate the degradation rate.

Although a first-order rate assumption may provide a reasonable approximation of how petroleum-hydrocarbon and CAH compounds are degrading in groundwater systems, this approach may neglect the importance of the electron donor-electron acceptor redox couples or the variable rates of biomass growth. A first-order kinetic model may not provide the best

approximation of how CAH compounds are dechlorinated in the presence of a limited substrate (electron donor or petroleum hydrocarbon). In these situations, second-order degradation rate estimates using bimolecular rate expressions may be useful. Although second-order rate estimates are useful in interpreting site data, fate and transport models are not currently available which can effectively incorporate changing biodegradation rates due to changes in parent and daughter compound concentrations. Such models, known as reactive transport models (e.g., RT3D), are under development (Sun *et al.*, 1996).

Both first-order and second-order degradation rates will be estimated, as appropriate, using the methods described above for this demonstration study. The first-order degradation rate estimates will be incorporated into the numerical model to model mass loss due to biodegradation. There are no analytical or numerical fate and transport models which can incorporate second-order rate constants. Therefore, the evaluation of a biodegradation rate based on a second-order rate constant is limited to a comparison of the second-order-derived rate to a first-order biodegradation rate and semi-quantitative discussions of the fate and transport implications of differences between them.

More specifically, a biodegradation rate based on a second-order rate constant can be calculated between any two sampling locations along a groundwater flow pathway, while a first-order biodegradation rate is calculated using the entire length of the pathway. Therefore, biodegradation rates based on second-order rate constants can be used to distinguish higher reductive dechlorination occurring in source areas (where high concentrations of both electron acceptor and donor exist) from lower reductive dechlorination occurring downgradient (where more oxidative conditions may exist or the electron donor mass becomes limiting). Conversely, second-order-derived biodegradation rates which are not significantly different from first-order biodegradation rates could indicate that electron donor mass is not limiting biodegradation.

Changes in second-order-derived rates with time can also provide early indications of changing plume behavior, before such conditions manifest themselves in a first-order rate calculation. Therefore, an important reason for calculating second-order rate constants is to establish a baseline against which to compare future rate estimates and to anticipate changes in plume behavior.

4.4.5 Model Development and Calibration

A discussion of model development and calibration is provided in Appendix D of the AFCEE technical protocol document (Wiedemeier *et al.*, 1996a); therefore, only a general discussion is included here. Model development includes selecting the model domain, discretizing the data in time and space, and assembling the discretized data in a form suitable for input to the numerical model. The model domain must cover the entire area within which the contaminant plume may travel and include any receptors of concern. Domain boundaries ideally should coincide with natural groundwater boundaries such as surface water or groundwater divides. However, isopleths of constant head often must be used to reduce model complexity and size. In either case, boundaries must be sufficiently far away from the area of concern so that boundary effects do not affect the solution. The model domain should generally be oriented so that the primary transport direction is parallel to a model axis.

To ensure that a groundwater flow and transport model is capable of accurately predicting the future extent of a contaminant plume, it must be calibrated to observed hydraulic and contaminant data. Calibration involves adjustment of key model input such as hydraulic conductivity, dispersivity, soil sorption coefficient, recharge, effective porosity, boundary conditions, and biodegradation rates until an adequate match between observed and simulated heads and contaminant concentrations is achieved. Because the statistical uncertainty in input parameters is rarely known with accuracy, models are generally calibrated in a trial-and-error fashion.

For numerical models, calibration of contaminant transport is a two-step process. First the groundwater flow system is calibrated and then the contaminant (solute) transport system is calibrated. For contaminant transport simulations, Spitz and Moreno (1996) strongly recommend that estimated source terms be used as initial conditions rather than currently observed concentrations, even if the source term is not well-defined.

The model outputs for MODFLOW and MT3D include mass balance error analysis for groundwater and contaminants to aid in developing a properly calibrated and defensible model. Published guidelines in the model documentation for acceptable mass balance errors will be used to evaluate the model developed for ICs 17/19/21. To determine if the model is properly calibrated to current conditions, the contaminant concentrations from the model output will be compared with current conditions using kriging interpolation and isopleth contouring. A root-mean-square error analysis will also be performed. A model which slightly overestimates contaminant concentrations and mass in the aquifer will also be considered acceptable because it will be considered conservative.

Since there is no long-term historical data on the concentrations of soil and soil gas contaminants, it will be necessary to vary the initial source term estimate in the contaminant transport model (described in Section 4.4.3) in a trial-and-error fashion until the groundwater contaminant plume predicted by the model adequately matches current conditions. The known historical changes in groundwater elevation and flow direction from the Final GWOU RI/FS (CH2M Hill, 1994) will also be used to guide the trial-and-error estimates of the source term and incorporated into the calibration of both the groundwater flow and contaminant transport model.

4.4.6 Model Sensitivity and Uncertainty Analysis

Because a deterministic, numerical model will be used (as opposed to a stochastic or analytical model), the sensitivity analyses will be also be deterministic rather than through rigorous statistical analysis (i.e., a "monte carlo" analysis). Individual model input parameters will be varied over reasonable ranges to establish the effect that changes in input parameters have on the model results. Professional judgment, known model sensitivities from the model documentation, and previously established ranges in the input parameters (e.g., range of hydraulic conductivities from aquifer tests) will be used in the sensitivity analysis.

The sensitivity of the contaminant transport model to the biodegradation rate will be part of the sensitivity analysis. In addition, the sensitivity analysis will include a model run that

assumes no expansion of the SVE system takes place and a model run that assumes the SVE system performs below its predicted efficiency.

If ranges are available from the data source, an uncertainty analysis will be performed to determine the uncertainty in the model from uncertainties in the input parameters. Available input parameter ranges are shown in Table 4.1. At least three model runs will be made, one each at the minimum, mean, and maximum values of the input parameter being analyzed. At minimum, the input parameters with the most sensitivity (expected to be hydraulic conductivity, source strength, biodegradation rate, and boundary conditions) will be used.

The presentation of model sensitivity and uncertainty will be shown graphically. For the sensitivity analysis, modeled contaminant concentrations along the centerline of the plume will be plotted for different runs in which the same parameter is varied. For the uncertainty analysis, the input parameter values will be plotted against contaminant mass loss due to biodegradation. A discussion will be also provided indicating to which parameters the model is most sensitive and where model uncertainty can be minimized by decreasing the uncertainty in the input parameters.

4.4.7 Long-Term Monitoring and Compliance Plan

Use of natural attenuation alone or natural attenuation combined with source reduction actions as remedial strategies for the site will require long-term monitoring. In coordination with McClellan AFB and its stakeholders, a site-specific, long-term monitoring and compliance plan will be developed and included in the results report for this study. The results report will be in the format specified by the National Environmental Technology Test Sites (NETTS) Program.

A contingency plan will be incorporated into the long-term monitoring and compliance plan. Contingency actions would be taken if contaminant concentrations at point-of-compliance (POC) (sometimes called point-of-action [POA]) wells reach specified levels (e.g., MCLs). Examples of contingency actions may include:

- Reevaluation of natural attenuation and biodegradation using the additional data collected during long-term monitoring, including use of an updated transport model if the plume does not behave as predicted by previous models;
- Expansion of the number of wells sampled or frequency of sampling under the long-term monitoring plan to determine plume stability, the extent of plume migration, or if significant changes in concentrations have occurred; and,
- Implementation of more active or faster methods of remediation.

The plan will specify the location of confirmation, POC, and other MWs, and which existing MWs will be used to monitor the effectiveness of an intrinsic remediation strategy at the site. The confirmation and POC wells will be used to verify that natural attenuation is occurring as predicted and that plume migration is limited. The plan will also specify the sampling methods and frequencies necessary to demonstrate long-term effectiveness and permanence of an intrinsic remediation strategy and/or engineered source reduction. The sampling

frequency of the well network will depend on their exact location, risk reduction needs, and other regulatory considerations.

Confirmation wells will be located in, upgradient, and downgradient of the existing plume and will provide for early confirmation of model predictions. The POC wells will be located further downgradient and used to verify that site-related contamination does not exceed state, federal, or risk-based groundwater standards. Typically, POC wells are located beyond the point where model results suggest groundwater contamination will migrate at concentrations exceeding specified standards. The location of POC wells may be impacted by the presence of groundwater contamination from sources downgradient of the site in the southern portions of OU C. The exact location of POC wells will be established in concert with the local regulatory agencies.

SECTION 5

FIELD ACTIVITIES

SECTION 5

FIELD ACTIVITIES

5.1 SITE CHARACTERIZATION

5.1.1 Installation of Additional Monitoring Wells and Rationale

Based on a review of existing site characterization data (Section 2.0), Parsons ES recommends that 5 additional MWs be installed within the A-monitoring zone at IC 19 and IC 17 (Figures 5.1 and 5.2). The 5 additional MWs will be designated MW-386 through MW-390. The 1997 McClellan Basewide RI/FS Quality Assurance Project Plan (QAPP) (Radian, 1997e) will be followed for all drilling and well installation procedures. A QAPP Applicability Checklist and Applicability Statement is included in Appendix F.

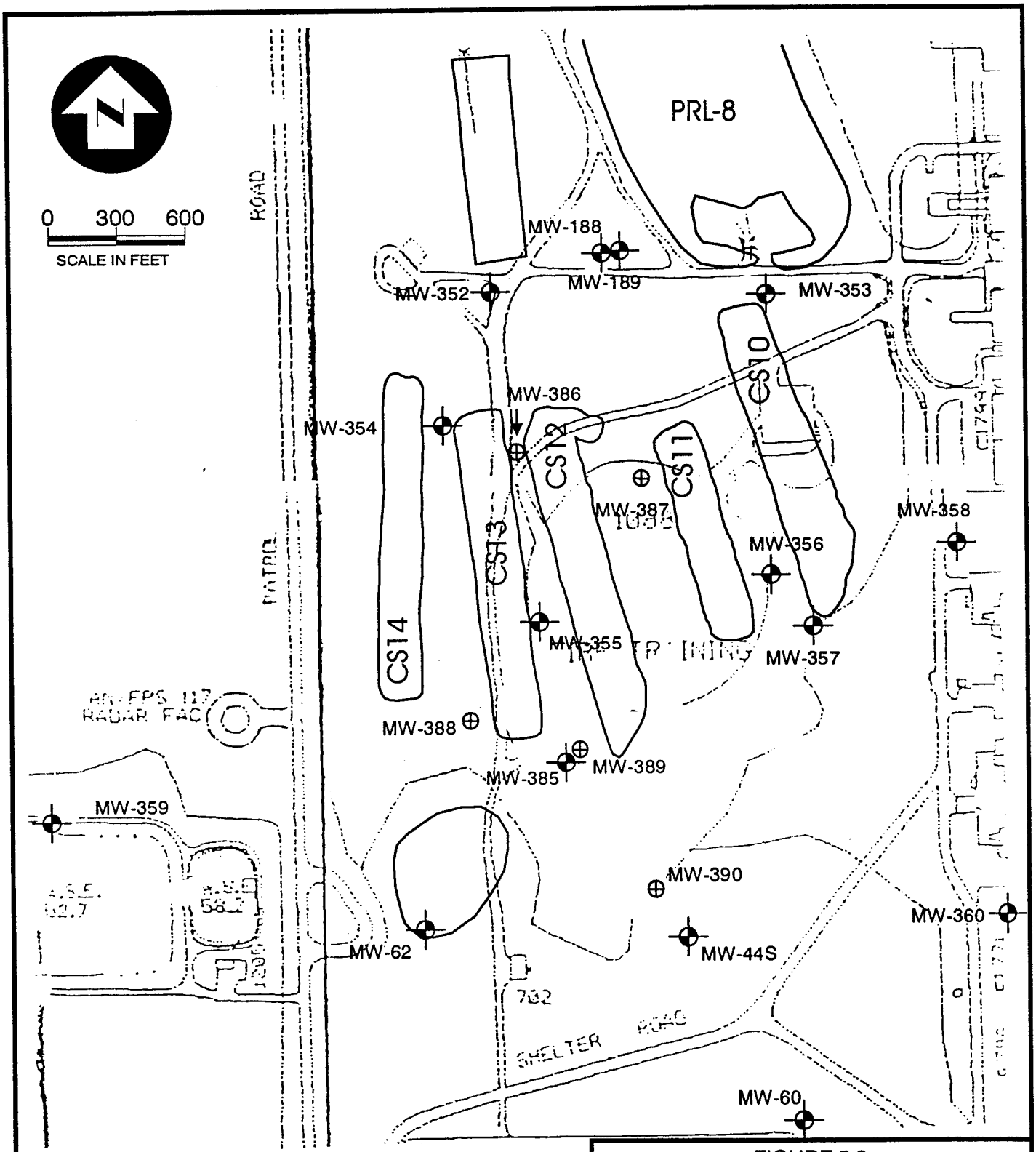
The purpose of these 5 additional MWs will be to:

1. Estimate site-specific biodegradation rates (using the methods detailed in Section 4.4.4);
2. Evaluate changes in plume behavior and geochemistry between the source area and downgradient locations; and,
3. Evaluate changes in groundwater contaminant concentrations and geochemistry as a result of extended SVE system operations.

The rationale for the location of each of the 5 additional MWs and how they achieve the purposes listed above are provided below.

Although numerous MWs exist within ICs 17/19/21, a review of the historic groundwater flow direction, gradient, and estimated hydraulic conductivity indicates that the existing MW network is not sufficient for calculating site-specific biodegradation rates because either the existing MWs are spaced too far apart or are not along a historically consistent groundwater flow pathway. The current estimated groundwater flow velocity for the A-monitoring zone at IC 19 is between 40 and 80 feet/year, based on the information provided in Table 4.1 and an estimated hydraulic gradient of 0.0011 ft/ft near the southern portion of IC 19. The groundwater flow direction in the southern portions of IC 19 has been relatively consistent in a south-southeasterly direction for at least the last six years based on groundwater elevation data collected during the Groundwater Monitoring Program (GWMP) (CH2M Hill, 1996a). Longer-term historical groundwater flow directions were probably in a south-southwesterly direction, based on regional Sacramento County water level contour maps records (CH2M Hill, 1994).

The nearest MWs in a southeasterly or southwesterly direction from the IC 19 sources area are MW44S, MW60, and MW62 located approximately 900 feet, 1,300 feet, and 850 feet



EXPLANATION

MW-356 ⊕ Existing Groundwater Monitoring Well

MW-386 ⊕ Proposed Additional Monitoring Well

FIGURE 5.2

PROPOSED ADDITIONAL MONITORING WELLS

McClellan AFB, California

PARSONS ENGINEERING SCIENCE, INC.

Oakland, California

downgradient, respectively. MW44S and MW60 are along a southeastern groundwater flow pathway; however, MW44S is screened only to 93 feet bgs and was dry during the third quarter sampling in 1996. Therefore, to provide at least three MWs along a southeastern groundwater flow pathway, 2 of the 5 additional MWs (MW389 and MW390) have been sited between the source areas and MW60. The location for MW389 was also chosen adjacent to MW385, which is screened in the B-monitoring zone, so that vertical gradients could be measured. To provide at least three MWs along a southwestern groundwater flow pathway, 1 of the 5 additional MWs (MW388) has been sited between the source areas and MW62.

The technical protocol document requires a minimum of three MWs within the contaminant plume, one specifically sited in the most contaminated portion of the aquifer. The isopleth maps presented on Figures 2.8 through 2.14 are primarily based on Hydropunch data and only two permanent MWs (MW354 and MW355). Although MW354 is near the source areas (the northern portions of CS 12 and CS 13), based on Figures 2.10 and 2.12, it is slightly upgradient of the TCE and 1,1-DCE sources. Therefore, 2 of the 5 additional MWs (MW386 and MW387) were sited within the boundaries defined by the existing isopleths. The locations for MW386 and MW387 were also chosen within the expected radius of influence of the existing SVE system to evaluate future changes in groundwater contaminant concentrations and geochemistry as a result of SVE system operations.

5.1.2 Additional Monitoring Well Construction and Surveying

Well installation and construction for the 5 new MWs will follow the procedures from SOP McAFB-004 from the Basewide QAPP. The 5 additional MWs will be constructed identically to the most recently installed A-monitoring zone MWs at the site (i.e., MW-352 through MW-357) (Appendix A). The screen will be constructed of 4-inch diameter (nominal), 0.01-inch slot-size stainless steel. The top of the screen will be set at approximately 94 feet bgs and extend 20 feet to approximately 114 feet bgs. The well casing will be solid, 4-inch diameter schedule 40 polyvinyl chloride (PVC). The sand pack will consist of #1C sand placed between approximately 3 feet above the top of the screen and extending approximately 1 foot below the bottom of the screen. Approximately 2 feet of #30 mesh sand will be placed above the sand filter pack to prevent intrusion of the overlying bentonite seal into the sand pack. The bentonite seal will be approximately 5 feet in length, followed by a bentonite/cement grout mixture to surface.

Because the purpose of the 5 new MWs is to collect groundwater samples and evaluate groundwater geochemistry and biodegradation of groundwater contaminants, no soil or soil vapor samples will be collected during well installation activities. Well development for the 5 new MWs will follow the procedures from SOP McAFB-004 from the Basewide QAPP.

A Third Order, Class I survey will be performed to determine the horizontal and vertical coordinates for the 5 new MWs. The north side of the top of the riser pipe where the well elevations are established will be notched. The elevation of the concrete pads at each MW and at least 4 landmarks at the site will also be surveyed to establish the ground surface elevation and aid in re-establishing MW locations. Benchmarks used for the survey will be established from and be traceable to a U.S. Geological Survey (USGS) marker.

5.1.3 Pre-Sampling Activities

The following activities will take place prior to groundwater sampling of both new and existing groundwater MWs. Specific references to Sections or SOPs from the Basewide QAPP are provided below in parentheses where appropriate.

- Site clearances (Section 5.2.1 and SOP McAFB - 042);
- Mobilization, equipment staging, site access (SOP McAFB - 004 and SOP McAFB - 042);
- Decontamination (Section 5.2.2 and SOP McAFB - 004);
- Well maintenance (SOP McAFB - 041);
- Water level measurements (Section 5.8.2); and,
- Equipment calibration (SOP McAFB - 020, SOP McAFB - 024, and Appendix C of this WIP).

The only field activities being proposed that are not covered by the Basewide QAPP are the use of two additional water sampling field instruments and one titrimetric field kit:

- Oxidation-reduction potential (ORP) meter;
- Portable colorimeter (Hach model DR/700) for analysis of ferrous iron, manganese, and sulfide; and,
- CHEMetrics titrimetric field kit for carbon dioxide.

The SOPs and calibration procedures for these instruments and the field kit are provided in Appendix C of this WIP.

5.1.4 Groundwater Sampling Activities

Groundwater samples will be collected from 20 existing MWs and the 5 additional MWs (a total of 25 MWs) (Figures 5.1 and 5.2). A list of these MWs is provided below.

- MW44S
- MW60
- MW62
- MW108
- MW110
- MW188
- MW189
- MW350
- MW351
- MW352
- MW353
- MW354
- MW355
- MW356
- MW357
- MW358
- MW359
- MW360
- MW385
- MW1012
- MW386
- MW387
- MW388
- MW389
- MW390

The field and analytical protocols for groundwater sampling activities is provided in Section 7 of this WIP (Field Sampling Plan). Section 5.1.1 provides a rationale for the 5 additional

MWs (MW386 through MW390) and Section 7.2.2 provides a rationale for remaining sampling locations.

5.2 SYSTEM INSTALLATION

System installation is not applicable to this demonstration study.

5.3 SYSTEM OPERATION

System operation is not applicable to this demonstration study.

5.4 RESIDUALS MANAGEMENT

Procedures detailed in Section 5.4.6 (Cuttings and Groundwater Disposal) from the Basewide RI/FS QAPP and Section 4.2 (Waste Management) of the Performance Work Statement (PWS) for this project will be followed for residuals management.

Assuming an average water column height of 15 feet for each of the 25 MWs proposed for sampling, an estimated 4 casing volumes removed during purging activities, and an estimated 20 casing volumes removed during well development from each of the 5 new MWs, approximately 2,000 gallons of wastewater will be generated by sampling, purging, and well development activities. All wastewater will be containerized in a portable, temporary holding tank provided by Parsons ES or its subcontractor. Upon approval from and in coordination with McClellan AFB personnel, wastewater will be transported and discharged at the industrial wastewater treatment plant by Parsons ES or its subcontractor.

Based on an 10-inch borehole size for each of the 5 new MWs, approximately 50 drums (55-gallon capacity) of soil cuttings will be generated during well construction. All drill cuttings will be containerized on site in labeled U.S. DOT-approved 55-gallon drums provided by the Base. The containerized wastes will be transported to an appropriate Base disposal facility by Base personnel.

5.5 DEMOBILIZATION AND SITE RESTORATION

Procedures detailed in SOP McAFB-004 (Drilling Operations, Well Installation, Completion, and Borehole Abandonment Procedures) from the Basewide RI/FS QAPP will be followed for demobilization and site restoration.

SECTION 6

PERMITTING AND REGULATORY COMPLIANCE

SECTION 6

PERMITTING AND REGULATORY COMPLIANCE

6.1 PERMITTING

Except for base digging permits and/or well installation permits which will be required for the proposed additional MWs (Section 5.1), no permitting is anticipated for this demonstration study.

6.2 REGULATORY COMPLIANCE

Discussed below are the regulations which apply to the work being conducted and the procedures which will be used to assure compliance with the regulations.

29 CFR 1910.120 - Hazardous Waste Operations and Emergency Response

29 CFR 1910.1200 - Hazard Communication

Parsons ES requires all employees and subcontractors to have completed 40-hour basic health and safety training, annual 8-hour refresher training, and prepare a site-specific health and safety plan (HASP) which covers site activities as specified in 29 CFR 1910.120. All supervisory personnel are required to have completed an 8-hour supervisory training course. All field employees are required to have completed a minimum of 3 days onsite training under the supervision of a trained and experienced supervisor. At least one field member will have completed Red Cross or equivalent first-aid and cardiopulmonary resuscitation (CPR) courses. All Parsons ES and subcontractor field team members will be enrolled in current medical monitoring programs in accordance with 29 CFR 1910.120 requirements. The site-specific HASP for this demonstration study is included as Section 7, which references the Program HASP included in Appendix E.

Compliance with hazard communication regulations will be met by proper container labeling and including material safety data sheets (MSDS) in the site-specific health and safety plan (HASP) for all hazardous materials used during this demonstration study. Hazard communications training is included for all Parsons ES field team members during annual 8-hour refresher training courses in compliance with 29 CFR 1910.120. Hazard communications will be covered during the initial and daily (as needed) health and safety "tailgate" meetings.

40 CFR 300 - National Oil and Hazardous Substance Pollution Contingency Plan (NCP)

Title 22, California Code of Regulations (CCR) - Environmental Health Standards - Hazardous Waste

49 CFR 171-178 - Department of Transportation (DOT) Requirements for Hazardous Materials

For the purposes of this demonstration study, compliance with these regulations will be met by:

- Notifying McClellan AFB of all hazardous materials brought on Base according to SOP McAFB - 042 (General Field Operations);
- Handling and Labeling soil cuttings and wastewater generated during site activities according to SOP McAFB - 004 (Drilling Operations, Well Installation, Well Completion, Well Development, and Borehole Abandonment Procedures), Table 11 (Waste Management and Disposal) and SOP McAFB - 013 (Sampling Groundwater from Monitoring and Extraction Wells);
- Not transporting any hazardous waste off-Base; and,
- Complying with the requirements of the *Spill Prevention, Control, and Counter Measures Plan* (Mitretek, 1996).

The applicable or Relevant and Appropriate Requirements (ARARs) for groundwater quality issues at ICs 17/19/21 are provided in the Basewide GWOU IROD (CH2M Hill, 1995). Selection of an intrinsic remediation strategy for groundwater cleanup or plume containment will be contingent upon meeting these ARARs. Determination of final ARARs for an intrinsic remediation strategy will be made in decision documents and final cleanup levels will be established in the Final Record of Decision.

SECTION 7

SAMPLING PLAN

SECTION 7

SAMPLING PLAN

This section contains a site-specific Sampling and Analysis Plan (SAP) for the intrinsic remediation demonstration study at ICs 17/19/21. Where appropriate, reference is made to the Basewide RI/FS QAPP (Radian, 1997e) for non-site-specific sampling protocols and standard operating procedures (SOPs). Procedures and SOPs to be used during this demonstration study that are not included in the Basewide QAPP are included in Appendix C.

7.1 PRE-OPERATIONAL SAMPLING

Pre-operational sampling is not applicable to this demonstration study.

7.2 DEMONSTRATION SAMPLING

An important focus of this intrinsic remediation study is an evaluation of all contaminants and natural attenuation indicator parameters for the entire study area at a single point in time. RI activities have adequately identified the vadose zone sources of groundwater contamination needed for evaluating intrinsic remediation potential at ICs 17/19/21. Sensitivity analyses will be performed during fate and transport modeling to evaluate uncertainties in the source terms (discussed in Sections 4.4.3 and 4.4.6).

To perform an appropriate evaluation of natural attenuation processes, groundwater samples from all MWs in the study area need to be collected at a single point in time. Currently, MWs are only sampled periodically in the study area over the course of the year. The samples collected for this study will be analyzed for all groundwater COPCs and for a comprehensive set of geochemical parameters, which are not part of the standard GWMP. In addition, a full round of groundwater levels in all monitoring wells in the study area is necessary to evaluate groundwater gradients and flow velocity to properly calibrate the fate and transport model. Sampling plans, results, and groundwater elevation measurements from this demonstration study will be forwarded to the Base point-of-contact who will then forward them to the appropriate GWMP contractor to avoid duplication of effort.

In order to meet the objectives of the intrinsic remediation study (Section 4), the existing and proposed additional MWs (Section 5) will be sampled to measure the concentrations, distribution, and mass of contaminants and electron acceptors at the site. Direct evidence of microbial activity will be evaluated by analyzing groundwater samples for volatile fatty acids (e.g., acetic acid and propionic acid) and increases in biomass (through phospholipid fatty acid [PLFA] analysis). Samples from both uncontaminated and contaminated areas will be collected and analyzed to accurately assess the extent to which contaminant mass can be

removed or attenuated under the natural geochemical and hydrogeologic conditions present at ICs 17/19/21.

A combination of both field and fixed-base laboratory analytical methods will be used to analyze groundwater samples. Methods and quantitation limits are provided in Table 7.1. Sampling locations and rationale are discussed in Section 7.2.2. Field procedures used to collect groundwater samples and the rationale for the field methods are discussed in Section 7.2.3.

7.2.1 Sampling Objectives

The primary objectives for the additional sampling activities are:

- Collect sufficient geochemical data and indicator parameters of biodegradation from uncontaminated wells and contaminated wells to determine if changes in groundwater chemistry are indicative of biodegradation of CAHs; and,
- Collect sufficient analytical data and hydrogeologic data to estimate site-specific biodegradation rates.

7.2.2 Sampling Locations, Methods, and Rationale

Sampling locations are shown on Figures 5.1 and 5.2. All existing MWs in the vicinity of IC 17, IC 19, and IC 21 and the five additional MWs to be installed during this demonstration study (discussed in Section 5) will be sampled and analyzed by the methods listed in Table 7.1. The rationale for the locations of the five additional MWs are provided in Section 5.1.1 and the rationale for the existing MWs is provided below. The rationale for each method is included in Section 2.3.2 and Table 2.1 of the technical protocol document (Appendix D) and are also summarized in Section 7.2.3.

The MWs which have been included in the sampling program include those within, upgradient, and cross-gradient of the contaminant source areas. Locations were chosen to evaluate any changes in contaminant concentrations within and downgradient of the source areas, to relate contaminant concentrations to temporal and spatial changes in geochemistry, and to aid in the determination of biodegradation rates.

Professional judgment and experience gained from similar studies was used to determine the number and locations of the proposed samples according to the following criteria:

- The schematic locations specified by the protocol document (Appendix D) should be used (i.e., upgradient, cross-gradient, downgradient, and within the plume);
- Because the sources of PCE, TCE, and TPH are potentially in different locations and the plume shapes are somewhat different, data should be collected from schematic locations associated with each contaminant plume;
- A priority for this study will be attempting to estimate a site-specific biodegradation rate (as opposed to a rate based on literature values); therefore, samples should be collected from locations along historical groundwater flow pathways to facilitate this estimate;

TABLE 7.1
METHODS AND QUANTITATION LIMITS
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Analyte	Field/Analytical Method	Field or Fixed-Base [1]	Quantitation Limit	Reporting Units
Dissolved Oxygen	Direct-reading meter	Field	0.2	mg/L
ORP	Direct-reading meter	Field	0.01	mv
Conductivity	Direct-reading meter	Field	10	µmhos/cm
pH	Direct-reading meter	Field	0.1	pH units
Temperature	Direct-reading meter	Field	1	degrees C
Ferrous Iron	Hach 8146	Field	0.014	mg/L
Manganese	Hach 8034	Field	0.1	mg/L
Sulfide	Hach 8131	Field	0.01	mg/L
Carbon Dioxide	CHEMetrics 4500	Field	10	mg/L
Alkalinity	E310.1	Fixed-Base	30	mg/L $CaCO_3$
Ammonia	E350.1	Fixed-Base	0.05	mg/L
Nitrate & Nitrite (quantitated separately)	E353.1	Fixed-Base	0.2	mg/L
Chloride	E300.0	Fixed-Base	1.0	mg/L
Sulfate	E300.0	Fixed-Base	2.5	mg/L
Biochemical Oxygen Demand (BOD)	E405.1	Fixed-Base	1.0	mg/L O_2
Chemical Oxygen Demand (COD)	E410.2	Fixed-Base	15	mg/L O_2
Total Organic Carbon (TOC)	SW9060	Fixed-Base	5.0	mg/L
Methane	RSKSOP-175	Fixed-Base	0.5	µg/L
Ethane	RSKSOP-175	Fixed-Base	0.5	µg/L
Ethene	RSKSOP-175	Fixed-Base	0.5	µg/L
Benzene	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
Carbon Tetrachloride	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
Chlorobenzene	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
Chloromethane	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
Chloroform	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
1,2-dichlorobenzene	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
1,1-DCA	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
1,2-DCA	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
1,1-DCE	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
cis-1,2-DCE	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
trans-1,2-DCE	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
Ethylbenzene	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
Freon 11 (Trichlorofluoromethane)	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
Freon 12 (Dichlorodifluoromethane)	SW5030A/SW8260A	Fixed-Base	5.0	µg/L
Methylene Chloride	SW5030A/SW8260A	Fixed-Base	3.0	µg/L
PCE	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
TCE	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
1,2,3-Trimethylbenzene	SW5030A/SW8260A	Fixed-Base	1.3	µg/L
1,2,4-Trimethylbenzene	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
1,3,5-Trimethylbenzene	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
Tetramethylbenzene	SW5030A/SW8260A	Fixed-Base	1.3	µg/L
Toluene	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
Vinyl Chloride	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
m,o,p-Xylenes (quantitated separately)	SW5030A/SW8260A	Fixed-Base	1.0	µg/L
TPH-d	SW3550/SW8015M	Fixed-Base	500	µg/L
Phospholipid fatty acids (PLFA)	Modified Bligh & Dyer Lipid Extraction	Fixed-Base	7	picomoles
Acetic acid	HPLC/UV	Fixed-Base	1.0	mg/L
Propionic acid	HPLC/UV	Fixed-Base	1.0	mg/L

[1] All fixed-base analyses performed by ITS (Richardson, TX) except:

PLFA: Microbial Insights, Inc. (Rockford, TN)

Acetic and propionic acids: Ortech Corp (Mississauga, Ontario Canada)

- A limited number of samples should be collected from existing wells in the B-monitoring zone to provide supplemental geochemical data in a cost-effective manner; however, the deeper monitoring zones are not proposed for contaminant fate and transport modeling due to the limited number of existing wells; and,
- Locations should be chosen to determine if the plume is exhibiting "mixed behavior" (Section 3.1.5.4), the potential for which is indicated by the limited extent of VC, and to identify the spatial extent of any mixed behavior.

Based on the above criteria, a total of 25 MWs were selected for groundwater sampling activities. The sample locations, sample IDs, quality control (QC) samples to be collected at each location, rationale, and the total number of samples to be collected by type and method are provided in Table 7.2.

7.2.3 Field Methods, Procedures, and Rationale

Groundwater sampling will consist of the following activities, implemented in the sequence shown below. Specific references to Sections or SOPs from the Basewide QAPP are provided in parentheses where appropriate.

1. Field meter/instrument calibration (Section 7 and SOPs McAFB-020 and McAFB-024);
2. Hach DR/700 colorimeter calibration as described in Appendix C of this WIP;
3. ORP meter calibration as described in Appendix C of this WIP;
4. Well Purging/Stability Measurements/Water Level Measurements (Section 5.8.2 and SOPs McAFB-020 and McAFB-024);
5. Sample collection for field and laboratory analysis (SOP McAFB-013);
6. Field lab analysis for ferrous iron, manganese, sulfide, and carbon dioxide as described in Appendix C of this WIP;
7. Completion of sample collection documentation and sample shipment (Section 6 and SOP McAFB-013); and,
8. Decontamination of equipment (Section 5.2.2 and SOP McAFB-013, with the exception that isopropanol may be substituted for methanol during decontamination of downhole equipment).

Sample storage and preservation requirements are provided in Table 7.3 for methods not included in the Basewide RI/FS QAPP. The field form used for the collection of groundwater samples is shown on Figure 7.1 and the field form used for the field methods is shown on Figure 7.2.

As indicated in Table 7.1, many of the groundwater chemical parameters will be measured onsite by Parsons ES scientists. Some of the measurements (i.e., pH, temperature, conductivity, dissolved oxygen, and ORP) will be made with direct-reading meters. A Hach® portable colorimeter will be used for the other field analyses in accordance with specific Hach® analytical procedures (Appendix C; Hach Corporation, 1996). CHEMetrics®

TABLE 7.2
SAMPLE LOCATIONS AND ANALYSIS SUMMARY
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Well	Sample ID	QC Sample	Field Lab Methods [1]	Fixed-Base Lab Methods [1]	Rationale/Location
MW44S	IC19MW044SNS1	-	all	all	downgradient extent of 1,1-DCE plume
MW60	IC19MW060NS1	-	all	all	downgradient extent of TCE plume
MW62	IC19MW062NS1	-	all	all	downgradient extent of TCE/cis-1,2-DCE plumes
	IC19MW062FD1	FD	all	all	
	IC19MW062AB1	AB	none	8015/8260 only	
	IC19MW062EB1	EB	none	8015/8260 only	
	IC19MW062MS1	MS	all	all	NOTE: MS requires twice normal volume
MW108	IC19MW108NS1	-	all	all	upgradient; interzone well (A/B)
MW110	IC19MW110NS1	-	all	all	background
MW188	IC19MW188NS1	-	all	all	upgradient
MW189	IC19MW189NS1	-	all	all	upgradient B-zone well
MW350	IC19MW350NS1	-	all	all	upgradient
MW351	IC19MW351NS1	-	all	all	upgradient extent of TCE plume
MW352	IC19MW352NS1	-	all	all	upgradient/within plumes
MW353	IC19MW353NS1	-	all	all	crossgradient/near source
MW354	IC19MW354NS1	-	all	all	source
MW355	IC19MW355NS1	-	all	all	source
	IC19MW355FD1	FD	all	all	
	IC19MW355AB1	AB	none	8015/8260 only	
	IC19MW355EB1	EB	none	8015/8260 only	
	IC19MW355MS1	MS	all	all	NOTE: MS requires twice normal volume
MW356	IC19MW356NS1	-	all	all	crossgradient/within plumes
MW357	IC19MW357NS1	-	all	all	crossgradient/within plumes
MW358	IC19MW358NS1	-	all	all	upgradient/crossgradient
MW359	IC19MW359NS1	-	all	all	upgradient/crossgradient
MW360	IC19MW360NS1	-	all	all	crossgradient/downgradient
MW385	IC19MW385NS1	-	all	all	downgradient B-zone well
MW386	IC19MW386NS1	-	all	all	source area and within SVE radius of influence
MW387	IC19MW387NS1	-	all	all	within plumes and SVE radius of influence
MW388	IC19MW388NS1	-	all	all	within plumes; along groundwater flow pathway
MW389	IC19MW389NS1	-	all	all	within plumes; along groundwater flow pathway
MW390	IC19MW390NS1	-	all	all	within plumes; along groundwater flow pathway
MW1012	IC19MW1012NS1	-	all	all	background

TOTAL NUMBER OF NORMAL SAMPLES:	25	(all field and fixed-base lab methods)
TOTAL NUMBER OF DUPLICATE SAMPLES:	2	(all field and fixed-base lab methods)
TOTAL NUMBER OF AMBIENT BLANKS:	2	(8015 and 8260 only)
TOTAL NUMBER OF EQUIPMENT BLANKS:	2	(8015 and 8260 only)
TOTAL NUMBER OF MATRIX SPIKES:	2	(all field and fixed-base lab methods)
TOTAL NUMBER OF TRIP BLANKS:	one per cooler	(8015 and 8260 only)

TOTAL NUMBER OF FIELD LAB SAMPLES:	29	
TOTAL NUMBER OF FIXED-BASE LAB SAMPLES:	33	(not including trip blanks)

[1] Field lab and fixed-base lab methods are listed in Table 7.1.

FD: Field Duplicate
EB: Equipment (rinseate) blank
AB: Ambient Blank
MS: matrix spike

GROUNDWATER SAMPLING FIELD NOTES
PARSONS ENGINEERING SCIENCE, INC.

PROJECT/LOCATION:

PROJECT NUMBER:

PERSONNEL:

WELL ID	SAMPLE DATE SAMPLE TIME SAMPLER(S)	INITIAL W.L. (ft) WELL DIA. (in) WELL DEPTH (ft)	FINAL W.L. (ft)	CASING VOLUME (gal)	PURGE METHOD	TIME PUMP ON/OFF	VOL. PURGED (gal)	TEMP (°C)	EC (µmhos/ cm)	pH	D.O. (mg/L)	ORP (mV)	SAMPLE METHOD	COMMENTS (odor, clarity, sheen, product, pump speed)
						/								
						/								
						/								
						/								
						/								
						/								
						/								
						/								
						/								
						/								
						/								
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						/								
						/								
						/								
						/								

NOTES:

W.L.: Water level from top of casing in feet (PL = product level, WL = water level)

Methods: G - Grundfos Redi-Flo Pump; B - Bailer; P - Peristaltic

NA: Not Applicable

NR: Not Recorded or Not Measured

Casing volume = (well depth - initial water level below TOC) x (# gal/lineal foot of casing)

Take readings at each purge volume until stabilized (minimum 3/maximum 6 purge volumes required)

Stability criteria: Temp +/- 1 °C, pH +/- 0.1 units, EC +/- 5% of reading,
D.O. +/- 0.5 mg/L, ORP +/- 50 mV

FIGURE 7.1

GROUNDWATER SAMPLING FIELD FORM

McClellan AFB, California

PARSONS ENGINEERING SCIENCE, INC.

Oakland, California

FIELD LABORATORY NOTES FOR NATURAL ATTENUATION
PARSONS ENGINEERING SCIENCE, INC.

PROJECT/LOCATION:
PROJECT NUMBER:

WELL ID: DATE: SCIENTIST:

FERROUS IRON (Fe^{2+})				CARBON DIOXIDE				MANGANESE				SULFIDE			
TIME	DILUTION	RAW READING	RESULT	TIME	RANGE	DROPS	RESULT	TIME	DILUTION	RAW READING	RESULT	TIME	DILUTION	RAW READING	RESULT

ALKALINITY						COMMENTS
TIME	RANGE	DROPS (Phenol.)	RESULT (Phenol.)	DROPS (Total)	RESULT (Total)	

WELL ID: DATE: SCIENTIST:

FERROUS IRON (Fe^{2+})				CARBON DIOXIDE				MANGANESE				SULFIDE			
TIME	DILUTION	RAW READING	RESULT	TIME	RANGE	DROPS	RESULT	TIME	DILUTION	RAW READING	RESULT	TIME	DILUTION	RAW READING	RESULT

ALKALINITY						COMMENTS
TIME	RANGE	DROPS (Phenol.)	RESULT (Phenol.)	DROPS (Total)	RESULT (Total)	

NOTES:
Range: H= High, M= Middle, L= Low
Number of drops per mg/L:
CO2: 5 (high); 2 (middle); 1.25 (low)
Alkalinity: 20 (high); 5 (low)

Standard additions check required for a background sample at start of job to check reagents.
Duplicate analysis required for every 10 samples.

FIGURE 7.3

ONSITE GEOCHEMICAL ANALYSIS FIELD FORM

McClellan AFB, California

PARSONS ENGINEERING SCIENCE, INC.

Oakland, California

TABLE 7.3
SAMPLE STORAGE AND PRESERVATION REQUIREMENTS
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Analyte [1]	Method(s)	Holding Time	Container(s)	Preservation	Storage Requirement
ORP	direct-reading meter	analyze immediately	flow-through cell	none	do not store
Ferrous Iron	Hach 8146	analyze immediately	250 ml polyethylene	none	do not store
Manganese	Hach 8034	analyze immediately	250 ml polyethylene	none	do not store
Sulfide	Hach 8131	analyze immediately	250 ml polyethylene	none	do not store
Methane, ethane, and ethene	RSKSOP-175	20 days	40-mL glass vial with Teflon lined septum (no head space)	none	4° Celsius
Phospholipid Fatty Acids (PLFA)	Modified Bligh and Dyer Lipid Extraction	10 days	2 L; glass or semi-transparent or transparent plastic	10 mL formaldehyde per liter	4° Celsius
Volatile Fatty Acids (e.g. acetic, propionic)	HPLC/UV	10 days	40-mL glass vial with Teflon lined septum (no head space)	none	4° Celsius

[1] Analytes which are not included on this table appear in Section 4.0 of the Basewide RI/FS QAPP (Radian, 1997e).

titration cells will be used for the carbon dioxide field measurements. These procedures are summarized in the following sections. Details on calibration and SOPs are provided in Appendix C.

All glassware or plasticware used for field lab analyses will have been cleaned prior to sample collection by thoroughly washing with a solution of Liquinox® and potable water, rinsing with isopropyl alcohol, and rinsing with deionized water to prevent interference or cross-contamination between measurements. If concentrations of an analyte are above the range detectable by the titrimetric method, the analysis will be repeated by diluting the groundwater sample with reagent-grade or double-distilled water until the analyte concentration falls to a level within the range of the method.

7.2.3.1 Temperature, Conductivity, and pH

Temperature, conductivity and pH will be measured continuously by direct-reading meters. The stability of these parameters will be used to evaluate the groundwater purging process as described in Section 5.8.2 of the Basewide QAPP. Procedures are provided in SOP McAFB-024. The pH of groundwater has an effect on the presence and activity of microbial populations in groundwater. Further details on the rationale for this parameter is contained in Appendix D.

7.2.3.2 Dissolved Oxygen (DO)

DO is the most thermodynamically favored electron acceptor used by microorganisms for the biodegradation of organic carbon and less-chlorinated CAHs. Anaerobic bacteria generally cannot function at DO concentrations above about 0.5 mg/L. Further details on the rationale for this parameter is contained in Appendix D.

DO measurements will be made in accordance with the SOP McAFB-024, with the exception that measurements will be continuously monitored during purging with a sensor in a flow-through cell.

7.2.3.3 Oxidation-Reduction Potential (ORP)

The ORP of groundwater is an indication of the relative tendency of a solution to accept or transfer electrons. Oxidation-reduction (redox) reactions in groundwater are usually biologically mediated; therefore, the ORP of a groundwater system depends upon and influences rates of biodegradation. ORP can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. The ORP of a groundwater sample taken inside the contaminant plume should be somewhat less than that taken upgradient or cross-gradient from the plume. Further details on the rationale for this parameter is contained in Appendix D.

The ORP of a groundwater sample can change significantly within a short time following sample acquisition and exposure to atmospheric oxygen. Therefore, this parameter will be will be continuously monitored during purging with a sensor in a flow-through cell.

7.2.3.4 Ferrous Iron

Iron is an important trace nutrient for bacterial growth, and different states of iron can affect the ORP of the groundwater. Ferric iron (iron III) is used as an electron acceptor during anaerobic biodegradation of organic carbon. During this process ferrous iron (iron II) is produced, which is soluble in water. Further details on the rationale for this parameter is contained in Appendix D.

Ferrous iron concentrations will be measured in the field via colorimetric analysis with a Hach® DR/700 portable colorimeter. Hach® Method 8146 for ferrous iron (0 to 3.0 mg/L Fe^{2+}) will be used to prepare and quantitate the samples. The SOP for this method is included in Appendix C.

7.2.3.5 Manganese

Manganese is a potential electron acceptor under anaerobic environments. Manganese concentrations will be measured in the field via colorimetric analysis with a Hach® DR/700 portable colorimeter. USEPA-approved Hach® Method 8034 (0 to 20.0 mg/L) will be used for quantitation of manganese concentrations. The SOP for this method is included in Appendix C.

7.2.3.6 Sulfide

Sulfate in groundwater is a potential electron acceptor for biodegradation in anaerobic environments, and sulfide is the resultant after sulfate reduction. Further details on the rationale for this parameter is contained in Appendix D.

Sulfide concentrations will be measured in the field via colorimetric analysis with a Hach® DR/700 portable colorimeter. USEPA-approved Hach® Method 8131 (0.60 mg/L S^{2-}) will be used to prepare samples and analyze sulfide concentrations. The SOP for this method is included in Appendix C.

7.2.3.7 Carbon Dioxide

The presence of free carbon dioxide dissolved in groundwater is unlikely because of carbonate buffering; however, carbon dioxide concentrations should be compared to background to determine whether they are elevated. Further details on the rationale for this parameter is contained in Appendix D.

Carbon dioxide concentrations in groundwater will be measured in the field via titrimetric analysis using CHEMetrics Method 4500 (10 to 10,000 mg/L as CO_2). The SOP for this method is included in Appendix C.

7.2.4 Quality Control Sampling and Procedures

Quality Control sampling for both field and analytical methods will follow Section 10 of the Basewide QAPP. A site-specific QAPP for this demonstration study is provided in Section 8 of this WIP.

The analytical quality level and sample type proposed for this demonstration study is WT3Q2C for groundwater samples as detailed in Attachment 2 of the Basewide QAPP based on data requirements for "Design or Action" and a "Plume Extent" decision type. Tentatively identified compounds (TICs) will not be requested or reported. Based on the guidance in Attachment 2, field QC sampling will be collected at the following frequencies:

- Field duplicates: 5%
- Ambient blanks: 5%
- Equipment (rinseate) blanks: 5%
- Matrix spikes: 5%
- Trip blanks: one per cooler

Table 7.2 summarizes total number and type of the required QA/QC sampling summary for this demonstration study.

7.3 POST-OPERATIONAL SAMPLING

Post-operational sampling is not applicable to this demonstration study. However, a long-term monitoring plan will be developed, as discussed in Section 4.4.7.

SECTION 8

QUALITY ASSURANCE PROJECT PLAN

SECTION 8

QUALITY ASSURANCE PROJECT PLAN

8.1 INTRODUCTION AND OBJECTIVES

This section contains a project-specific Quality Assurance Project Plan (QAPP) for the intrinsic remediation demonstration study at ICs 17/19/21. Where appropriate, reference is made to the Basewide QAPP for non-project-specific sampling protocols and SOPs. A McClellan QAPP Applicability Checklist and Applicability Statement is contained in Appendix F.

This section has been developed for use in conjunction with sampling and analysis activities and describes the QA/QC procedures and protocols that will be used during sample analysis. This section will serve as a controlling mechanism during this investigation to ensure that a sufficient quantity of data is collected and that all data collected are valid, reliable, and defensible.

The objectives of this site-specific QAPP are:

1. Define the measurements and quality assurance objectives (QAOs) which will be used for this demonstration study, referencing the Basewide QAPP where appropriate;
2. List the project-specific data quality objectives (DQO);
3. Describe the analytical procedures, internal quality control (QC) checks, and corrective action plans for methods not covered by the Basewide QAPP; and,
4. Describe the data review, data reporting, and performance audits to be followed during this demonstration study.

8.2 MEASUREMENTS AND QUALITY ASSURANCE OBJECTIVES

Measurements will be used to evaluate the assess the quality of both field data and analytical laboratory data for the project. Measurements to be made include: precision, accuracy, representativeness, completeness, and comparability. For this project, these measurements are identical to those defined in Section 4.2.2 of the Basewide QAPP.

Quality assurance objectives (QAOs) are the detailed QC specifications for precision, accuracy, comparability, and completeness. Precision and accuracy objectives are usually method-specific. For this project, the precision and accuracy objectives from Tables 4-1, 4-3, 4-6, 4-11a, and 4-11b from the Basewide QAPP will be followed. Precision and accuracy objectives for methods not provided in the Basewide QAPP are listed in Table 8.1 and Table 8.2. The objective for completeness for this project will be 95%.

TABLE 8.1
QUALITY ASSURANCE OBJECTIVES FOR FIELD MEASUREMENTS
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Parameter/Method [1]	Precision	Accuracy
ORP (field meter)	+/- 20 mv	+/- 30 mV of Zobell solution standard
Dissolved Oxygen (field meter)	≤ 20% RPD	+/- 5% air saturated water standard +/- 0.2 mg/L of zero standard (sodium sulfite)
Ferrous Iron (Hach 8146)	+/- 10%	+/- 50%, three concentration points
Manganese (Hach 8034)	+/- 10%	+/- 50%, three concentration points
Sulfide (Hach 8131)	+/- 10%	+/- 50%, three concentration points
Carbon Dioxide (CHEMetrics A4500)	+/- 10%	+/- 50%, three concentration points

[1] Parameters which are not included on this table appear in Table 4-1 of the Basewide RI/FS QAPP (Radian, 1997e).

RPD: Relative Percent Difference

TABLE 8.2
QUALITY CONTROL ACCEPTANCE CRITERIA
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Method [1]	Analyte(s)	LCS % Recovery	MS % Recovery	MS/MS Duplicate RPD	FD RPD
RSKSOP-175	Methane, ethane, and ethene	80-120%	75%-125%	≤ 30	≤ 30
Modified Bligh & Dyer Lipid Extraction	Phospholipid Fatty Acids	60-120%	not applicable	not applicable	≤ 30
HPLC/UV	Volatile Fatty Acids	90-110%	90-110%	≤ 10	≤ 30

[1] Methods which are not included on this table appear in Section 4.0 of the Basewide RI/FS QAPP (Radian, 1997e).
LCS: Laboratory Control Sample
MS: Matrix Spike
RPD: Relative Percent Difference
FD: Field Duplicate

The objectives for comparability for this project will be to collect data which can be compared to that collected under the McClellan GWMP and compared to other sites evaluated using the AFCEE technical protocol. This objective will be met by using standard methods from the Basewide QAPP and the AFCEE technical protocol and utilizing contaminant fate and transport model input parameters from previous successful modeling efforts (as discussed in Section 4.4.2). Data will be reported in standard units and using standard and comprehensive reporting formats.

The sample handling and custody control discussed in Section 6.0 of the Basewide QAPP will be followed for this demonstration study. A sample chain-of-custody form is shown in Figure 8.1.

8.3 QUALITY ASSURANCE ORGANIZATION AND KEY PERSONNEL

Parsons ES personnel and subcontractor personnel responsible for quality assurance for this project are shown in Figure 8.2 along with their respective roles.

8.4 DATA QUALITY OBJECTIVES

The data quality objectives (DQOs) for this demonstration project are:

1. Satisfy the biodegradation criteria listed for "Remedy Selection" in the *Guide for Conducting Treatability Studies Under CERCLA: Biodegradation Remedy Selection* (USEPA, 1993), which are reproduced below.

Criteria	**Action/Result**
Biodegradation of most-resistant contaminants of concern	Meets cleanup standards under test conditions
Initial contaminant concentration	Max. concentration expected during remediation
Environmental conditions	Simulate expected site treatment conditions
Extent of biodegradation	Quantify
Biodegradation Rate	Defensible estimate
Estimate time to reach cleanup standards	Estimate
Mass balance	Closure or defensible explanation
Toxic byproducts	Test for if appropriate/possible
Process control and reliability	Assess potential
Microbial activity	Verify/quantify if possible
Process optimization	Estimate if possible
Cost estimate for full-scale	Rough (-30%, +50%)
Experimental scale	Estimate if possible
Process optimization	Either bench or pilot scale

PARSONS ENGINEERING SCIENCE, INC.
2101 Webster Street, Suite 700
Oakland, California 94612
Phone: (510) 891-9085
FAX: (510) 835-4355

CHAIN OF CUSTODY RECORD

Project No.: 731010.02000
Project Name/Location: McClellan AFB, IC 19
Project Manager: Michael Phelps (Oakland, CA)
Site Manager: Marcus Pierce (Oakland, CA)
Sampler(s): (Initials and Signature(s))

Sample ID	Date	Time	Begin Depth	End Depth	QC (MS/ MSD)	Matrix	NO. OF CONTAINERS	ANALYTES (METHOD)	ORGANICS							INORGANICS						OTHER	Remarks
						water		TPH-gasoline/GRO (5030/8015AM)	Extract. TPH/DRO (3550/8015AM)	VOCs, full list (5030/8260A)	TOC (9060)	Ammonia (E350.1)	Nitrate/Nitrite (E353.3/E354.1)	Methane, Ethane, Ethene (RSKSOP-175/147)	Chloride (E300.0)	Sulfate (E300.0)	Alkalinity (E310.1)				
						water																	
						water																	
						water																	
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RELINQUISHED BY: (SIGNATURE)	DATE	TIME	RECEIVED BY: (SIGNATURE)	DATE	TIME	NOTES:
RELINQUISHED BY: (SIGNATURE)	DATE	TIME	RECEIVED FOR LAB BY: (SIGNATURE)	DATE	TIME	COMMENTS:

FIGURE 8.1

SAMPLE CHAIN OF CUSTODY

McClellan AFB, California

PARSONS ENGINEERING SCIENCE, INC.

Oakland, California

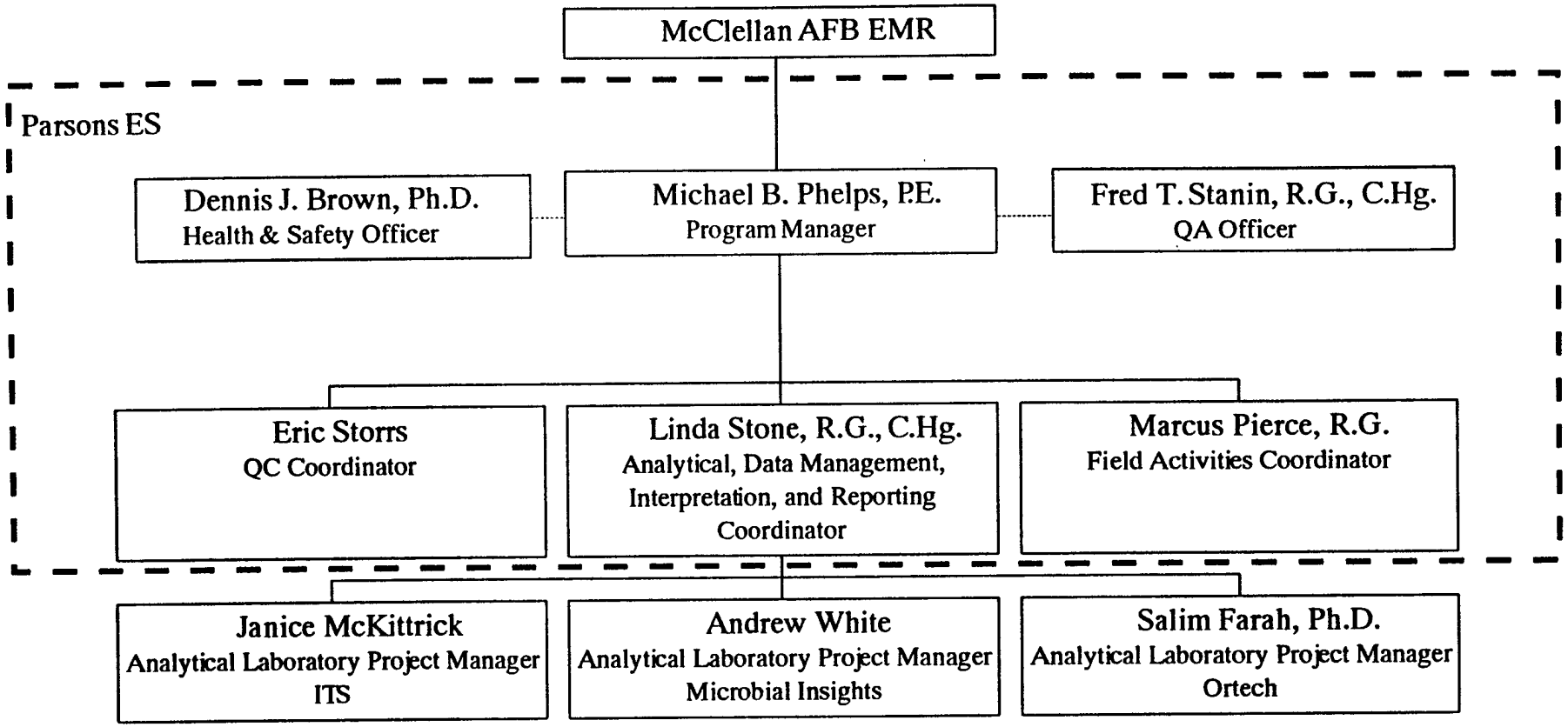


FIGURE 8.2

PROJECT ORGANIZATIONAL CHART

McClellan AFB, California

PARSONS ENGINEERING SCIENCE, INC.

Oakland, California

Contaminant concentrations, including byproducts of biodegradation and indicators of microbial activity, will be measured as discussed in Section 7. Because the demonstration is a field/pilot-scale study, actual site treatment conditions and maximum concentrations expected during remediation will be measured. A defensible biodegradation rate will be estimated as described in Section 4.4.4, supported by the installation of 5 additional MWs as described in Section 5. Fate and transport modeling, as described in Section 4.4, will be performed in order to estimate the time to reach cleanup standards and a sensitivity analysis will be performed to determine the reliability of the estimate. The model chosen for this demonstration performs a mass balance.

The types of cost to be included in the results report include:

- Maintaining institutional controls;
- Installation of point-of-compliance wells;
- Long-term monitoring;
- Waste disposal costs;
- Update of the fate and transport model; and,
- Reporting and project management.

Costs will be documented in accordance with the *Guide to Documenting Cost and Performance for Remediation Projects, Member Agencies of the Federal Remediation Technologies Roundtable* (USEPA, 1995). The estimated costs will be used to estimate a present-worth cost estimate to facilitate comparison with other remediation technologies.

The long-term monitoring and compliance plan included in the results report will be designed to meet the criteria of the next tier in the guidance document ("Remedy Design").

2. Meet or exceed the DQOs of the AFCEE technical protocol document (Table 2.2 from Appendix D).
3. Collect data on the type, concentration, and extent of contaminants and geochemical indicators of biodegradation in groundwater to determine if natural attenuation and biodegradation processes are occurring at ICs 17/19/21. This DQO will be achieved by following the guidelines for sampling locations and DQOs from the AFCEE technical protocol document, the DQOs from the Basewide QAPP, and analyzing groundwater samples for PLFA and volatile fatty acids for direct evidence of biodegradation.
4. Estimate defensible, site-specific first-order and second-order biodegradation rates using linear regression techniques. The R-squared parameter will be used to evaluate the reliability of the calculated value.
5. Collect additional groundwater elevation data with the same level of accuracy as historical groundwater elevation data (i.e., to the nearest 0.01 feet) in order to identify the current groundwater gradients and flow directions at the site.

6. Meet the data input requirements of the selected contaminant fate and transport model (Section 4.4.2) so that the long-term effectiveness of natural attenuation processes can be evaluated. Sensitivity and uncertainty analyses (Section 4.4.6) will be used to evaluate the quality of the model output.

8.5 ANALYTICAL PROCEDURES AND CALIBRATION

Detailed analytical procedures and calibration requirements are summarized in Section 4.0, 5.0, 7.0, and 8.0 of the Basewide QAPP. Detailed analytical procedures and calibration requirements for field lab and analytical laboratory methods to be used for this demonstration study that are not included in the Basewide QAPP are provided in Appendix C. Method detection and quantitation limits for these methods are provided in Table 8.3 and sample storage and preservation requirements are provided in Table 7.3.

8.6 DATA REDUCTION, VALIDATION, AND REPORTING

Data reduction, assessment, and reporting will follow the procedures in Sections 9.0 and 13.0 and SOPs McAFB-028 and McAFB-030 from the Basewide QAPP. Data validation is not being proposed for this demonstration study as discussed in Section 8.8.

8.7 INTERNAL QUALITY CONTROL CHECKS

Calibration and internal QC checks are summarized in Section 10 of the Basewide QAPP. Calibration and internal QC checks for field laboratory and analytical laboratory methods to be used for this demonstration study that are not included in the Basewide QAPP are summarized in Table 8.4.

8.8 PERFORMANCE AND SYSTEM AUDITS

Following the guidelines in Section 11.4 of the Basewide QAPP, a comprehensive Technical Systems Audit, data validation, and double-blind performance evaluation is not being proposed for this demonstration for the following reasons:

- Total number of samples is not expected to exceed 50 per method;
- All existing MWs are currently included in the GWMP;
- All new MWs are expected to be included in the GWMP; and,
- The analytical laboratory proposed in this study (ITS of Richardson, TX) has recently undergone a QA audit as part of similar sampling activities at other DoD facilities.

However, because the field activities for natural attenuation sampling have not been conducted at McClellan AFB, one General Sampling Systems Audit and Soil/Water

TABLE 8.3
METHOD DETECTION AND QUANTITATION LIMITS
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Method [1]	Parameter	Analytes	Detection Limits	Quantitation Limits
RSKSOP-175	Dissolved gases	Methane	0.05 µg/L	0.5 µg/L
		Ethane	0.05 µg/L	0.5 µg/L
		Ethene	0.05 µg/L	0.5 µg/L
Modified Bligh & Dyer Lipid Extraction	Phospholipid fatty acids (PLFA)	--	2 picomoles	7 picomoles
HPLC/UV	Volatile fatty acids	acetic acid	0.5 mg/L	1 mg/L
		propionic acid	0.5 mg/L	1 mg/L

[1] Methods which are not included on this table appear in Section 4.0 of the Basewide RI/FS QAPP (Radian, 1997e).

TABLE 8.4
SUMMARY OF CALIBRATION AND INTERNAL QUALITY CONTROL PROCEDURES
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Analytical Method [1]	Applicable Parameter	Quality Control Check	Minimum Frequency	Acceptance Criteria	Corrective Action
E360.1	Dissolved oxygen	Calibration with zero standard (sodium sulfite) and air saturated water	Daily	± 5% air saturated water standard ± 0.2 mg/L of zero standard	1) check meter, standard solutions 2) replace if necessary 3) repeat calibration check
		Field duplicate	10% of field samples	RPD < 20%	recalibrate instrument
ASTM D1498	ORP	Calibration with Zobell standard	Daily	± 30 mv of standard	recalibrate; mix new Zobell standard
		Field duplicate	10% of field samples	± 20 mv of primary	recalibrate instrument
Hach 8146	Ferrous Iron	Accuracy check, (3 concentration points)	Daily	± 50 % of standard	1) check colorimeter, standard solutions, and optical cell 2) replace if necessary 3) repeat calibration check
		Field duplicate	10% of field samples	± 10 % of primary	same as above
Hach 8034	Manganese	Accuracy check, (3 concentration points)	Daily	± 50 % of standard	1) check colorimeter, standard solutions, and optical cell 2) replace if necessary 3) repeat calibration check
		Field duplicate	10% of field samples	± 10 % of primary	same as above
Hach 8131	Sulfide	Accuracy check, (3 concentration points)	Daily	± 50 % of standard	1) check colorimeter, standard solutions, and optical cell 2) replace if necessary 3) repeat calibration check
		Field duplicate	10% of field samples	± 10 % of primary	same as above
CHEMetrics A4500	Carbon dioxide	Accuracy check, (3 concentration points)	Daily	± 50 % of standard	1) check titrant, standard solution 2) replace if necessary 3) repeat calibration check
		Field duplicate	10% of field samples	± 10 % of primary	same as above

TABLE 8.4 (continued)
SUMMARY OF CALIBRATION AND INTERNAL QUALITY CONTROL PROCEDURES
Intrinsic Remediation Demonstration at ICs 17/19/21
McClellan AFB, California

Analytical Method [1]	Applicable Parameter	Quality Control Check	Minimum Frequency	Acceptance Criteria	Corrective Action
RSKSOP-175	Methane, ethane, and ethene	Initial 3-point calibration	During instrument setup, whenever system components are changed, or when continuing calibration fails.	The RSD of the response factors should be within 20% using an FID.	1) correct problem according to instrument manufacturer's recommendations. 2) Repeat calibration.
		Continuing Calibration	Daily, prior to any analyses	Percent difference of response factors between continuing and initial calibration should be within 20% using an FID.	A new initial calibration must be made.
		Method Blank	Daily, immediately following initial or continuing calibration	Target components should be less than the detection limit.	repeat calibration
		LCS	With each batch of samples	The target compounds using an FID should be within 80-120%.	repeat calibration
Modified Bligh & Dyer Lipid Extraction	Phospholipid fatty acids (PLFA)	GC calibration	Daily	C19 within 10% and C12-C24 within 20%	1) correct problem according to instrument manufacturer's recommendations. 2) repeat calibration
		Method Blank	Daily, immediately following initial or continuing calibration	Target components must be twice those found in the blank	reprocess the samples or report below method detection limit
		LCS	With each batch of samples	60 - 120%	reanalyze the samples
HPLC/UV	Acetic, butyric, formic, propionic and n-valeric acids	Initial 5-point calibration	During instrument setup, whenever system components are changed, or when continuing calibration fails.	Recovery must be 90% or greater	do not proceed with calculations until an explanation is found and approved by the lab supervisor.
		Method Blank	Daily, immediately following initial or continuing calibration	verify that there are no peaks eluting in the area of the analyte peaks	same as above
		LCS	Every 6 injections	within 10% of corresponding calibration standard	same as above
		Lab Duplicate	1 in 10 samples	Duplicate peak responses must agree within 10% of primary	same as above

[1] Methods which are not included on this table appear in Section 10.0 of the Basewide RI/FS QAPP (Radian, 1997e).

LCS: Laboratory control spike
RPD: Relative percent difference
HPLC: High performance liquid chromatography
RSD: Relative Standard Deviation
FID: Flame ionization detector

Sampling Systems Audit, including an audit of procedures for field methods not included in the McClellan QAPP, will be performed. The audit will follow the procedures detailed in 11.0 of the Basewide QAPP.

8.9 CORRECTIVE ACTION PLAN

Corrective actions are summarized in Section 14.0 of the Basewide QAPP. Corrective actions for field laboratory and analytical laboratory methods to be used for this demonstration study that are not included in the Basewide QAPP are summarized in Table 8.4.

8.10 ANALYTICAL LABORATORY REQUIREMENTS

The analytical laboratory assumes responsibility for providing all "fixed-base" analytical services specified in Section 7 and following all procedures referenced in the Basewide QAPP and presented in this project-specific QAPP. Instrument testing, equipment testing, preventive maintenance, inspections, and maintenance of data on magnetic tapes from gas chromatography/mass spectroscopy analyses are also required. The laboratory must conduct internal system audits on a periodic basis. The results of these audits will be documented by the laboratory QC coordinator, and the laboratory will provide Parsons ES with the results of these internal audits. The QA officers from both the analytical laboratory and the Parsons ES will monitor the data from the laboratory and correct any nonconformances.

To facilitate data handling and management, laboratory data will be entered into a computerized format. All data will be delivered to Parsons ES from the laboratory in the database format specified in the *Installation Restoration Program Information Management System (IRPIMS) Data Loading Handbook*, Version 2.3 or later (AFCEE, 1994). The laboratory will be responsible for running QC Tools on the analytical data files prior to delivery to the contractor.

SECTION 9

HEALTH AND SAFETY

SECTION 9

HEALTH AND SAFETY

9.1 INTRODUCTION AND OBJECTIVES

This section contains a site-specific Health and Safety Plan (HASP) for the intrinsic remediation demonstration study at ICs 17/19/21. Where appropriate, reference is made to the *Program Health and Safety Plan for Risk-Based Remediation Demonstrations* which is included as Appendix E. Included or referenced in this section are the project team organization, hazard assessment, engineering controls, personnel and subcontractor training, site monitoring, medical surveillance requirements, decontamination procedures, and emergency contacts.

Both this site-specific HASP and a copy of the Program HASP will remain on site at all times.

9.2 HEALTH AND SAFETY ORGANIZATION AND KEY PERSONNEL

The following personnel will be responsible for health and safety for this project.

Parsons ES Contacts	Telephone Number
Dennis Brown, Ph.D. Oakland Office Health and Safety Manager	(510) 891-9085 (Work)
Ed Grunwald, CIH Corporate Health and Safety Manager	(404) 235-2300 (Work) (404) 299-9970 (Home)
Marcus Pierce Site Health and Safety Officer	(510) 891-9085 (Work) (415) 898-8996 (Home)
Michael Phelps, P.E. Project Manager	(510) 891-9085 (Work) (415) 664-4445 (Home)

9.3 HAZARD ASSESSMENT

9.3.1 Chemical Hazards

The contaminants of concern in groundwater in OU C are primarily CAHs and petroleum hydrocarbons. Metals and radionuclides have also been detected in OU C groundwater at low concentrations. Potential health hazards for CAHs and other historically detected groundwater contaminants are presented in Table 9.1.

TABLE 9.1
POTENTIAL HEALTH AND SAFETY HAZARDS
INTRINSIC REMEDIATION DEMONSTRATION AT IC 19
MCCLELLAN AFB, CALIFORNIA

Chemical	Hazard Potential	Hazardous Concentrations			Odor	Ionization	Route of Exposure	Recognition Qualities	Symptoms of Exposure	Last Update
		PEL (ppm)	TLV (ppm)	IDLH (ppm)	Threshold (ppm)	Potential (eV)				
					ORGANICS					
Acetone	Flammable liquid	750 (TWA) 1000 (STEL)	750 (TWA)	20,000	100	9.69	Inhalation Ingestion Contact	Colorless liquid with a fragrant mint-like odor	Irritation of eyes, nose, throat; headache, dizziness, dermatitis	3/11/94
Benzene	OSHA-regulated carcinogen Highly flammable Moderate explosion hazard	1 (TWA) 5 (STEL)	10 (TWA)	3,000	4.68	9.25	Inhalation Absorption Ingestion Eye contact	Colorless liquid with aromatic solventy odor	Eye, nose, respiratory irritation; giddiness, nausea, headache, staggered gait, fatique, dermatitis, abdominal pain	5/18/93
Carbon Tetrachloride	Not combustible Incompatible with active metals NIOSH-carcinogen	2 (TWA)	5 (TWA)	300	21.4-200	11.47	Inhalation Absorption Ingestion Contact	Colorless liquid with an ether-like odor	CNS depressant, eyes, lungs, liver, kidneys, skin	6/1/93
Chloroform (Trichloromethane)	Suspected carcinogen Emits highly toxic fumes when heated	2 (TWA)	10 (TWA)	1,000	205-307	11.42	Inhalation Ingestion Contact	Colorless liquid with a pleasant, sweet odor	Dizziness, mental dullness, nausea, headache, fatique, anesthesia, hepatomegaly, eye and skin irritation	9/1/92
Dichlorodifluoromethane (Freon 12)	Emission of phosgene gas when heated	1000 (TWA)	1000 (TWA)	50,000	NA	11.75	Inhalation Eye contact	Colorless and almost odorless gas	Dizziness/tremors, cardiac arrhythmias, cardiac arrest	9/1/92
1,2-Dichlorobenzene	Combustible Poisonous gases produced in fire	25 (TWA)	25 (TWA)	1,000	4.0	9.06	Inhalation Ingestion Contact	Colorless liquid with pleasant aromatic odor	Eyes, nose, skin irritation; drowsiness, coughing, CNS depression	6/1/95
1,1-Dichloroethane (DCA)		100 (TWA)	100 (TWA)	4,000	120	11.06	Inhalation Ingestion Contact	Colorless liquid with chloroform-like odor	CNS depression, skin irritation, drowsiness, unconsciousness	3/11/94
1,2-Dichloroethane (1,2-DCA) (Ethylene Dichloride)	Carcinogen	1 (TWA)	10 (TWA)	1,000	100	11.05	Inhalation Ingestion Contact	Colorless liquid, pleasant odor	Nausea, drunkenness, depression, liver/kidney damage, eye/skin irritant	5/18/93

TABLE 9.1 (continued)

Chemical	Hazard Potential	Hazardous Concentrations PEL (ppm)	TLV (ppm)	IDLH (ppm)	Odor Threshold (ppm)	Ionization Potential (eV)	Route of Exposure	Recognition Qualities	Symptoms of Exposure	Last Update
1,1-Dichloroethene (DCE) (1,1-Dichloroethylene) (Vinylidene Chloride)	Possible carcinogen	1 (TWA)	5 (TWA) 20 (STEL)	NA	500	9.46	Inhalation Ingestion Contact	Watery liquid, colorless, sweet odor	CNS depression, skin irritation, drowsiness, unconsciousness, dizziness	3/11/94
1,2-Dichloroethene (DCE) (1,2-Dichloroethylene)	Possible carcinogen	200 (TWA)	200 (TWA)	4,000	0.085	9.65	Inhalation Ingestion Contact	Colorless liquid with chloroform-like odor	CNS depression, skin irritation, drowsiness, unconsciousness	12/21/92
Diesel Fuel (based on naphtha) VM&P	Moderate fire/explosion hazard	300 (TWA)	300 (TWA)	10,000	0.08		Inhalation Absorption Ingestion	Colorless to brown liquid	Headache, stupor, nausea, vomiting, pneumonitis	3/11/94
Methylene Chloride (Dichloromethane)	Carcinogen	50[a]	50 (TWA)	5,000	25-320	11.35	Inhalation Ingestion Contact	Colorless liquid with faint sweet odor	CNS depression symptoms, eye irritation	3/11/94
Tetrachloroethene (Tetrachloroethylene) (Perchloroethylene)	Suspected carcinogen	25 (TWA) 200 (c)	50 (TWA) 200 (c)	500	5-50	9.47	Inhalation Ingestion Eye/skin	Colorless liquid with chloroform-like odor	Headache, vertigo, nausea, vomiting, vision disturbance	8/16/90
Toluene	Flammable Suspected teratogen/mutagen	50 (TWA)	50 (TWA)	2,000	0.17-40	8.82	Inhalation Absorption Ingestion Eye contact	Colorless liquid with benzene-like odor	Dizziness, headache, fatigue and weakness, confusion, tearing, nervousness, dermatitis	6/1/95
Trichloroethene (Trichloroethylene)	Carcinogen	25 (TWA)[a]	50 (TWA) 200 (STEL)	1,000	21.4-400	9.47	Inhalation Ingestion Contact	Colorless liquid unless dyed, chloroform odor	Nausea, vomiting, eye irritant, vertigo, visual disturbances, carcinogen	7/14/93
Trichlorofluoromethane (Freon-11)		1000 (TWA)[2]	1000 (c)	10,000	135-209	11.77	Inhalation Contact	Colorless, odorless liquid	Dizziness, drowsiness	5/3/94
Vinyl Chloride	Carcinogen	1	5 (TWA)	NA	260	9.995	Inhalation	Colorless gas, liquifies in a freezing mixture	Weakness, abdominal pain, cyanosis of the extremities	12/21/92

Notes:

PEL Permissable Exposure Limit, Title 29, CFR, Department of Labor, Occupational Safety and Health Administration

TLV Threshold Limit Value, 8 hour time weighted average, American Conference of Governmental Industrial Hygienists

IDLH Immediately Dangerous to Life and Health, National Institute of Occupational Safety and Health

STEL Short Term Exposure Limit (15 minutes unless otherwise specified)

TABLE 9.1 (continued)

C Ceiling Limit
TWA Time weighted Average
a) Permissable Exposure Limit, Title 8, California Code of Regulations, General Industry Safety Orders, Section 5155
NA Not available
c) Based on coal tar pitch volatiles
$\mu g/m^3$ microgram per cubic meter
mg/m^3 milligram per cubic meter

9.3.2 Physical Hazards

Potential physical hazards at McClellan AFB include hazards associated with 1) lifting and operating heavy equipment (submersible pumps and generators); 2) motor vehicle traffic; 3) slip/trip/fall hazards; 4) noise; and, 5) heat exposure. These hazards are discussed in detail Section 5.0 of the Program HASP.

9.4 ENGINEERING CONTROLS

Engineering controls are discussed in detail in Section 9 of the Program HASP.

9.5 PERSONNEL AND SUBCONTRACTOR TRAINING

Personnel training is covered in Section 4 of the Program HASP. All personnel will be required to sign the site-specific health and safety plan acceptance form shown in Figure 9.1.

9.6 SITE MONITORING AND PERSONAL PROTECTIVE EQUIPMENT

Prior to purging and sampling activities, groundwater elevations will be collected from each well. During collection of groundwater elevations, each well will be screened with a photoionization detector (PID). The field crew shall position themselves on the upwind side of each well to minimize risk of potential exposure to CAHs. Screening will be conducted by placing the PID probe in the anticipated worker breathing zone above the top of the well casing as soon as the well cap is removed. If the initial well head reading does not exceed background levels, then additional air monitoring will not be required during the purging/sampling of the well. If the initial well head reading exceeds background levels, then monitoring of the breathing zone shall be conducted during well purging/sampling activities as described below.

The personal protection level prescribed for field activities at ICs 17/19/21 at McClellan AFB is OSHA Level D with a contingency for the use of OSHA Level B or C as site conditions require. It is considered unlikely that site conditions will require additional personal protection beyond level D. However, this health and safety addendum includes a contingency for upgrading to OSHA Level B or C personal protection based on the results of air monitoring.

9.6.1 IC 17 and IC 21

For sampling conducted within IC 17 and IC 21, a reading of 5 ionizable vapor units above background in the worker breathing zone will require the use of Dräger®/Sensidyne® tubes or equivalent to determine if benzene and/or vinyl chloride are present at a concentration greater than or equal to the permissible exposure limit (PEL) of 1 parts per million by volume (ppmv). Due to the inadequate warning properties of benzene and vinyl chloride, Level B protection must be used if concentrations of benzene or vinyl chloride exceed 1 ppmv in the worker breathing zone.

If benzene or vinyl chloride are not present, the flow chart presented in Figure 9.2 will be followed. Periodic testing of vapor concentrations for the presence of benzene and vinyl

PROJECT HEALTH AND SAFETY PLAN
BRIEFING ACKNOWLEDGMENT

I have attended a tailgate Health & Safety meeting
and agree to abide by the contents of **my employer's**
Health and Safety Plan
for

_____

at the

_____

_____

Name (Print)	Signature	Company	Date

FIGURE 9.1

SIGNATURE PAGE FOR HEALTH AND SAFETY PLAN

McClellan AFB, California

PARSONS ENGINEERING SCIENCE, INC.

Oakland, California

chloride will be performed if PID meter readings exceed background levels in the worker breathing zone. Additional personal protective equipment will be selected as detailed in Section 7.1 of the Program HASP.

9.6.2 IC 19

1,2-DCA is one of the COCs at IC 19. A PID cannot detect 1,2-DCA and colorimetric detector tubes are not available in the proper range for 1,2-DCA. Therefore, OSHA Level C will not be allowed at IC 19. All other requirements of Section 7 from the Program HASP remain in effect. Respiratory protection criteria for IC 19 is described below.

Although the PID cannot detect 1,2-DCA, based on the distribution and sources of site contamination, it is highly unlikely that 1,2-DCA will be present without the presence of any of the other COCs (e.g. TCE, PCE, 1,2-DCE, vinyl chloride), which are all detectable with the PID. Therefore, a respiratory protection criteria of 1 part per million by volume (ppmv) as indicated on a PID is considered reasonable and prudent at IC 19. Due to the inadequate warning properties of benzene, vinyl chloride, 1,1-DCE, and 1,2-DCA, Level B protection must be used if concentrations of these contaminants exceed 1 ppmv in the worker breathing zone. No colorimetric detector tubes are available in the proper range for 1,2-DCA; therefore, they cannot be used to screen for the presence of 1,2-DCA.

A sustained (greater than 30 seconds) reading of 1 ionizable vapor units (ppmv) above background in the worker breathing zone as indicated by a PID will require the use of engineering controls (e.g., ventilation) to lower readings in the worker breathing zone below 1 ppmv. If engineering controls are unsuccessful, OSHA Level B will be required before continuing site operations (Parsons ES corporate approval is also required before proceeding to OSHA Level B).

9.7 MEDICAL SURVEILLANCE REQUIREMENTS

Medical surveillance requirements are covered in Section 4 of the Program HASP.

9.8 DECONTAMINATION PROCEDURES

Decontamination procedures are covered in Section 10 of the Program HASP.

9.9 EMERGENCY CONTACTS

In the event of any emergency, situation, spill or other unplanned occurrence requiring assistance, the appropriate contacts should be made from the list below. In addition to the site-specific and Program HASPs, the *Spill Prevention, Control, and Countermeasures Plan* (Mitretek, 1996) must be kept on site at all times. A list of emergency contacts must be kept at the site.

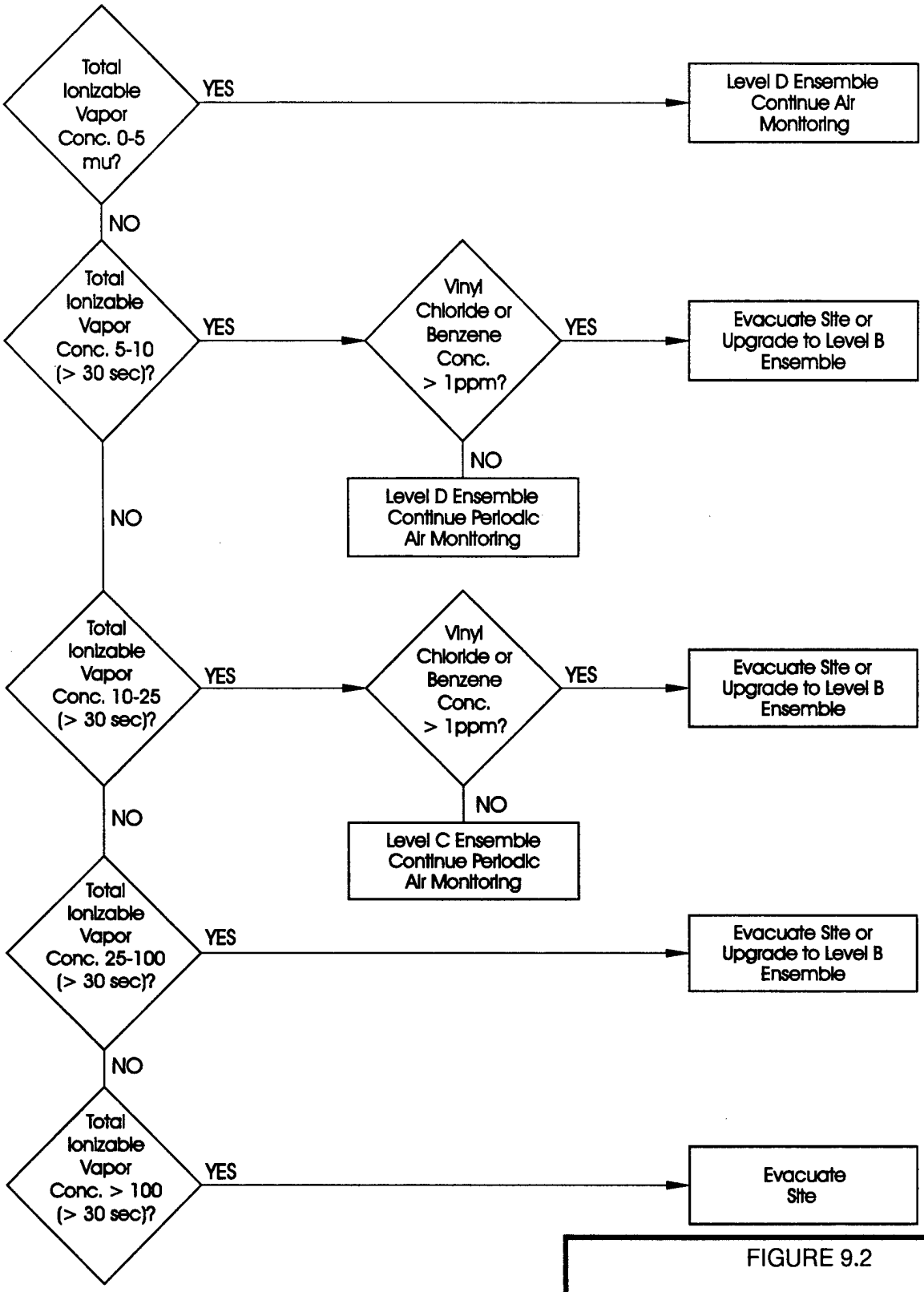


FIGURE 9.2

PERSONAL PROTECTIVE EQUIPMENT FLOWCHART FOR IC 21 AND IC 17

McClellan AFB, California

PARSONS ENGINEERING SCIENCE, INC.

Oakland, California

EMERGENCY CONTACTS	TELEPHONE NUMBER
Fire/Police/Medical	911 117/112/115 (military phone)
McClellan AFB Incident Commander: Fire Dept.(Spill Response)	117 or (916) 643-6666
McClellan AFB Security (Non-emergency)	(916) 643-6160
McClellan AFB Fire Dept.	(916) 765-3400
Poison Control Center	(800) 523-2222
Chem-trec (Emergency Chemical Spill Response Information)	(800) 424-9300
Chemtel (Parsons ES 24-hour response number for shipments of hazardous materials)	(800) 255-3924
Medical Services Network	(800) 874-4676 x211
Site Contacts:	
Duty Officer	(916) 643-2517
Craig Burnett (EM Representative)	(916) 643-3672 x327
Tim Chapman (EM Representative)	(916) 643-1739
Larry Haramio (Contracting Officer)	(916) 643-0741
Mercy American River Hospital 4797 Engle Road, Carmichael, CA	(916) 484-2100
McClellan AFB Clinic **Acute Treatment Team, 77th Medical Group** 5342 Dudley Blvd., McClellan AFB	(916) 643-8420

Directions to Hospital:

Directions to emergency room nearest to site: Exit the Base through the Peacekeeper gate and turn right on Watt Avenue. Travel south on Watt for 3 miles and turn left on Edison Avenue. Travel east on Edison Avenue for 2.5 miles and turn right on Gibbons Drive. Travel on Gibbons for 0.5 mile. The Emergency Room is in back of the hospital, which is located on the south side of Gibbons Drive. **The location of the hospital is shown on Figure 9.3.**

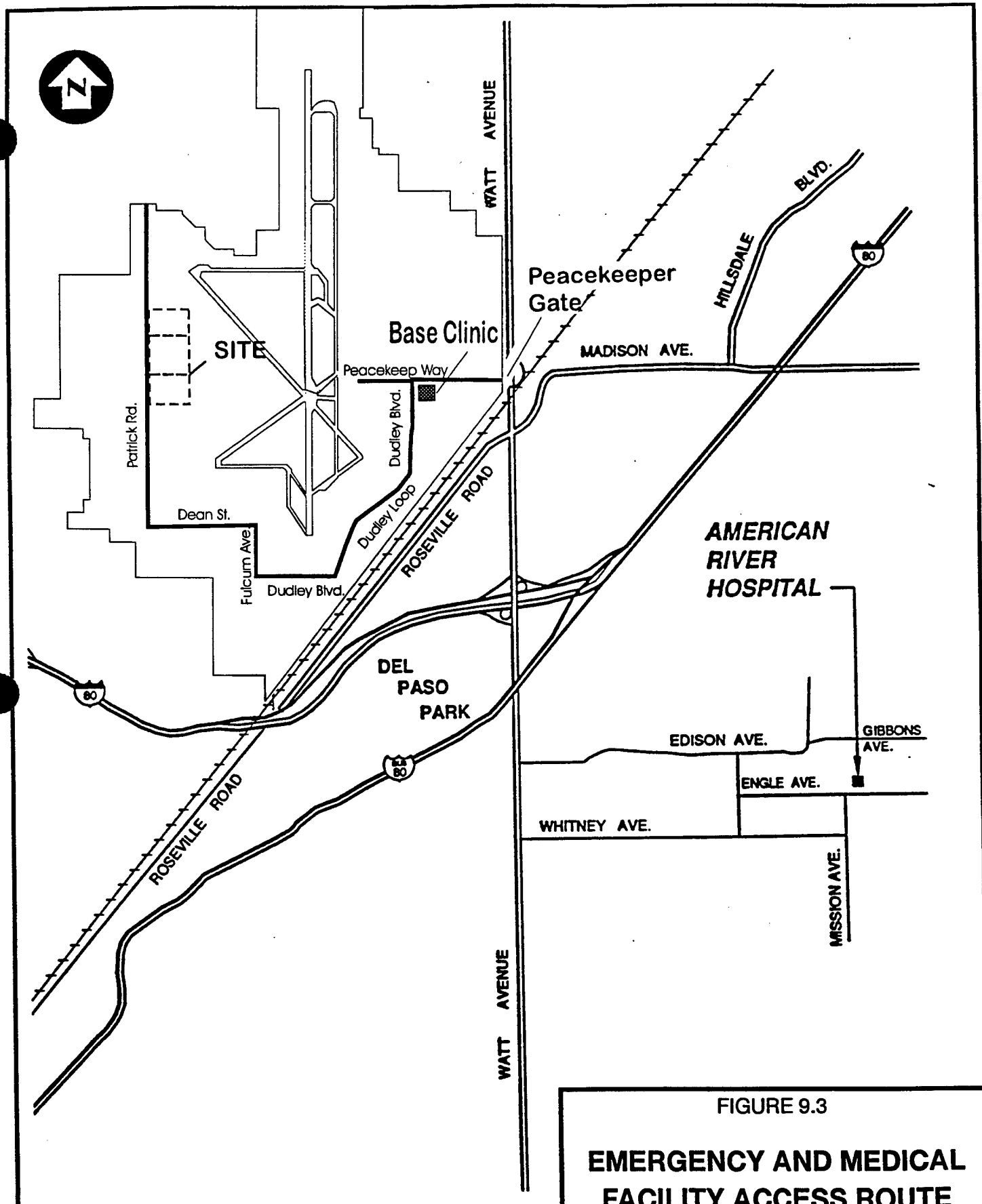


FIGURE 9.3

EMERGENCY AND MEDICAL FACILITY ACCESS ROUTE

McClellan AFB, California

PARSONS ENGINEERING SCIENCE, INC.

Oakland, California

Directions to McClellan AFB on-site clinic (Acute Treatment Team): The location of the clinic is shown on Figure 9.3. From the site, drive south on Patrick Road. Turn left on Dean Street, right on Forcum Ave, and left on Dudley Blvd. The Clinic is at Building 98, 5342 Dudley Blvd., at the corner of Peacekeeper Way. **The location of the clinic is shown on Figure 9.3.**

SECTION 10

SCHEDULE

SECTION 10

PROJECT SCHEDULE

The following schedule is based on the time requirements anticipated for regulatory agency reviews and approvals and assumes this Final Work Implementation Plan will be submitted to the regulatory agencies in its current form. A Gantt chart is shown in Figure 10.1.

Event	Date
Date of Contract Award	31 December 1996
Draft WIP delivered to McClellan AFB	10 April 1997
Comments to Draft WIP received from McClellan AFB	23 June 1997
Response to Draft WIP Comments delivered to McClellan AFB	13 August 1997
Confirm start date of field work with McClellan AFB Field Manager	01 October 1997
Final WIP delivered to McClellan AFB	03 October 1997
Begin field activities	20 October 1997
Complete field activities	14 November 1997
Draft Results Report (including long-term monitoring and compliance plan) due to McClellan AFB	30 January 1998
Comments to Draft Results Report due from McClellan AFB	14 March 1998
Final Results Report due to McClellan AFB	31 March 1998

SECTION 11

MANAGEMENT AND STAFFING

SECTION 11

MANAGEMENT AND STAFFING

11.1 DEMONSTRATION STUDY MANAGEMENT PERSONNEL

The personnel involved in this demonstration study, their project roles, and their contact information are shown in Table 11.1. Additional field personnel not shown in Table 11.1 may be used during the field work and data collection phase of the project. Three analytical laboratories and one drilling subcontractor will be used during this demonstration study.

TABLE 11.1
POINTS-OF-CONTACT
INTRINSIC REMEDIATION DEMONSTRATION AT IC 19
McCLELLAN AFB, CALIFORNIA

Name	Organization	Project Role	Mailing Address	Phone/FAX Number	E-Mail Address
Craig Burnett	SM-ALC/EMR	Program Manager	SM-ALC/EMP 5050 Dudley Blvd, Suite 3 McClellan AFB, CA 95652	(916) 643-3672 x327 FAX (916)643-0827	burnett.craig@email.mcclellan.af.mil
Tim Chapman	SM-ALC/EMR (BDM)	Senior Environmental Engineer/ Technical Coordination	SM-ALC/EMR (BDM) 5050 Dudley Blvd, Suite 3 McClellan AFB, CA 95652	(916) 643-0830 x412 FAX (916)643-5880	chapman.timothy@sma1.mcclellan.af.mil
Jerry Vincent	SM-ALC/EMR	Field Manager	SM-ALC/EMR 5050 Dudley Blvd, Suite 3 McClellan AFB, CA 95652	(916) 643-0830 x147 FAX (916) 643-0827	jvincent@sm0249.mcclellan.af.mil
Larry Jaramillo	SM-ALC/PKOP	Contracting Officer	SM-ALC/PKOP 5120 Dudley Blvd McClellan AFB, CA 95652	(916) 643-0741	
Michael Phelps	Parsons ES	Project Manager	2101 Webster St, Suite 700 Oakland, CA 94612	(510) 891-9085 FAX (510) 835-4355	michael_phelps@parsons.com
Marcus Pierce	Parsons ES	Site Manager/Site Health and Safety Officer	2101 Webster St, Suite 700 Oakland, CA 94612	(510) 891-9085 FAX (510) 835-4355	marcus_pierce@parsons.com
Todd Wiedemeier	Parsons ES	Technical Director	100 W. Walnut Ave Pasadena, CA 91124	(818) 440-6133 FAX (818) 440-6200	todd_wiedemeier@parsons.com
Rob Hinchee	Parsons ES	Technical Manager	406 W. S. Jordan Pkwy, 300 Salt Lake City, UT 84095	(801) 572-5999 FAX (801) 572-9069	robert_hinchee@parsons.com
Dennis Brown	Parsons ES	Office Health and Safety Manager	2101 Webster St, Suite 700 Oakland, CA 94612	(510) 891-9085 FAX (510) 835-4355	dennis_brown@parsons.com
Janice McKittrick	Intertek Testing Services	Analytical Laboratory	1089 E. Collins Boulevard Richardson, TX 75081	(972) 238-5591 FAX (972) 238-5592	
Andrew White	Microbial Insights, Inc.	Analytical Laboratory (PLFA only)	2340 Stock Creek Road Rockford, TN 37853	(423) 573-8188 FAX (423) 573-8133	microbe@microbe.com
Dr. Salim Farah	Ortech Corp.	Analytical Laboratory (volatile fatty acids only)	2395 Speakman Dr. Mississauga, Ontario Canada L5K 1B3	(905) 822-4111 FAX (905) 823-1446	
Don Motsko	Water Development Corporation	Drilling subcontractor	1202 Kentucky Ave Woodland, CA 94716	(916) 662-2829 FAX (916) 662-1592	

SECTION 12

REFERENCES

SECTION 12

REFERENCES

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APPENDIX A

BORING LOGS AND WELL CONSTRUCTION

APPENDIX A

BORING LOGS AND WELL CONSTRUCTION

RADIAN CORPORATION

Monitoring Well #: MW351

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LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base
TOTAL DEPTH 115.00 START DATE 8/16/94 FINISH DATE 8/17/94
GEOLOGIST Michelle Stalder APPROVED BY Thomas F. Cutbirth R.G.# 4473
DRILLING COMPANY Water Development DRILLER Paul Frederickson
DRILLING METHOD Hollow Stem Auger EQUIPMENT CME-55
DRILL BIT TYPE AND SIZE 8" Bullet
BORING LOCATION (ST. ADDRESS OR DESCRIPTION) 200 Feet East of Building 710

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
0				SANDY SILT brown (10 YR 4/3), minor gravel; fine to medium grained sand, secondary porosity, dry, (ML).
8		0.4/0		SAND dark yellowish brown (10 YR 4/4), minor silt, medium to coarse grained; well graded; subangular; 70% quartz, 20% mafics, 5% granite, 5% mica, trace clay, dry, (SW).
12				NO RECOVERY
14		0.4/0		SAND dark yellowish brown (10 YR 4/4), minor silt, medium to coarse grained; well

Lithologic Log / Permeability Log / Concentration (PPBV): 1K, 10K, 100K, 1M

Well Construction Details

Casing elevation = 66.64'

Boring # IC21B001

Backfilled to surface from 91.3' with bentonite grout. Mixture consisted of approximately 4 lbs. bentonite to 8 gal. water to 1 bag (94 lbs.) cement. Weight and volume not recorded.
4.0" schedule 40 PVC blank casing 0'-99.0'

NOTES
PID = Photoionization Detector
LEL = Lower Explosive Limit
PID readings in parts per million by volume

PERMEABILITY
Fill
High
Moderate
Low
No Recovery

Depth While Drilling ▽ 102.50
Depth at Development ▼ 105.77

PERM OUC 10/10/5

RADIAN CORPORATION

Monitoring Well #: MW351

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LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
14				graded; subangular; 70% quartz, 20% mafics, 5% granite, 5% mica, trace clay, dry, (SW).				
16								
18								
		0.2/0		SILT olive (5 Y 5/3), minor fine sand; strongly compacted; silty sand interbed @ 21.0'-21.5', secondary porosity, dry, (ML).				
20								
22								Soil Gas Sample IC21FD000101N (experienced equipment problems) Soil Gas PID=0 ppmv
24				SAND olive brown (2.5 Y 4/3), medium grained; poorly graded; subrounded; 75% quartz, 20% mafics, <5% feldspar, <5% mica, dry, (SP).				
26				SILT brown (10 YR 5/3), minor sand, silty sand interbed @ 34.5'-35.5', secondary porosity, dry, (ML).				PID=0.2 ppmv on core
28								PID=0.4 ppmv on core
		0.6/0						PID=0.6 ppmv on core
30								PID=0.2 ppmv on core
32								

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW351

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
32					
		1.0/0.8			
34					
36				SILTY SAND olive brown (2.5 Y 4/4), fine grained; poorly graded; subangular; 75% quartz, 20% mafics, <5% feldspar, <5% mica, iron staining; sand interbed @ 36.5'-37.0', dry, (SM).	
		0.8/1.0			PID=0.4 ppmv on core
38					
		0.4/0.6			PID=0 ppmv on core Soil Gas Sample IC21FD000102N Soil gas PID not recorded
40					
42				SAND olive brown (2.5 Y 4/4), fine grained; poorly graded; subrounded; 75% quartz, 15% mafics, 5% feldspar, <5% mica, dry, (SP).	
44				SILT dark brown (10 YR 3/3), minor sand, minor iron staining; sand content increases @ 46.0'-47.0', secondary porosity, (ML).	
46					PID=0.6 ppmv on core
48		0.4/0.4		SAND olive brown (2.5 Y 4/3), fine grained; poorly graded; subrounded; 70% quartz, 20% mafics, 5% feldspar, <5% mica, lower contact gradational, dry, (SP).	
50				SILT olive brown (2.5 Y 4/3), color changes to 10 YR 4/6 @ 56.0'; trace sand	

Lithologic Log | Permeability Log | Concentration (PPBV) 1K 10K 100K 1M

PERM OUC 10/10/95

RADIAN CORPORATION

Monitoring Well #: MW351

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
50				below 55.0'; black stained pores; dry, (ML).				PID=0 ppmv on core
52								
54		0.8/0						
56		1.3/0						
58		1.2/0						
60								
62		1.2/0		SAND dark yellowish brown (10 YR 4/6), dry, (SP).				
64		1.2/0		SILT olive brown (2.5 Y 4/3), color changes to 10 YR 4/6 @ 56.0'; abundant black staining @ 66.5'-77.5'; dry, (ML).				Soil gas sample not collected; Equipment problems
66								
68								

PERM OUC 10/10/95

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW351

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
68				
		1.5/0		
70				
72				
		1.5/0		
74				
				SILTY SAND olive brown (2.5 Y 4/3), very fine to fine grained; poorly graded; subrounded; 75% quartz, 20% mafics, <5% mica, lower silt content @ 78.0', dry, (SM).
76				
78				
		1.2/0		
				Soil Gas Sample IC21FD000103N Soil gas PID not recorded
80				
				SAND dark grayish brown (2.5 Y 4/2), fine grained; poorly graded; subrounded; 75% quartz, 20% mafics, <5% mica, dry, (SP).
82				
				NO RECOVERY
		3.9/0		SAND dark grayish brown (2.5 Y 4/2), fine grained; poorly graded; subrounded; 75% quartz, 20% mafics, <5% mica, dry, (SP).
84				
				SANDY SILT olive (5 Y 5/3), 75% quartz, 20% mafics, <5% mica, lower contact
86				

Concentration (PPBV): 1K, 10K, 100K, 1M

Lithologic Log | Permeability Log | Well Construction Details

PERM OUC 10/10/95

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW351

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
86				gradational, secondary porosity, dry, (ML).	
88		0/0			
90					
92					Top of bentonite seal @ 91.3' (2-50 lb bags of bentonite chips)
		0/0			Top of sand bridge @ 93.3' (2-100 lb bags #30 mesh sand)
94				SAND olive (5 Y 5/3), fine to medium grained; poorly graded; subrounded; 75% quartz, 20% mafics, <5% mica, well graded @ 104.0'-104.5'; stongly cemented silt layer @ 103.0'-103.5'; lower contact gradational, dry @ 93.8'-99.0'; moist @ 99.0'; wet @ 102.0'; (SP).	Soil Gas Sample IC21FD000104N Soil gas PID not recorded
96					Top of sand pack @ 96.0' (13-100 lb bags #1C sand)
				NO RECOVERY	
98		0/0		SAND olive (5 Y 5/3), fine to medium grained; poorly graded; subrounded; 75% quartz, 20% mafics, <5% mica, well graded @ 104.0'-104.5'; stongly cemented silt layer @ 103.0'-103.5'; lower contact gradational, dry @ 93.8'-99.0'; moist @ 99.0'; wet @ 102.0'; (SP).	Top of screen @ 99.0' (0.01" slot stainless steel screen)
100					
102				NO RECOVERY	
104				SAND olive (5 Y 5/3), fine to medium grained; poorly graded; subrounded; 75%	

Concentration (PPBV): 1K, 10K, 100K, 1M

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RADIAN CORPORATION

Monitoring Well #: MW351

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LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
104				quartz, 20% mafics, <5% mica, well graded @ 104.0'-104.5'; stongly cemented silt layer @ 103.0'-103.5'; lower contact gradational, dry @ 93.8'-99.0'; moist @ 99.0'; wet @ 102.0'; (SP).
				SILT olive (5 Y 5/3), minor sand, secondary porosity,lower contact gradational, wet, (ML).
106				SILTY SAND very dark grayish brown (2.5 Y 3/2), fine grained; poorly graded; subrounded; 75% quartz, 20% mafics, <5% mica, sand interbeds @ 106.0'-107.0' and 109.0'-109.5', wet, (SM).
		0/0		
108				
110		0/0		SILT olive (5 Y 5/3), black staining, secondary porosity, wet, (MH).
112				
				NO RECOVERY
114				

Lithologic Log | Permeability Log | Concentration (PPBV) 1K 10K 100K 1M

Well Construction Details

Water level @ 105.0'

Hydropunch Groundwater Sample IC21GY000101N

Bottom of screen 114.0'

#1C sand @ 114.0'-115.0'

Total Depth=115.0' BGS

104 106 108 110 112 114

PERM OUC 10/10/95

RADIAN CORPORATION

Monitoring Well #: MW352

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LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base
TOTAL DEPTH 114.00 START DATE 8/22/94 FINISH DATE 8/24/94
GEOLOGIST Wendy Linck APPROVED BY Thomas F. Cudzilo R.G.# 4473
DRILLING COMPANY Water Development DRILLER Cliff Rambolt
DRILLING METHOD Hollow Stem Auger EQUIPMENT CME 75
DRILL BIT TYPE AND SIZE 6" Bullet
BORING LOCATION (ST. ADDRESS OR DESCRIPTION) 50 Feet East of Building 701

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
0		0/0		NO RECOVERY
2				SAND light gray (10 YR 7/2), fill, fine grained; poorly graded; subangular; 60% quartz, 20% mafics, 10% feldspar, 10% mica, sharp lower contact, dry, (SP).
				SILTY SAND brown (7.5 YR 4/4), fine grained; well graded; subangular; 50% quartz, 30% mafics, <5% feldspar, 5% mica, fine to medium grained sand, dry, (SM).
4		0/0.2		NO RECOVERY
6				SAND brown (7.5 YR 4/4), medium grained; poorly graded; subrounded; 70% quartz, 15% mafics, 10% feldspar, 5% mica; moderate to strongly cemented, dry, (SP).
8				
10		0/0		SILTY SAND brown (7.5 YR 4/4), medium grained; poorly graded; subangular; 70% quartz, 15% mafics, 10% feldspar, 5% mica, medium grained micas, dry, (SM).
12				SAND light brownish gray (2.5 Y 6/2), fine grained; subangular; banded with coarser grained sand layers (<0.2" thick), dry, (SP).
14				SANDY SILT light brownish gray (2.5 Y 6/2), fine grained; subrounded; 70%

Concentration (PPBV): TCE, VC, FC12 — 1K, 10K, 100K, 1M

Well Construction Details

Casing elevation=60.76'

Boring # IC21B002
PID=0 ppmv on core

Backfilled to surface from 84.0' with bentonite grout. Mixture consisted of approximately 4 lbs. bentonite to 10 gal. water to 1 bag (94 lbs.) cement. Weight and volume not recorded.
4.0" schedule 40 PVC blank casing 0'-93.0'

PID=0 ppmv on core

PID=0 ppmv on core

PERMEABILITY: Fill, Low, High, No Recovery, Moderate

Depth While Drilling ▽99.00

Depth at Development ▼99.90

NOTES
PID = Photoionization Detector
LEL = Lower Explosive Limit
PID readings in parts per million by volume

PERM OUC 10/10/95

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW352

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
14		0/0		quartz, 20% mafics, 10% mica, minor root bores; high mafic content, dry, (ML).	
				SILTY SAND light olive brown (2.5 Y 5/3), fine grained; subangular; 70% quartz, 20% mafics, 10% mica, moderately cemented; abundant iron stained root bores; secondary porosity, dry, (SM).	PID=0 ppmv on core
16		0/0			
18				SAND light olive brown (2.5 Y 5/3), fine grained; poorly graded; subangular; 70% quartz, 20% mafics, dry, (SP).	
		0/0		NO RECOVERY	
20				SILTY SAND light olive brown (2.5 Y 5/3), fine grained; subangular; 60% quartz, 20% mafics, 10% feldspar, 10% mica, fine to medium grained micas; dry, (SM).	PID=0 ppmv on core Soil Gas Sample IC21FD000201N Soil Gas PID=0 ppmv
22				SAND light brownish gray (2.5 Y 6/2), fine grained; poorly graded; subangular; 60% quartz, 20% mafics, 10% feldspar, 10% mica, moderately cemented, dry, (SP).	
				SAND brown (7.5Y 5/4), fine grained; poorly graded; 60% quartz, 20% mafics, 15% feldspar, 5% mica, moderately cemented, secondary porosity, dry, (SP).	
24		0/0		NO RECOVERY	
				SAND brown (7.5Y 5/4), well graded; iron staining; secondary porosity, dry, (SW).	
26				SANDY SILT brown (10 YR 5/3), very fine grained sand; moderately to strongly cemented; iron staining, dry, (ML).	
					PID=0 ppmv on core
28				SILTY SAND brown (10 YR 5/3), fine grained; subangular; 70% quartz, 10% mafics, 10% feldspar, 10% mica, iron staining, secondary porosity, dry, (SM).	
		0/0			
30					
32					

Lithologic Log | Permeability Log | Concentration (PPBV): TCE, VC, FC12 (1K, 10K, 100K, 1M)

PERM OUC 10/10/95

RADIAN CORPORATION

Monitoring Well #: MW352

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LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
32					PID=0 ppmv on core
				SAND light brownish gray (10 YR 6/2), fine grained; poorly graded; subangular; 70% quartz, 20% mafics, <5% feldspar, <5% mica, dry, (SP).	
34		0/0		SAND yellowish brown (10 YR 5/4), fine grained; poorly graded; subangular; 60% quartz, 25% mafics, <5% feldspar, 10% mica, sharp upper contact, dry, (SP).	
36				SANDY SILT brown (10 YR 5/3), very fine grained; trace root bores; iron staining, dry, (ML).	PID=0 ppmv on core
38					
		0/0		SILTY SAND fine grained; poorly graded; subangular; 60% quartz, 20% mafics, 10% feldspar, 10% mica, cemented below 40.0', iron staining, dry, (SM).	
40				SANDY SILT brown (10 YR 5/3), very fine grained; moderately cemented; iron staining; secondary porosity, dry, (ML).	Soil Gas Sample IC21FD000202N Soil Gas PID=0 ppmv
42				SAND yellowish brown (10 YR 5/4), fine grained; poorly graded; subangular; 60% quartz, 20% mafics, 10% feldspar, 10% mica, sharp lower contact, dry, (SP).	PID=0 ppmv on core
44		0/0		SILT brown (10 YR 5/3), strongly cemented; secondary porosity, dry, (ML).	
46					
48				SILTY SAND brown (10 YR 5/3), fine grained; well graded; subangular; 60% quartz, 20% mafics, <5% feldspar, 15% mica, downward coarsening, dry, (SM).	
		0/0			
50					

Lithologic Log | Permeability Log | Concentration (PPBV): TCE, VC, FC12 (1K, 10K, 100K, 1M)

PERM OUC 10/10/.

RADIAN CORPORATION

Monitoring Well #: MW352

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
50				SILTY SAND brown (10 YR 5/3), fine grained; poorly graded; subangular; 70% quartz, 15% mafics, <5% feldspar, 10% mica, strong to moderately cemented; secondary porosity, dry, (SM).	
52					PID=0 ppmv on core
54		0/0		SILTY SAND brown (10 YR 5/3), minor clay, fine grained; poorly graded; subangular; 50% quartz, 25% mafics, 10% feldspar, 15% mica, medium grained mica; minor black stained root bores, (SM).	
56				SILT light yellowish brown (2.5 Y 6/3), strongly cemented; secondary porosity, dry, (ML).	PID=0 ppmv on core
58		0/0			
60				SILTY SAND brown (10 YR 5/3), fine grained; poorly graded; subangular; 70% quartz, 20% mafics, <5% feldspar, 5% mica, iron staining, secondary porosity, dry, (SM).	
62				SAND light olive brown (2.5 Y 5/3), medium grained; poorly graded; subangular; 65% quartz, 20% mafics, <5% granite, 10% feldspar, 5% mica, dry, (SP).	
		0/0			Soil Gas Sample IC21FD000203N Soil Gas PID=0 ppmv
64				NO RECOVERY	
66				SAND light olive brown (2.5 Y 5/3), medium grained; poorly graded; subangular; 50% quartz, 30% mafics, <5% granite, <5% feldspar, 10% mica, finer sand @ 67.5'-68.0', dry, (SP).	PID=0 ppmv on core
68					

Lithologic Log | Permeability Log | Concentration (PPBV): TCE, VC, FC12; 1K, 10K, 100K, 1M

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RADIAN CORPORATION

Monitoring Well #: MW352

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
68		0/0		NO RECOVERY	
70				SAND olive gray (5Y 5/2), medium grained; moderately graded; subangular; 55% quartz, 30% mafics, <5% feldspar, 10% mica, sharp lower contact, dry, (SP).	
72				SILTY SAND olive grey (5Y 5/2), fine grained; poorly graded; subangular; 55% quartz, 20% mafics, <5% feldspar, 10% mica, moderately cemented, dry, (SM). SAND olive (5Y 5/3) medium grained; poorly graded; subangular; 50% quartz, 20% mafics, <5% volcanic, <5% granite, 10% feldspar, 10% mica, dry, (SP).	PID=0 ppmv on core
74		0/0		SILTY SAND olive (5Y 3/3), fine grained; moderately graded; subangular; moderately cementation below 78.0', (SM).	
76					PID=0 ppmv on core
78		0/0		SANDY SILT olive (5Y 3/3); moderately cemented, secondary porosity, dry, (ML).	
80					Soil Gas Sample IC21FD000204N Soil Gas PID=0 ppmv
82				SILTY SAND olive (5Y 3/3), fine grained; moderately graded; subangular; 55% quartz, 25% mafics, <5% feldspar, 15% mica, dry, (SM).	PID=0 ppmv on core
84		0/0		SILT, moderately to strongly cemented; minor mica, secondary porosity, dry, (ML).	Top of bentonite seal @ 84.0' (1-50 lb bag of bentonite chips)
86					

Concentration (PPBV): TCE, VC, FC12 — 1K, 10K, 100K, 1M

Lithologic Log | Permeability Log

PERM OUC 10/10/...

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW352

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) TCE VC FC12 1K 10K 100K 1M	Well Construction Details
86								PID=0 ppmv on core
88								Top of sand bridge @ 88.0' (1-100 lb bag #30 mesh sand)
90		0/0		SAND olive (5Y 5/3), medium grained; poorly graded; subangular; 55% quartz, 15% mafics, 10% feldspar, 10% mica, moderately to strongly cemented, secondary porosity, dry, (SP).				Top of sand pack @ 90.0' (9-100 lb bags #1C sand)
92				SAND olive (5Y 5/3), medium grained; well graded; subangular; dry, (SW).				PID=0 ppmv on core
94				NO RECOVERY				Top of screen @ 93.0' (0.10" slot stainless steel screen)
96				SAND olive gray (5Y 5/2), medium grained; poorly graded; subangular; 40% quartz, 40% mafics, <5% granite, 10% feldspar, 5% mica, sharp lower contact, dry, (SP).				Soil Gas Sample IC21FD000205N Soil Gas PID=0 ppmv
98								PID=0 ppmv on core
100		0/0		SAND pale olive (5Y 6/3); fine grained; poorly graded; subangular; 70% quartz, 20% mafics, 10% mica, saturated @ 99.0'; minor silt, dry, (SP).				Water level @ 99.0'
102								
104								

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LOG OF DRILLING OPERATIONS

Monitoring Well #: MW352

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) TCE / VC / FC12 (1K, 10K, 100K, 1M)	Well Construction Details
104		0/0		NO RECOVERY				Hydropunch Groundwater Sample IC21GL000201N pH=6.7, Ec=550, T=22 C
106				SANDY SILT olive (5Y 3/3); very fine grained sand; subangular; waxy appearance; moist below 109.0', dry, (ML).				
108								
110				SAND olive (5Y 5/3), very fine grained; poorly graded; subangular; 60% quartz, 30% mafics, 10% mica, moderately cemented; secondary porosity, saturated, (SP).				
112								Bottom of screen @ 113.0' Natural silt/sand @ 113.0'-114.0'
114								Total Depth=114.0' BGS

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RADIAN CORPORATION

Monitoring Well #: MW353

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LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base
TOTAL DEPTH 115.00 START DATE 8/22/94 FINISH DATE 8/24/94
GEOLOGIST Michelle Stalder APPROVED BY Thomas F. Cudzilo R.G.# 4473
DRILLING COMPANY Water Development DRILLER Gary Whitley
DRILLING METHOD Hollow Stem Auger EQUIPMENT CME 75
DRILL BIT TYPE AND SIZE 8" Bullet
BORING LOCATION (ST. ADDRESS OR DESCRIPTION) 750 Feet East of the Brick Fire Training Building

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
0				SANDY SILT brown (7.5 YR 4/4), black staining, dry, (ML).
6		0/0		SILT olive brown (2.5 Y 4/3), iron staining, black staining along pores; trace mica in silt, secondary porosity, dry, (ML).
				SILTY SAND olive brown (2.5 Y 4/3), (SM).
8				SILT olive brown (2.5 Y 4/3), black staining along pores; moderate iron staining, secondary porosity, dry, (ML).
12				NO RECOVERY

Lithologic Log / Permeability Log / Concentration (PPBV): PCE, VC, FC12 (1K, 10K, 100K, 1M)

Well Construction Details

Casing elevation = 62.07'

Boring # IC21B003

Backfilled to surface from 89.5' with bentonite grout. Mixture consisted of approximately 4 lbs. bentonite to 8 gal. water to 1 bag (94 lbs.) cement. Weight and volume not recorded.
4.0" schedule 40 PVC blank casing 0'-94.0'
PID = 1 ppmv on core

PID = 1 ppmv on core

PID = 1 ppmv on core

PERMEABILITY: Fill, Low, High, No Recovery, Moderate

Depth While Drilling ▽ 102.50

Depth at Development ▼ 100.95

NOTES
PID = Photoionization Detector
LEL = Lower Explosive Limit
PID readings in parts per million by volume

PERM OUC 10/10/95

RADIAN CORPORATION

Monitoring Well #: MW353

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
14		0/0		SILT olive brown (2.5 Y 4/3), black staining along pores; moderate iron staining, secondary porosity, dry, (ML).	
16					
18		2.7/0			Soil Gas Sample IC21FD000301N Soil Gas PID=4 ppmv Soil Sample IC21SB000301N
20		2.7/0			PID=1 ppmv on core
22				SILTY SAND fine grained; poorly graded; (SM).	
24				SILT olive brown (2.5 Y 4/3), secondary porosity, dry, (ML).	
26				SANDY SILT dark yellowish brown (10 YR 4/4), secondary porosity, dry, (ML).	PID=1 ppmv on core
28				SILT dark yellowish brown (10 YR 4/4), dry, (ML).	PID=1 ppmv on core
30		1/0		SANDY SILT dark yellowish brown (10 YR 4/4), secondary porosity, dry, (ML).	
32				SILT dark yellowish brown (10 YR 4/4), dry, (ML).	

Concentration (PPBV): PCE, VC, FC12 — 1K, 10K, 100K, 1M

Lithologic Log | Permeability Log

PERM OUC 10/10/95

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW353

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
32				SANDY SILT dark yellowish brown (10 YR 4/4), secondary porosity, dry, (ML).	
34		1/0		SILT dark yellowish brown (10 YR 4/4), dry, (ML).	PID=1 ppmv on core
36				CLAYEY SILT brown (10 YR 4/3), minor sand, (MH).	
38				SILTY SAND fine grained; poorly graded; subrounded; 75% quartz, 15% mafics, 5% mica, iron staining, dry, (SM).	
40		1.1/0		SANDY SILT minor clay, black and milky white staining, secondary porosity; clayey silt interbed 40.0' - 40.5';(ML).	PID=1 ppmv on core
42					Soil Gas Sample IC21FD000302N Soil gas PID not recorded Soil Sample IC21SB000302N
44				SAND olive brown (2.5 Y 4/3), fine grained; poorly graded; subrounded; 75% quartz, 20% mafics, 5% mica, dry, (SP).	PID=2 ppmv on core
46		1.1/0		SILTY SAND olive brown (2.5 Y 4/4), fine grained; poorly graded; subrounded; 80% quartz, 15% mafics, <5% mica, black and iron staining, dry, (SM).	PID=2 ppmv on core
48					PID=1.6 ppmv on core
50				SAND fine grained; poorly graded; subrounded; 75% quartz, 20% mafics, <5% mica, dry, (SP).	

Concentration (PPBV): PCE, VC, FC12 — 1K, 10K, 100K, 1M

Lithologic Log; Permeability Log

TERM OUC 10/10/5

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW353

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
50		1.1/0		SILT brown (10 YR 5/3), minor clay, secondary porosity, (MH).	
52					PID=1 ppmv on core
54				SANDY SILT light olive brown (2.5 Y 5/4), black staining and iron staining, secondary porosity, dry, (ML).	
		2/0		CLAYEY SILT light olive brown (2.5 Y 5/3), minor sand, secondary porosity, dry, (MH).	
56					
58				SANDY SILT dark yellowish brown (10 YR 4/4), increased clay content @ 62.5'-63.5', increased sand content @ 63.5'-64.0', minor secondary porosity, (ML).	PID=1 ppmv on core
60		2.1/0			Soil Gas Sample IC21FD000303N Soil Gas PID not recorded
62					
64				SAND dark grayish brow (2.5 Y 4/2), fine grained; poorly graded; subrounded; 80% quartz, 10% mafics, <5% feldspar, <5% mica, dry, (SP).	
		0/0			PID=0 ppmv on core
66					
68				CLAYEY SILT pale olive (5 Y 6/3), white material lining pores, interfingered sand @ 69.0'-70.0', minor secondary porosity, dry, (MH).	

Lithologic Log / Permeability Log / Concentration (PPBV): PCE, VC, FC12 (1K, 10K, 100K, 1M)

PERM GUC 10/10/95

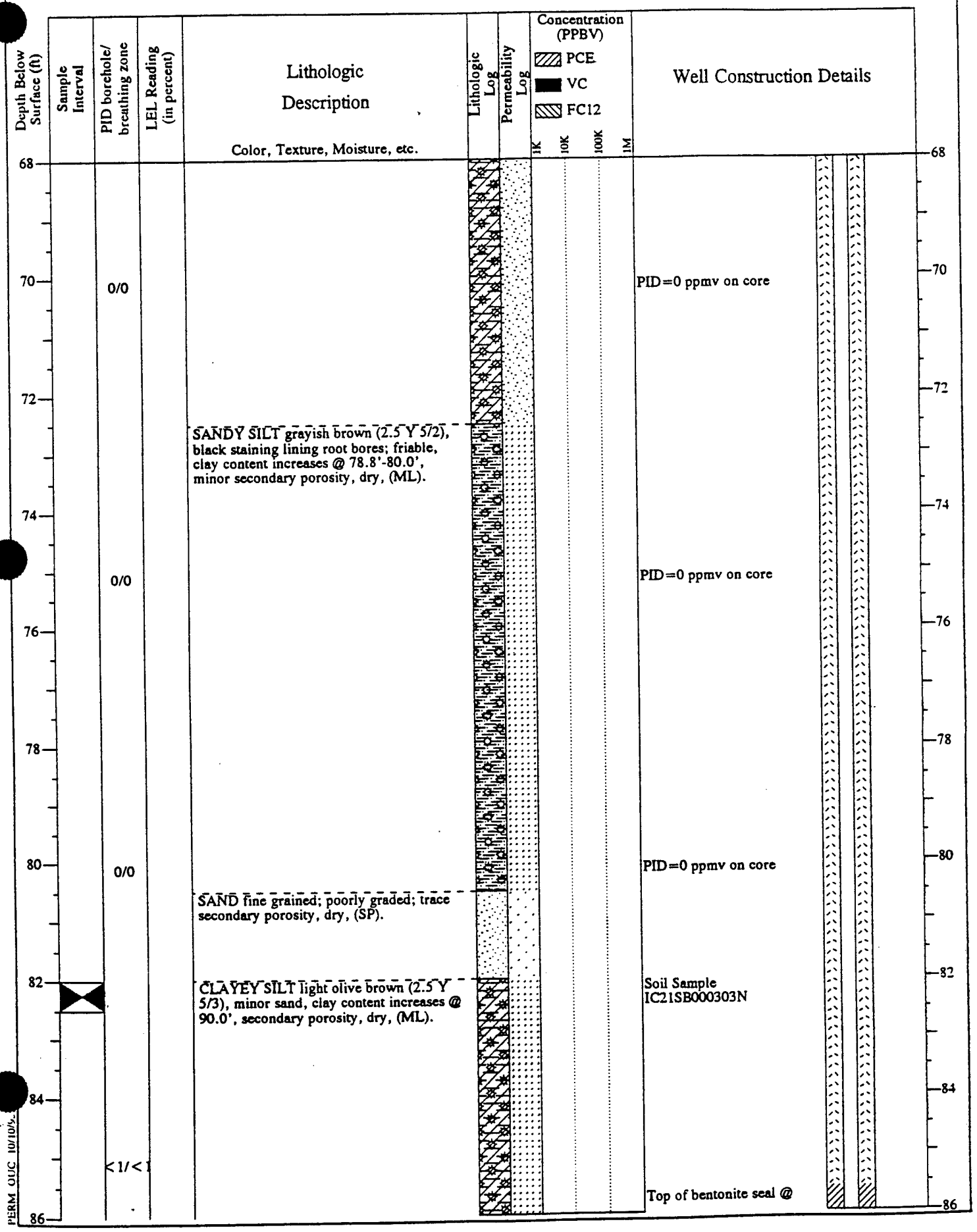
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LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base



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LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) PCE VC FC12 1K 10K 100K 1M	Well Construction Details
86								85.6' (2.5-50 lb bags of bentonite chips) Soil Gas Sample IC21FD000304N Soil Gas PID=1 ppmv Soil Sample IC21SB000304N
88								
90		< 1/ < 1						Top of sand bridge @ 89.5' (0.5-50 lb bag of #30 mesh sand)
								Top of sand pack @ 90.8' (10-100 lb bags of #1C sand)
92								
94								Top of screen @ 94.0' (0.02" slot stainless steel screen)
				SANDY SILT olive brown (2.5 Y 4/4), damp, (ML).				
96								Soil Gas Sample IC21FD000305N Soil Gas PID=1 ppmv
				SAND fine grained; poorly graded; moist to wet, (SP).				
				SANDY SILT olive brown (2.5 Y 4/4), damp, (ML).				
98				SAND fine grained; poorly graded, moist, (SP).				
				CLAYEY SILT olive brown (2.5 Y 4/3), iron staining, wet, (ML).				
100								
				SILT olive brown (2.5 Y 4/3), iron staining, wet, (MH).				
102								Water level @ 99.0'
104								

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RADIAN CORPORATION

Monitoring Well #: MW353

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
104				CLAYEY SILT pale olive (5 Y 6/3), wet, (MH).
106				SILTY CLAY pale olive (5 Y 6/3), wet, (CL).
108				NO RECOVERY
				CLAYEY SILT pale olive (5 Y 6/3), saturated, (MH).
110				
112				
114				NO RECOVERY

Lithologic Log | Permeability Log | Concentration (PPBV): PCE, VC, FC12 (1K, 10K, 100K, 1M)

Well Construction Details

PID=1 ppmv on core

Bottom of screen @ 114.0'

#1C sand @ 114.0'-115.0'

Total Depth=115.0'

RADIAN CORPORATION

Monitoring Well #: MW354

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LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base
TOTAL DEPTH 115.00 START DATE 12/7/94 FINISH DATE 12/8/94
GEOLOGIST Wendy Linck APPROVED BY Thomas F. Lindley R.G.# 4473
DRILLING COMPANY Water Development DRILLER Cory Wilson
DRILLING METHOD Hollow Stem Auger EQUIPMENT CME 75
DRILL BIT TYPE AND SIZE 8" Bullet
BORING LOCATION (ST. ADDRESS OR DESCRIPTION) 200 Feet Southeast of Building 1088

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
0				SANDY CLAY brown (10 YR 4/3), fill, 30% very fine to fine sand; 10% silt; 60% clay; concrete @ 2.0', moist, (CL).
2				SILT yellowish brown (10 YR 5/4), fill, sharp lower contact; 10% very fine sand; 20% very fine sand @ 4.0'-6.5'; 10 YR 4/4 @ 4.0'-5.5'; 2.5 Y 5/4 @ 5.5'-6.5', dry, (ML).
4		0/0		
6				SILTY CLAY yellowish brown (10 YR 5/4), fill, sharp lower contact; 30-50% silt; 50-70% clay, dry, (CL).
8				CLAYEY SILT pale olive (5 Y 6/3), 10% very fine sand; 60-70% silt, 20-30% clay, iron stained bores, secondary porosity, hardpan, dry, (ML).
				NO RECOVERY
10		0/0		SILT olive (5 Y 5/3), 10% very fine sand @ 9.0'-9.8'; sand @ 9.8'-10.2'; 30% very fine sand @ 10.2'-14.0'; sandy planar lamination, secondary porosity, hardpan, dry, (ML).
12				
14				

Lithologic Log / Permeability Log / Concentration (PPBV) 1K 10K 100K 1M

Well Construction Details

Casing elevation=62.59'

Boring # IC19B038

Backfilled to surface from 85.0' with bentonite grout. Mixture consisted of approximately 4 lbs. bentonite to 9 gal. water to 1 bag (94 lbs.) cement. Weight and volume not recorded.
4.0" schedule PVC blank casing 0'-94.0'

PID=0 ppmv on core

PID=0 ppmv on core

NOTES
PID = Photoionization Detector
LEL = Lower Explosive Limit
PID readings in parts per million by volume

PERMEABILITY
Fill Low
High No Recovery
Moderate

Depth While Drilling ▽ 100.50
Depth at Development ▼ 102.65

RM OUC 10/10/95

RADIAN CORPORATION

Monitoring Well #: MW354

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
14				SILTY SAND greenish gray (5 GY 5/1), poorly graded; subangular; 70% quartz, 30% mafics, very fine sand @ 15.0'-15.2'; 30% silt @ 15.2'-17.2', dry, (SM).	
16					PID=1 ppmv on core
18				SILT light yellowish brown (2.5 Y 6/3), 30% very fine to fine sand; iron stained bores; cemented, secondary porosity, hardpan, dry, (ML).	
20					PID=0.6 ppmv on core
22					
24		0/0		SAND greenish gray (5 GY 5/1), 40% very fine grained, 60% fine grained; poorly graded; subangular; 70% quartz, 30% mafics, sharp lower contact, dry, (SP).	PID=5.7 ppmv on core
26					
28				SILT yellowish brown (10 YR 5/4), iron staining, secondary porosity, dry, (ML).	
				NO RECOVERY	
30				SANDY SILT yellowish brown (10 YR 5/4), 20-30% very fine sand; 70-80% silt, iron stained bores, secondary porosity, hardpan, dry, (ML).	PID=1.3 ppmv on core
32					

Lithologic Log | Permeability Log | Concentration (PPBV) 1K 10K 100K 1M

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LOG OF DRILLING OPERATIONS

Monitoring Well #: MW354

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
32				SILTY SAND greenish gray (5 GY 3/1), very fine grained; 70% quartz, 30% mafics, 60% very fine sand; 40% silt, dry, (SM).
				NO RECOVERY
34		0/0		SANDY SILT greenish gray (5 GY 3/1), 20-50% very fine sand; 50-70% silt; sand @ 36.5'-36.8', dry, (ML).
				SAND greenish gray (5 GY 5/1), poorly graded; subangular; 70% quartz, 30% mafics, sharp lower contact, dry, (SP).
36				
38				
40				SILT greenish gray (5 GY 3/1), 10-20% very fine sand; 40% very fine to fine sand @ 45.3'-45.5' and 46.0'-46.5'; iron stained bores; 2.5 Y 5/3 @ 42.5'-43.0', secondary porosity, hardpan, dry, (ML).
42				
44		1/0		
46				
48				NO RECOVERY
				CLAYEY SILT light yellowish brown (2.5 Y 6/3), 5% very fine sand; 10-15% clay; 80-85% silt; 20% clay and 20% sand @ 49.0'-50.0'; iron stained bores, secondary
50				

Lithologic Log | Permeability Log | Concentration (PPBV) 1K 10K 100K 1M

Well Construction Details

PID=164 ppmv on core

PID=25 ppmv on core

PERM OUC 10/10/9

RADIAN CORPORATION

Monitoring Well #: MW354

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
50				porosity, hardpan, dry, (ML).				PID=21 ppmv on core
52								
54				SILTY SAND brown (10 YR 5/3), subangular; 70% quartz, 20% mafics, 10% mica, 60-70% very fine to fine sand; 30-40% silt; lamination @ 54.1', dry, (SM).				PID=40 ppmv on core
				CLAYEY SILT light yellowish brown (2.5 Y 6/3), sharp upper contact; 5% very fine sand; 10-15% clay; 80-85% silt; iron stained bores, secondary porosity, hardpan, dry, (ML).				
56				SANDY SILT brown (10 YR 5/3), 30% very fine sand; 5% clay; 65% silt, dry, (ML).				
				NO RECOVERY				
58								
60		0/0		SANDY SILT yellowish brown (10 YR 5/4), sharp lower contact; 40-50% very fine to fine sand; 50-60% silt; iron stained bores; cemented, dry, (ML).				PID=24 ppmv on core
62				SAND yellowish brown (10 YR 5/4), 20% very fine grained; 70% fine grained; 10% medium grained; well graded; subangular; 60% quartz, 30% mafics, 5% feldspar, 5% mica, dry, (SW).				
				NO RECOVERY				
64		0/0		SAND yellowish brown (10 YR 5/4), 20% very fine grained; 50% fine grained; 30% medium grained; well graded; subangular; 60% quartz, 30% mafics, 5% feldspar, 5% mica, 20% white colored silt @ 66.8'-67.0', dry, (SW).				
66								
				NO RECOVERY				
68								

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RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

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PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
68								
70				SAND yellowish brown (10 YR 5/4), 20% very fine grained; 60% fine grained; 20% medium grained;well graded; subangular; 60% quartz, 30% mafics, 5% feldspar, 5% mica, 20% silt @ 71.8'-72.0'; rounded pebbles @ 71.0', dry, (SW).				PID=0 ppmv on core
72				NO RECOVERY				
74		0/0		CLAYEY SILT light yellowish brown (2.5 Y 6/3), 10% very fine sand; 20-30% clay; 60-70% silt, dry, (ML).				
76								PID=11 ppmv on core
78				NO RECOVERY				
80		0/0		SILTY SAND light yellowish brown (2.5 Y 6/3), 80% very fine grained; 20% fine grained; subangular; 70% quartz, 30% mafics, 70% very fine to fine sand; 30% silt; white colored silt @ 81.7'-81.8', dry, (SM).				PID=18 ppmv on core
82				NO RECOVERY				
84				SILTY SAND light olive brown (2.5 Y 5/3), subangular; 70% quartz, 30% mafics, 50-80% very fine to fine sand; 20-50% silt; silt @ 84.0'-84.5', dry, (SM).				Top of bentonite seal @ 85.0' (2-50 lb bag of bentonite chips)
86				SILT light olive brown (2.5 Y 5/3), sharp				

PERM OUC 10/10/9

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW354

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
86				upper contact; 10% very fine sand, dry, (ML).				
				NO RECOVERY				
88								Top of sand bridge @ 88.5' (1-100 lb bag of #30 mesh sand)
				SANDY SILT olive (5 Y 5/3), 20% very fine to fine sand; 80% silt; cemented, secondary porosity, hardpan, dry, (ML).				
90								PID=2 ppmv on core
				SAND light yellowish brown (2.5 Y 6/3), subangular; 60% quartz, 40% mafics, 20% silt @ 91.0'-91.5', dry, (SP).				Top of sand pack @ 91.0' (12-100 lb bags of #1C sand)
92				NO RECOVERY				
94		0/0		SAND dark grayish brown (2.5 Y 4/2), well graded; 55% quartz, 40% mafics, 5% feldspar, white colored silt @ 96.8'-97.0', dry, (SW).				Top of screen @ 94.0' (0.01" slot stainless steel screen)
								PID=0 ppmv on core
96								
				NO RECOVERY				
98								
				SAND dark grayish brown (2.5 Y 4/2), 10% very fine grained; 70% fine grained; 20% medium grained; well graded; subangular; 60% quartz, 40% mafics, moist @ 100.0'-100.5'; saturated below 100.5'; lamination @ 101.0'-101.4', dry, (SP).				PID=0 ppmv on core
100								Water level @ 100.5'
102				NO RECOVERY				

RADIAN CORPORATION

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LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
104				SAND dark grayish brown (2.5 Y 4/2), well graded; subangular; 60% quartz, 30% mafics, 5% feldspar, 5% mica, 30% silt @ 105.5'-106.5', saturated, (SW).				
106				CLAYEY SILT light yellowish brown (2.5 Y 6/3), sharp upper contact; 10% very fine sand; 60% silt; 30% clay, dry, (ML). NO RECOVERY				
108				SILT light olive brown (2.5 Y 5/3), 10% very fine to fine sand, saturated, (ML).				
110								
112				SANDY SILT light olive brown (2.5 Y 5/3), 20-40% very fine to fine sand; 50-70% silt; 5-10% clay, saturated, (ML).				
114								Bottom of screen @ 114.0' #1C sand @ 114.0'-115.0' Total Depth=115.0' BGS Backfilled to surface with bentonite grout. Mixture consisted of approximately 4 lbs. of bentonite to 9 gal. of water to 1 bag (94 lbs.) cement.

RADIAN CORPORATION

Monitoring Well #: MW355

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base
TOTAL DEPTH 114.50 START DATE 12/5/94 FINISH DATE 12/7/94
GEOLOGIST Wendy Linck APPROVED BY Thomas F. Ludzik R.G.# 4473
DRILLING COMPANY Water Developement DRILLER Cory Wilson
DRILLING METHOD Hollow Stem Auger EQUIPMENT CME 65
DRILL BIT TYPE AND SIZE 8" Bullet
BORING LOCATION (ST. ADDRESS OR DESCRIPTION) 300 Feet Southeast of the Center of Fire Training Area

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
0				GRAVELLY SAND fill, gap graded; sharp lower contact; 20% angular gravel; 80% very fine sand, saturated, (SW).
				CLAYEY SAND yellowish brown (10 YR 5/4), fill, subangular; 70% quartz, 30% mafics, 20-30% clay; 10% silt; 5 % angular gravel; 55-65% very fine to fine sand, dry, (SC).
2				NO RECOVERY
4		0/0		SAND greenish gray (5 GR 5/1), fill, poorly graded; subangular; 70% quartz, 30% mafics, glass; concrete; 10% silt, dry, (SP).
				NO RECOVERY
6				
8				
		0/0		SILTY CLAY greenish gray (5 GY 3/1), fill, 10% very fine to fine sand; 40% silt; 50% clay; slight odor, dry, (CL).
10				NO RECOVERY
12				
14				

Lithologic Log | Permeability Log | Concentration (PPBV) 1K 10K 100K 1M

Well Construction Details

Casing elevation=60.70'

Boring # IC19B039

NaI (background=6.5K cpm) and alpha (background=4 cpm) probes to measure maximum radiation in counts per minute (cpm) on soil cores.
Backfilled to surface from 84.5' with bentonite grout. Mixture consisted of approximately 4 lbs. bentonite to 9 gal. water to 1 bag (94 lbs.) cement. Weight and volume not recorded.
4.0" schedule 40 PVC blank casing 0'-93.5'
PID=13 ppmv on core
NaI=7.03K cpm; alpha=0 cpm on soil core

PID=2 ppmv on core

NOTES
PID = Photoionization Detector
LEL = Lower Explosive Limit
PID readings in parts per million by volume

PERMEABILITY
Fill | Low
High | No Recovery
Moderate

Depth While Drilling ▽101.85
Depth at Development ▼100.07

ERM OUC 10/10/

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW355

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
14		2/0		CLAYEY SILT greenish gray (5 GY 5/1), iron staining; 20-30% clay; 10% very fine sand; 60-70% silt; hard, secondary porosity, hardpan, dry, (ML).				NaI=6.95K cpm; alpha=0 cpm on soil core
16				SAND greenish gray (5 G 5/1), 80% very fine grained; 20% fine grained; poorly graded; subangular; 70% quartz, 30% mafics, dry, (SP). NO RECOVERY				
18								
20		1/0		CLAYEY SILT greenish gray (5 GY 5/1), 30% clay; 70% silt; 30% very fine sand @ 20.0'-20.4'; laminations <1" thick, secondary porosity, hardpan, dry, (ML).				PID=0 ppmv on core
22				NO RECOVERY				
24		1/0		SANDY SILT greenish gray (5 GY 5/1), sharp lower contact; iron staining below 26.0'; 30% very fine to fine sand; color is 5 GY 5/1) below 28.0', secondary porosity, hardpan, dry, (ML).				NaI=7.23K cpm; alpha=0 cpm on soil core PID=0 ppmv on core
26								
28		0/0						NaI=6.91K cpm; alpha=0 cpm on soil core
30								PID=0 ppmv on core

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RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW355

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
32				SAND light olive brown (2.5 Y 5/3), 60% very fine grained; 40% fine grained; poorly graded; subangular; 60% quartz, 40% mafics, dry, (SP).	
34		0/0		CLAYEY SILT light olive brown (2.5 Y 5/3), iron stained bores; sand @ 36.5'-36.7'; 10% very fine sand; 30% clay; 60% silt, secondary porosity, hardpan, dry, (ML).	PID=5 ppmv on core
36					
38					PID=0.5 ppmv on core
40		0/0		SILTY SAND light yellowish brown (2.5 Y 6/3), subangular; 70% quartz, 20% mafics, 10% mica, iron staining; silty laminations; 20-40% silt; 60-80% very fine to fine sand, dry, (SM).	NaI=7.15K cpm; alpha=0 cpm on soil core
42				SILT light olive brown (2.5 Y 5/3), 40% very fine to fine sand @ 42.4'-42.6'; sand @ 42.6' and 42.8', secondary porosity, hardpan, dry, (ML).	PID=1.6 ppmv on core PID=6 ppmv on core
44		0/0		SAND light olive brown (2.5 Y 5/3), well graded; subangular; 60% quartz, 35% mafics, 5% mica, 30-40% silt @ 43.8'-44.0', dry, (SW).	NaI=6.69K cpm; alpha=0 cpm on soil core PID=13.7 ppmv on core
46				SILTY CLAY light olive brown (2.5 Y 5/3), iron staining; 30-40% silt; 10% very fine sand; 50-60% clay, secondary porosity, hardpan, dry, (CL).	PID=0.1 ppmv on core
48				SAND light olive brown (2.5 Y 5/3), poorly graded; 70% quartz, 20% mafics, 10% mica, iron staining; 30% silt @ 48.0'-48.5', dry, (SP).	NaI=7.01K cpm; alpha=0 cpm on soil core
50					

Concentration (PPBV): 1K, 10K, 100K, 1M

Lithologic Log | Permeability Log

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW355

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
50								
				SILT light yellowish brown (2.5 Y 6/3), iron staining; 20% clay; 10% very fine sand; 70% silt, secondary porosity, hardpan, dry, (ML).				
52								PID=0 ppmv on core
				NO RECOVERY				
54		0/0		SILT yellowish brown (10 YR 5/4), manganese coated bores @ 57.8'; 10% very fine sand @ 54.0'-56.0'; 20% clay @ 56.0'-58.0', secondary porosity, hardpan, dry, (ML).				NaI=7.09K cpm; alpha=0 cpm on soil core
56								
58				SAND yellowish brown (10 YR 5/4), 20% very fine grained; 50-70% fine grained; 30% medium grained; subangular; 60% quartz, 40% mafics, sharp lower contact; 20% silt @ 58.0'-59.0'; 10YR 6/2 @ 67.0'-69.0', dry, (SW).				PID=0.8 ppmv on core
		0/0						NaI=6.74K cpm; alpha=0 cpm on soil core
60								
62								
64		0/0						PID=0 ppmv on core
66								

RADIAN CORPORATION

Monitoring Well #: MW355

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
68								
		0/0						NaI=6.63K cpm; alpha=0 cpm on soil core
70								
				SANDY SILT light yellowish brown (2.5 Y 6/3), iron staining; 30-45% very fine to fine sand; 55-70% silt; secondary porosity, dry, (ML).				PID=0 ppmv on core
72				NO RECOVERY				
74		0/0		SILT light yellowish brown (2.5 Y 6/3), iron staining; 70% silt; 30% clay, secondary porosity, hardpan, dry, (ML).				NaI=6.74K cpm; alpha=0 cpm on soil core
				SILTY SAND olive (5 Y 5/3), subangular; 70% quartz, 30% mafics, 30% silt; 70% very fine sand, dry, (SM).				
76				NO RECOVERY				
78								
		0/0		SAND light brownish gray (2.5 Y 6/2), 60% very fine grained; 40% fine grained; poorly graded; subangular; 70% quartz, 30% mafics, dry, (SP).				NaI=6.00K cpm; alpha=0 cpm on soil core
80				SILT light olive brown (2.5 Y 5/3), 40% sand @ 81.5'-82.5'; sandy laminations; planar, secondary porosity, hardpan, dry, (ML).				PID=1.1 ppmv on core
82								PID=0 ppmv on core
				NO RECOVERY				
84		0/0		SILT light olive brown (2.5 Y 5/3), 10% clay @ 84.0'-86.0', secondary porosity, hardpan, dry, (ML).				Top of bentonite seal @ 84.5' (2-50 lb bags of bentonite chips)

RADIAN CORPORATION

Monitoring Well #: MW355

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
86				NO RECOVERY	
88					Top of sand bridge @ 87.5' (1-100 lb bag of #30 mesh sand)
90		0/0		SILT light yellowish brown (2.5 Y 6/3), 20% very fine sand, dry, (ML).	NaI=6.20K cpm; alpha=0 cpm on soil core
92				NO RECOVERY	Top of sand pack @ 90.0' (11-100 lb bags of #1C sand)
94		0/0		SANDY SILT light olive brown (2.5 Y 5/3), 30-40% very fine sand; 60-70% silt, dry, (ML).	Top of screen @ 93.5' (0.01" stainless steel screen)
96				SAND light olive brown (2.5 Y 5/3), poorly graded; subangular; 65% quartz, 35% mafics, gradational upper contact; sharp lower contact; 20% silt @ 44.0'-45.0', damp, (SP).	PID=0 ppmv on core
98				SILT light yellowish brown (2.5 Y 6/3), dry, (ML). NO RECOVERY	NaI=6.90K cpm; alpha=0 cpm on soil core
100				SILTY SAND light olive brown (2.5 Y 5/3), subangular; 70% quartz, 20% mafics, 10% mica, sharp lower contact; 70% very fine to fine sand; 30% silt, saturated, (SM).	
102				SAND light olive brown (2.5 Y 5/4), 30% very fine grained; 60% fine grained; well graded; subangular; 60% quartz, 30% mafics, 5% feldspar, 5% mica, sharp lower contact, saturated, (SW). SILT light olive brown (2.5 Y 5/4), saturated @ 101.2'-101.4'; moist @ 101.4'-102.0'; dry @ 102.2'-103.0', dry, (ML). NO RECOVERY	Water level @ 101.85'

Concentration (PPBV): 1K, 10K, 100K, 1M

Lithologic Log | Permeability Log

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RADIAN CORPORATION

Monitoring Well #: MW355

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
104		0/0		SILT light yellowish brown (2.5 Y 6/3), 15% clay @ 107.5'-108.5'; 20-40% very fine to fine sand @ 111.5'-114.0', secondary porosity, hardpan, (ML).				NaI=7.46K cpm; alpha=0 cpm on soil core
106								
108								
110								
112								
114		0/0						Bottom of screen @ 113.5' #1C sand @ 113.5-114.5' Total Depth=114.5'

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RADIAN CORPORATION

Monitoring Well #: MW356

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base
TOTAL DEPTH 115.00 START DATE 12/14/94 FINISH DATE 12/15/94
GEOLOGIST Windy Linck APPROVED BY Thomas F. Cadigan R.G.# 4473
DRILLING COMPANY Water Development DRILLER Corey Wilson
DRILLING METHOD Hollow Stem Auger EQUIPMENT CME 75
DRILL BIT TYPE AND SIZE 8" Bullet
BORING LOCATION (ST. ADDRESS OR DESCRIPTION) 100 Feet East of Fire Training Area

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
0				SILT dark yellowish brown (10 YR 4/4), 20% fine sand @ 0.0'-2.0'; 20% clay; 10% very fine sand @ 2.0'-3.0', damp, (ML).
4		0/0		SILTY CLAY dark grayish brown (10 YR 4/2), fill, 10% very fine sand; 30% silt; 60% clay; stiff clay @ 5.5'-6.0', damp, (CL).
6				SILTY SAND yellowish brown (10 YR 5/4), fill, subangular; 70% quartz, 30% mafics, 80% very fine to fine sand;20% silt, moist, (SM).
				SAND yellowish brown (10 YR 5/4), fill, subangular; 80% quartz, 20% mafics, 5% silt; 5% clay; 7.5 Y 5/4 @ 5.8', dry, (SW).
8				NO RECOVERY
		0/0		SILTY SAND light yellowish brown (2.5 Y 6/3), fill, sharp lower contact; 70% very fine to fine sand; 30% silt, dry, (SM).
10				SILT olive (5 Y 5/3), 10% clay; 20% very fine sand; 70% silt; 40% very fine sand @ 10.0'-10.2'; iron staining @ 12.0'-13.0', secondary porosity, hardpan, dry, (ML).
12				NO RECOVERY
14				

Concentration (PPBV): 1K, 10K, 100K, 1M

Well Construction Details

Casing elevation=62.09'

Boring # IC19B042

Backfilled to surface from 84.5' with bentonite grout. Mixture consisted of approximately 4 lbs. bentonite to 9 gal. water to 1 bag (94 lbs.) cement. Weight and volume not recorded.
4.0" schedule 40 PVC blank casing 0'-94.0'

PID=0 ppmv on core

NOTES
PID = Photoionization Detector
LEL = Lower Explosive Limit
PID readings in parts per million by volume

PERMEABILITY
Fill, Low, High, No Recovery, Moderate

Depth While Drilling ▽99.00
Depth at Development ▼101.28

ERM OUC 10/10.

RADIAN CORPORATION

Monitoring Well #: MW356

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
14		0/0		SILTY CLAY light olive brown (2.5 Y 5/3), 30%-40% silt; brittle; iron staining, secondary porosity, hardpan, dry, (CL).	
				SAND light yellowish brown (2.5 Y 6/3), 70% very fine grained; 30% fine grained; poorly graded; subangular; 70% quartz, 30% mafics, sharp lower contact, dry, (SP).	
16					PID=0 ppmv on core
				SILTY CLAY light yellowish brown (2.5 Y 6/3), 20% very fine sand @ 19.0'-20.0'; 20-40% silt; 60-80% clay; iron staining; brittle, secondary porosity, hardpan, dry, (CL).	
18					
		0/0			Soil Sample IC19SB004201N
20				SANDY SILT light olive brown (2.5 Y 5/3), 70% quartz, 20% mafics, 10% mica, sharp lower contact; 10-40% very fine to fine sand; 10-20% clay, 40-80% silt, secondary porosity, hardpan, dry, (ML).	
22				SAND light olive brown (2.5 Y 5/4), 40% very fine grained; 60% fine grained; well graded; subangular; 70% quartz, 30% mafics, stained 5 GY 4/1 @ 23.0'-23.5', dry, (SW).	PID=0 ppmv on core
				NO RECOVERY	
24		0/0		SILT dark gray (10 YR 4/1), 20-30% very fine to fine sand, 20-30% clay, 2 GY 4/1 sand @ 24.0'-24.2', secondary porosity, hardpan, (ML).	
26					
				NO RECOVERY	
28					
		0/0		SILTY CLAY, 10% very fine sand; 20-40% silt, iron staining; brittle, secondary porosity, hardpan, dry, (CL).	
30				SANDY SILT light yellowish brown (2.5 Y 6/3), 20-40% very fine sand; iron staining; sandy lamination, dry, (ML).	PID=0 ppmv on core

Lithologic Log | Permeability Log | Concentration (PPBV) 1K 10K 100K 1M

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RADIAN CORPORATION

Monitoring Well #: MW356

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)
32				NO RECOVERY
34		0/0		CLAYEY SILT light olive brown (2.5 Y 5/3), 10% very fine sand; 60% silt; 30% clay; iron staining; laminations, secondary porosity, hardpan, dry, (ML).
36				SANDY SILT light yellowish brown (2.5 Y 6/3), 40% very fine sand; 60% silt, dry, (ML).
				NO RECOVERY
38				
		0/0		SAND light yellowish brown (2.5 Y 6/3), poorly graded; subangular; 70% quartz, 30% mafics, sharp lower contact; clayey silt @ 39.0'-39.2', dry, (SP).
40				SILTY CLAY light yellowish brown (2.5 Y 6/3), 40% silt; 60% clay; iron staining; planar lamination @ 42.0'-42.5', secondary porosity, hardpan, dry, (CL).
42				NO RECOVERY
44		0/0		CLAYEY SILT light olive brown (2.5 Y 5/3), 20-30% clay; 70-80% silt; iron staining; brittle, secondary porosity, hardpan, dry, (ML).
46				
				SILTY SAND light yellowish brown (2.5 Y 6/3), 80% very fine grained; 20% fine grained; subangular; 70% quartz, 30% mafics, 60-70% very fine sand; 30-40% silt, dry, (SM).
48				NO RECOVERY
		0/0		SILT light olive brown (2.5 Y 5/3), 10% very fine sand, 20-30% clay, 60-70% silt, 30% very fine to fine sand @ 52.0'-54.0', iron staining, manganese stained bores,
50				

Lithologic Log | Permeability Log | Concentration (PPBV) 1K 10K 100K 1M

Well Construction Details

PID=0 ppmv on core

Soil Sample IC19SB004202N

PID=0 ppmv on core

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW356

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
50				secondary porosity, hardpan, dry, (ML).				PID=0 ppmv on core
52								
54		0/0						
56				SILTY SAND dark yellowish brown (10 YR 4/4), subangular; 70% quartz, 30% mafics, 50-70% very fine to fine sand; 30-50% silt; iron coated grains, dry, (SM).				PID=0 ppmv on core
				NO RECOVERY				Soil Sample IC19SB004203N
58								
		0/0		SAND brown (7.5 YR 4/4), well graded; subangular; 60% quartz, 40% mafics, 2.5 Y 5/3 below 64.0'; iron coated grains, dry, (SW).				
60								PID=0 ppmv on core
62								
64		0/0						PID=0 ppmv on core
66				NO RECOVERY				

RADIAN CORPORATION

Monitoring Well #: MW356

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
68								
		0/0		SAND light olive brown (2.5 Y 5/3), 10% very fine grained, 70% fine grained, 15% medium grained, 5% coarse grained, well graded; subangular; 50% quartz, 50% mafics, sharp lower contact, dry, (SW).				
70				SAND light olive brown (2.5 Y 5/3), poorly graded; subangular; 70% quartz, 30% mafics, porous sandy silt @ 69.9'-70.2'; 10-20% silt @ 70.2'-70.5'; hard, secondary porosity, hardpan, dry, (SP).				PID=0 ppmv on core
72				NO RECOVERY				
74		0/0		SAND light yellowish brown (2.5 Y 6/3), 20% very fine grained, 70% fine grained, 10% medium grained, well graded; subangular; 60% quartz, 40% mafics, sharp lower contact, dry, (SW).				
76				SILT olive (5 Y 5/3), 30% clay @ 75.5'-76.0'; soft with low sand content from 20% @ 76.0' to 40% @ 77.0', dry, (ML).				
78				SILTY SAND light olive brown (2.5 Y 5/3), subangular; 70% quartz, 30% mafics, 60-80% very fine sand; 20-40% silt, dry, (SM).				
				NO RECOVERY				
80		0/0		SAND light olive brown (2.5 Y 5/3), 40% very fine grained, 60% fine grained, poorly graded; subangular; 70% quartz, 20% mafics, moderately cemented @ 79.4'-80.2', dry, (SP).				PID=0 ppmv on core Soil Sample IC19SB004204N
				SILTY CLAY light olive brown (2.5 Y 5/3), sharp upper contact; 10-30% very fine to fine sand; 10-30% silt, secondary porosity, hardpan, dry, (CL).				
82				SAND light olive brown (2.5 Y 5/3), 30% very fine grained 70% fine grained, poorly graded; subangular; 70% quartz, 30% mafics, gradational upper contact; 10-30% silt; laminations below 82.0', dry, (SP).				
				NO RECOVERY				
84		0/0		SILT yellowish brown (10 YR 5/4), 10-30% very fine to fine sand; 10-20% clay; sandy lamination @ 87.0'-88.0', secondary porosity, (ML).				Top of bentonite seal @ 84.5' (2-50 lb bags of bentonite chips)

RADIAN CORPORATION

Monitoring Well #: MW356

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
86								
88				NO RECOVERY				Top of sand bridge @ 88.0'(1-100 lb bag #30 mesh sand)
90		0/0		SAND yellowish brown (10 YR 5/4), 20% very fine grained, 70% fine grained, 10% medium grained, well graded; subangular; 55% quartz, 35% mafics, 5% feldspar, moderately cemented @ 88.4'-88.8', dry, (SW).				PID=0 ppmv on core Top of sand pack 90.5' (10-100 lb bags #1C sand)
92				NO RECOVERY				
94		0/0		SAND light olive brown (2.5 Y 5/3), 10% very fine grained, 70% fine grained, 20% medium grained, well graded, subangular; 60% quartz, 40% mafics, sharp lower contact, dry, (SW).				Top of screen @ 94.0' (0.10" slot stainless steel screen) PID=0 ppmv on core
96				CLAYEY SILT light olive brown (2.5 Y 5/3), brittle silty clay @ 95.4'-96.2'; 20% clay with 40% clay below 100.0', saturated, dry below 100.0', (ML).				
98		0/0						
100								PID=0 ppmv on core
102				NO RECOVERY				
104								Groundwater Sample IC19GL004201N

ERM OUC 10/10/95

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW356

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
104		0/0		CLAYEY SILT light yellowish brown (2.5 Y 6/3), 10% very fine sand; 20-30% very fine sand @ 107.0'-109.0'; 20-30% clay; fractured; 10 YR 5/4 @ 107.0'-109.0'; 5 Y 5/3 below 109.0', saturated, (ML).				
106								
108		0/0						
110								PID=0 ppmv on core
112				SAND yellowish brown (10 YR 5/4), 20% very fine grained, 85% fine grained, 5% medium grained, well graded, subangular, 60% quartz, 30% mafics, 10% mica, sharp lower contact; moderately cemented @ 113.5'; fractured, saturated, (SW).				
114		0/0		SILT yellowish brown (10 YR 5/4), 10% very fine sand; 10-20% clay; iron staining; fractured, saturated, (ML).				Bottom of screen @ 114.0' #1C sand @ 114.0'-115.0'
								Total Depth=115.0' BGS

RADIAN CORPORATION

Monitoring Well #: MW357

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base
TOTAL DEPTH 115.00 START DATE 12/12/94 FINISH DATE 12/12/94
GEOLOGIST Wendy Linck APPROVED BY Thomas F. Lindbald R.G.# 4473
DRILLING COMPANY Water Development Corp. DRILLER Corey Wilson
DRILLING METHOD Hollow Stem Auger EQUIPMENT CME 75
DRILL BIT TYPE AND SIZE 8" Bullet
BORING LOCATION (ST. ADDRESS OR DESCRIPTION) 230 Feet Southeast of Center of Fire Training Area

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
0				GRAVEL fill, 1.0"-8.0" diameter loose cobbles, (GW).				Casing elevation=62.73'
								Boring # IC19B043
2				SANDY SILT brown (10 YR 3/3), fill, 10% clay; 30-40% fine sand; 50-60% silt; few rounded pebbles < 1.0" in diameter; rock @ 3.0', wet, (ML).				NaI (background=6.5K cpm) and alpha (background=4 cpm) probes to measure maximum radiation in counts per minute (cpm) on soil cores. Backfilled to surface from 85.5' with bentonite grout. Mixture consisted of approximately 4 lbs. bentonite to 9 gal. water to 1 bag (94 lbs.) cement. Weight and volume not recorded.
				NO RECOVERY				
4				SANDY SILT brown (10 YR 4/3), fill, 10% clay; 30% very fine sand; 60% silt; minor angular to rounded pebbles, moist, (ML).				
				NO RECOVERY				Cobble preventing recovery 4.0" schedule 40 PVC blank casing 0'-94.0'
6								NaI=7.98K cpm; alpha=0 cpm on core
								PID=0 ppmv on core
8								
10				SILTY CLAY brown (10 YR 4/3), 10% very fine sand; 40% silt; 50% mod. plastic clay, dry, (CL).				NaI=7.92K cpm; alpha=0 cpm on core
								PID=0 ppmv on core
				SILTY SAND yellowish brown (10 YR 5/4), subangular; 70% quartz, 30% mafics, moist, (SM).				First soil sample not collected
12								
14								

NOTES
PID = Photoionization Detector
LEL = Lower Explosive Limit
PID readings in parts per million by volume

PERMEABILITY
Fill Low
High No Recovery
Moderate

Depth While Drilling ▽ 101.50
Depth at Development ▼ 102.05

RM OUC 10/16

RADIAN CORPORATION

Monitoring Well #: MW357

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
14		0/0			NaI=7.65K cpm; alpha=0 cpm on core
16				SILTY CLAY light yellowish brown (2.5 Y 6/3), iron stained bores; 20-50% silt; 10-20% very fine sand; 40% silt @ 17.0'-19.0', secondary porosity, hardpan, dry, (CL).	PID=0 ppmv on core
18					
20		5/0		SILT light yellowish brown (2.5 Y 6/3), 10-25% very fine sand; 10% clay; 80-65% silt; color change @ 25.2' 10 YR 5/4, secondary porosity, dry, (ML).	NaI=7.91K cpm; alpha=0 cpm on core Soil Sample IC19SB004302N PID=0 ppmv on core
22					
24		0/0			NaI=7.68K cpm; alpha=0 cpm on core
26					PID=0 ppmv on core
28				NO RECOVERY	
30		0/0		SILTY CLAY light yellowish brown (2.5 Y 6/3), lower contact gradational; hard and brittle; iron stained bores; specks of manganese staining, secondary porosity, hardpan, dry, (CL).	NaI=7.80K cpm; alpha=0 cpm on core PID=0 ppmv on core
32				SILT light yellowish brown (2.5 Y 6/3), patchy iron staining in finer portions; 10% clay @ 31.0'-31.3'; 20-60% very fine sand @ 31.3-32.0'; silty sand @ 31.9'-32.0',	

Lithologic Log | Permeability Log | Concentration (PPBV) 1K 10K 100K 1M

RM OUC 10/10/95

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW357

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
32				secondary porosity, dry, (ML).	
				NO RECOVERY	
34		0/0		SILT light olive brown (2.5 Y 5/3), patchy iron staining; 30-45% very fine sand @ 34.8'-35.5', secondary porosity, dry, (ML).	NaI=7.74K cpm; alpha=0 cpm on core PID=0 ppmv on core
36				SAND light olive brown (2.5 Y 5/3), 70% very fine grained; 30% fine grained; poorly graded; subangular; 70% quartz, 20% mafics, 10% mica, patchy iron staining; planar laminations, secondary porosity, dry, (SP).	
38		0/0		SILT light yellowish brown (2.5 Y 6/3), iron stained bores @ 39.0'-40.0'; 20% clay @ 40.0'; 30% very fine sand @ 38.3'-38.5', secondary porosity, hardpan, dry, (ML).	NaI=8.31K cpm; alpha=0 cpm on core Soil Sample IC19SB004303N
		0/0			
40				SAND light olive brown (2.5 Y 5/3), 30% very fine grained; 65% fine grained; 5% medium grained; well graded; subangular; 70% quartz, 30% mafics, sandy silt @ 41.1'-41.5', dry, (SW).	PID=0 ppmv on core
42				NO RECOVERY	
44		0/0		SANDY SILT light olive brown (2.5 Y 5/3), patchy iron staining; 20-30% very fine sand; 5% clay; 75-65% silt, secondary porosity, hardpan, dry, (ML).	NaI=8.40K cpm; alpha=0 cpm on core
46				SAND light olive brown (2.5 Y 5/3), 20% very fine grained; 80% fine grained; poorly graded; subangular; 70% quartz, 30% mafics, 40% silt @ 45.8'-46.0', dry, (SP).	PID=0 ppmv on core NaI=9.10K cpm; alpha=0 cpm on core
				NO RECOVERY	
50		0/0		SANDY SILT light yellowish brown (2.5 Y 6/3), 20% fine sand; 80% silt, secondary porosity, hardpan, dry, (ML).	

Lithologic Log | Permeability Log | Concentration (PPBV) 1K 10K 100K 1M

PERM OUC 10/1

RADIAN CORPORATION

Monitoring Well #: MW357

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
50				SAND light yellowish brown (2.5 Y 6/3), 60% very fine grained; 40% fine grained; poorly graded; subangular; 70% quartz, 30% mafics, sharp lower contact; 30% silt @ 50.0'-50.4', dry, (SP).	PID=0 ppmv on core
52				SILT brown (10 YR 3/3), iron stained bores, secondary porosity, dry, (ML). NO RECOVERY	
54		0/0		SANDY SILT brown (10 YR 5/3), iron stained; 10-20% very fine to fine sand; 5% clay; 35-75% silt, secondary porosity, dry, (ML).	NaI=9.20K cpm; alpha=0 cpm on core PID=0 ppmv on core
56					
58				SAND brown (7.5 YR 4/4), 20% very fine grained; 70% fine grained; 10% medium grained; well graded; subangular; 60% quartz, 40% mafics, white colored silt @ 61.8'-62.0', dry, (SW).	Soil Sample IC19SB004304N
60					PID=0 ppmv on core Alpha probe not working
62				NO RECOVERY	
64		0/0		SAND light olive brown (2.5 Y 5/3), 20% very fine grained; 60% fine grained; 20% medium grained; well graded; subangular; 60% quartz, 40% mafics, lower contact sharp, dry, (SW).	NaI=8.69K cpm on core PID=0 ppmv on core
66				SILT light gray (2.5 Y 7/2), dry, (ML). NO RECOVERY	
68					

Lithologic Log | Permeability Log | Concentration (PPBV) 1K 10K 100K 1M

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW357

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
68					
		0/0		SILT light olive brown (2.5 Y 5/3), manganese coated bores @ 69.0'-69.5'; 10% clay @ 69.0'-69.5'; 20-40% very fine to fine sand @ 69.5'-70.5', secondary porosity, hardpan, dry, (ML).	
70					PID=0 ppmv on core
				SAND light yellowish brown (2.5 Y 6/3), 20% very fine grained; 80% fine grained; poorly graded; subangular; 70% quartz, 30% mafics, upper contact gradational; white colored silt @ 71.8'-72.0'; silty sand @ 70.5'-70.7', dry, (SP).	
72				NO RECOVERY	
74		0/0		SAND light olive brown (2.5 Y 5/3), 30% very fine grained; 70% fine grained; poorly graded; subangular; 70% quartz, 30% mafics, lower contact sharp, dry, (SP).	NaI=7.82K cpm on core
					PID=0 ppmv on core
76				SILT light yellowish brown (5 Y 6/3), 20-40% very fine sand @ 77.5'-78.0', secondary porosity, dry, (ML).	
78				NO RECOVERY	
		0/0		SAND light yellowish brown (2.5 Y 6/3), poorly graded; subangular; 70% quartz, 30% mafics, loose sand; well graded; sharp contact @ 80.8'-81.5'; 30% silt @ 79.0'-79.5', dry, (SP).	NaI=7.50K cpm on core
80					Soil Sample IC19SB004305N PID=0 ppmv on core
82				SANDY SILT light olive brown (2.5 Y 5/3), upper contact sharp; 30-40% very fine sand; 60-70% silt, secondary porosity, dry, (ML).	
				NO RECOVERY	
84		0/0		SILT grayish brown (2.5 Y 5/2), iron stained bores; color 5 Y 7/3 below 86.5'; 40% very fine sand @ 84.0'-85.0'; brittle below 85.0'-85.8'; 10% clay @ 86.5'-88.0'; soft below 86.5', secondary porosity, hardpan, dry, (ML).	NaI=8.10K cpm on core
86					Top of bentonite seal @ 85.5' (2-50 lb bags of

Concentration (PPBV): 1K, 10K, 100K, 1M

Lithologic Log | Permeability Log

PERM OUC 10/10/

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW357

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description (Color, Texture, Moisture, etc.)	Well Construction Details
86					bentonite chips)
88				NO RECOVERY	
90		4.4/0		SANDY SILT light olive brown (2.5 Y 5/3), lower contact gradational; 20-40% very fine to fine sand; 60-80% silt, secondary porosity, hardpan, dry, (ML).	Top of sand bridge @ 89.0' (1-100 lb bag of #30 mesh sand) PID=0 ppmv on core
92				SILTY SAND light yellowish brown (2.5 Y 6/3), 50-70% very fine to fine sand; 50-30% silt, dry, (SM). NO RECOVERY	Top of sand pack @ 91.0' (5.5-100 lb bags of #1C sand) NaI=6.11K cpm on core
94		3.5/0		SAND grayish brown (2.5 Y 5/2), 20% very fine grained; 60% fine grained; 20% medium grained; well graded; subangular; 60% quartz, 40% mafics, 20-30% silt @ 96.5'-97.0'; planar lamination below 96.5', dry, (SW).	Top of screen @ 94.0' (0.01" slot stainless steel screen) PID=0 ppmv on core
96				NO RECOVERY	
98					
100		0.9/0		SANDY SILT light olive brown (2.5 Y 5/3), color change to 5 Y 7/3 below 102.1'; 10% very fine sand; 30% clay; 60% silt @ 100.8'-102.0'; 20-45% sand; 55-80% silt to 100.8'; wet @ 99.0'-99.5'; saturated @ below 99.5'; dry @ 102.5'-103.0', secondary porosity, wet, (ML).	NaI=8.21K cpm on core PID=0 ppmv on core Problem pulling up core barrel raise augers to 102.0' Water level @ 101.5' Groundwater Sample IC19GL004301N
102				NO RECOVERY	
104					

Concentration (PPBV): 1K, 10K, 100K, 1M

Lithologic Log / Permeability Log

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RADIAN CORPORATION

Monitoring Well #: MW357

LOG OF DRILLING OPERATIONS

PROJECT Operable Unit C Remedial Investigation LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	LEL Reading (in percent)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentration (PPBV) 1K 10K 100K 1M	Well Construction Details
104				SILT pink (5 YR 7/3), fractured; manganese coated bores; color change to 10 YR 5/4 below 106.2'; 30% clay @ 104.0'-106.2'; 10% clay and 20-30% very fine sand below 106.2', secondary porosity, saturated, (ML).				PID=0 ppmv on core
106								
108		0/0						NaI=8.20K cpm on core
110								
112								
114		0/0						Bottom of screen @ 114.0' #1C sand @ 114.0'-115.0' Total Depth 115.0' BGS

PERM OUC 10/10

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW-385

PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base
TOTAL DEPTH (ft) 190 START DATE 11/13/96 FINISH DATE 11/19/96
GEOLOGIST W. Linck/C. Denver APPROVED BY Thomas F. Lutzke R.G.# 4473
DRILLING COMPANY WESTEX (C-57 Lic# 552198) DRILLER T. Jaramillo/B. Clarke
DRILLING METHOD HSA/ARCH EQUIPMENT Mobile Drill B-61/TH-70
DRILL BIT TYPE AND SIZE 8" Bullet/12" ODEX
BORING LOCATION (ST. ADDRESS OR DESCRIPTION) 48' E, 265' S of MW-355

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	NaI Reading (cpm)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentrations ppbv (TCE / PCE / VC; 1K, 10K, 100K, 1M)	Well Construction Details
0				SILTY SAND brown (10 YR 5/3), gap grading, asphalt, gravel, loose, dry (SM).				Casing elevation=59.41'
				SILTY SAND brown (10 YR 5/3), fill, 50% very fine and 50% fine grained sand, poor-gap grading, subrounded, 60% quartz, 40% mafic, root bores, wood at 0.5'-1', minor inclusions at 2.5'-3', high estimated permeability, lower contact sharp, dry (SM).				Borehole number CS12SB0001 Bentonite/cement grout at 0-142'. Grout mixture consisted of approximately 140 lbs bentonite to 280 gals water to 36 sacks of cement. The weight was 13.4 lb/gal. Estimated grout volume was 443 gals; actual grout volume was 480 gal. 4" Schedule 40 Polyvinyl Chloride (PVC) blank casing at ~3' above ground suface to 151' below ground surface.
		0/0						LEL = 0%
				SILTY SAND brown (7.5 Y 4/3), 70% very fine and 30% fine grained sand, poor grading, subrounded, 40% quartz, 60% mafic, slightly to moderately dense, moderate estimated permeability, lower contact sharp, dry (SM).				
5				SILTY SAND olive (5 Y 5/3), 80% very fine and 20% fine grained sand, poor grading, subrounded, 80% quartz, 20% mafic, moderate-high estimated permeability, horizontal bedding (iron stained sands), lower contact gradational from 4.9'-5.2', dry (SM).				LEL = 0% PID = 0 ppmv on core
		0/0		SANDY SILTY CLAY brown (7.5 YR 4/3), 20% very fine-fine grained sand, 30% silt, stiff, moderately to very dense, sugary texture, minor black manganese staining, low estimated permeability, lower contact gradational, dry (CL).				
				SILTY SAND olive (5 Y 4/3), 80% very fine and 20% fine grained sand, poor grading, subrounded, 70% quartz, 30% mafic, moderate estimated permeability, laminar bedding, loose to moderately dense, lower contact sharp, dry (SM).				LEL = 0%
10		0/0						LEL = 0%
				SAND olive (5 Y 5/3), 50% very fine and 50% fine grained sand, poor grading, subrounded, 60% quartz, 40% mafic, loose, high estimated permeability, laminar bedding, dry (SP).				
				NO RECOVERY				
		0/0		SAND olive (5 Y 4/3), poor grading, subrounded, 70% quartz, 30% mafic, loose, very high estimated permeability, lower contact sharp, dry (SP).				LEL = 0% PID = 0 ppmv on core
				SILTY SAND olive (5 Y 4/3), 80% very fine and 20% fine grained sand, poor grading, subrounded, 70% quartz, 30% mafic, slightly				
15								

NOTES
PID = Photoionization Detector (ppmv)
NaI = Sodium Iodide Probe

PERMEABILITY
Fill Low
High No Recovery

Depth while drilling ≈ 110

OUC2N.0PJ 1/28

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW-385

PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	NaI Reading (cpm)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentrations ppbv TCE PCE VC 1K 10K 100K 1M	Well Construction Details
15		0/0		dense, moderate-high estimated permeability, dry (SM).				LEL = 0% Drilled 8" diameter pilot hole to 15' with Hollow Stem Auger Rig for collection of background downhole NaI readings. The borehole was reamed to 12" from 0-15' and drilled (12") from 15' to total depth (190') with an Air Rotary Casing Hammer Rig.
20				SAND minor silt, light olive brown (25Y 5/4), fine-medium grained sand, poor grading, subrounded, 100% quartz, damp (SP).				
25				SILTY SAND minor clay, light olive brown (2.5 Y 5/4), 60% very fine-medium grained sand, 35% silt, 5% clay, well graded, subrounded, 98% quartz, 2% mica, clayey balls (1 mm), damp to moist (SM).				
30				CLAYEY SILT minor sand, light olive brown (2.5 Y 5/4), 25% very fine-fine grained sand, 40% silt, 35% clay, well graded, significant clay fraction, clay displays moderate plasticity and is soft, moist (ML).				Centralizer at 31'
				SAND light olive brown (2.5 Y 5/6), medium grained sand, poor grading, subrounded, 100% quartz, slight mica fraction, moist (SP).				
				SILTY SAND minor clay, light olive brown				

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW-385

PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	NaI Reading (cpm)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentrations ppbv TCE PCE VC 1K 10K 100K 1M	Well Construction Details
35				balls (1mm), damp to moist (SM).				
40				CLAYEY SILT minor sand, light olive brown (2.5 Y 5/4), very fine grained sand, well graded, faint iron staining in spots (1 mm diameter), damp (ML).				
45								
50				CLAYEY SILT minor sand, yellowish brown (10 YR 5/4), very fine grained sand, well graded, faint iron staining in spots (1 mm diameter), damp (ML).				

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW-385

PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	NaI Reading (cpm)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentrations ppbv TCE PCE VC 1K 10K 100K 1M	Well Construction Details
55				SAND minor silt, dark yellowish brown (10 YR 4/6), 10% silt, trace clay, very fine-coarse grained sand, poor grading, rounded-subrounded, 100% quartz, silt and clay form 1-5 mm balls, damp (SP).				
60				SAND minor silt, dark yellowish brown (10 YR 4/6), 10% silt, trace clay, very fine-coarse grained sand, poor grading, rounded-subrounded, 100% quartz, silt and clay form 1-5 mm balls, damp (SP).				
65				SAND yellowish brown (10 YR 5/4), fine-medium grained sand, poor grading, subrounded, 80% quartz, 20% mafic, some iron staining, moist (SP).				
70				SAND yellowish brown (10 YR 5/4), fine-medium grained sand, poor grading, subrounded, 80% quartz, 20% mafic, some iron staining, moist (SP).				Centralizer at 71'

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW-385

PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	NaI Reading (cpm)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentrations ppbv TCE PCE VC 1K 10K 100K 1M	Well Construction Details
75								
80				SAND light olive brown (2.5 Y 5/3), fine grained sand, poor grading, rounded, 100% quartz, moist (SP).				
85				SILTY SAND minor clay, light yellowish brown (2.5 Y 6/3), 65% very fine-medium grained sand, 30% silt, 5% clay, well graded, subrounded, 100% quartz, moist (SM).				
90				SAND light yellowish brown (2.5 Y 6/3), fine-medium grained sand, poor grading, subrounded, 100% quartz, 10% silt fraction becomes noticeable at 93', moist (SP).				

OUC2N.GPJ 1/28...

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: **MW-385**

PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	NaI Reading (cpm)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentrations ppbv (TCE, PCE, VC; 1K, 10K, 100K, 1M)	Well Construction Details
95				SAND light yellowish brown (2.5 Y 6/3), fine-medium grained sand, poor grading, subrounded, 100% quartz, 10% silt fraction becomes noticeable at 93', moist (SP).				
				CLAYEY SILT minor sand, light yellowish brown (2.5 Y 6/3), 5% very fine grained sand, 70% silt, 20% clay, well graded, subrounded, 100% quartz, moist (ML).				
100				SAND yellowish brown (10 YR 5/4), fine-medium grained sand, poor grading, subrounded, 80% quartz, 20% mafic, some iron staining, moist (SP).				Water level at development = 100.4
105				CLAYEY SILT minor sand, light yellowish brown (2.5 Y 6/3), very fine-fine grained sand, well graded, several large 1-4 cm diameter chips of thickly (1mm) laminated clay (dark olive brown [2.5 Y 3/3]), moist at 110', (ML).				
110				CLAYEY SILT minor sand, light yellowish brown (2.5 Y 6/3), very fine-fine grained				Water level during drilling =

95 100 105 110

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW-385

PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	Nal Reading (cpm)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentrations ppbv TCE PCE VC 1K 10K 100K 1M	Well Construction Details
				(ML). SAND, medium-coarse grained sand, poor grading, subrounded, 75% quartz, 25% mafic, saturated (SP).				
115								115
120				SAND, medium-coarse grained sand, poor grading, subrounded, 75% quartz, 25% mafic, saturated (SP).				120
125				SAND, medium-coarse grained sand, poor grading, subrounded, 75% quartz, 25% mafic, saturated (SP).				125
130				CLAYEY SAND minor silt, light olive brown				130

OUC2N GPJ 1/2

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW-385

PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	NaI Reading (cpm)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentrations ppbv TCE PCE VC 1K 10K 100K 1M	Well Construction Details
				15% silt, 10% clay, well graded, subrounded, 100% quartz, appears to be confining layer for "B" zone, moist (SC).				
135				SAND, medium-coarse grained sand, poor grading, subrounded, 75% quartz, 25% mafic, saturated (SP).				
140								Bentonite chip seal at 142'-146' (2 - 50 lb bags).
				SAND yellowish brown (10 YR 5/4), fine-medium grained sand, poor grading, subrounded, 75% quartz, 25% mafic, very compact unit, hardpan, saturated (SP).				
145								Type 1C sand at 146' - 148.5' (3 - 100 lb bags).
								Monterey #3 sand at 148.5' 165'.

135 140 145

C2N.GPJ 1/28/97

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW-385

PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	NaI Reading (cpm)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentrations ppbv TCE / PCE / VC 1K 10K 100K 1M	Well Construction Details
150				SAND yellowish brown (10 YR 5/4), fine-coarse grained sand, poor grading, subrounded, 75% quartz, 25% mafic, saturated (SP).				4" stainless steel 0.020" slot continuous wrap screen at 151'-161'. Centralizer at 151'
155				SAND yellowish brown (10 YR 5/4), fine-coarse grained sand, poor grading, subrounded, 75% quartz, 25% mafic, saturated (SP).				
160				SILTY CLAY minor sand, yellowish brown (10 YR 5/4), 5% very fine grained sand, well graded, some iron staining, hardpan, compact, saturated (CL).				Centralizer at 160'. Bottom of screen at 161'. Bottom of well casing at 161.5'.
165				SILTY CLAY minor sand, yellowish brown (10 YR 5/4), 5% very fine grained sand, well graded, some iron staining, hardpan, compact, saturated (CL).				Backfilled to 165' from 191' with bentonite chips.

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: MW-385

PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	NaI Reading (cpm)	Lithologic Description Color, Texture, Moisture, etc.	Lithologic Log	Permeability Log	Concentrations ppbv TCE PCE VC 1K 10K 100K 1M	Well Construction Details
170				SILTY CLAY minor sand, yellowish brown (10 YR 5/4), 5% very fine grained sand, well graded, some iron staining, hardpan, compact, saturated (CL).				
				SILTY CLAY minor sand, yellowish brown (10 YR 5/4), 5% very fine grained sand, well graded, some iron staining, hardpan, compact, saturated (CL).				
175				SILTY CLAY minor sand, yellowish brown (10 YR 5/4), 5% very fine grained sand, well graded, some iron staining, hardpan, compact, saturated (CL).				
180				SILTY CLAY minor sand, yellowish brown (10 YR 5/4), 5% very fine grained sand, well graded, some iron staining, hardpan, compact, saturated (CL).				
185				SILTY CLAY minor sand, yellowish brown (10 YR 5/4), 5% very fine grained sand, well graded, some iron staining, hardpan, compact, saturated (CL).				
				SILTY CLAY yellowish brown (10 YR 5/4), well graded, moist (CL).				

RADIAN CORPORATION

LOG OF DRILLING OPERATIONS

Monitoring Well #: **MW-385**

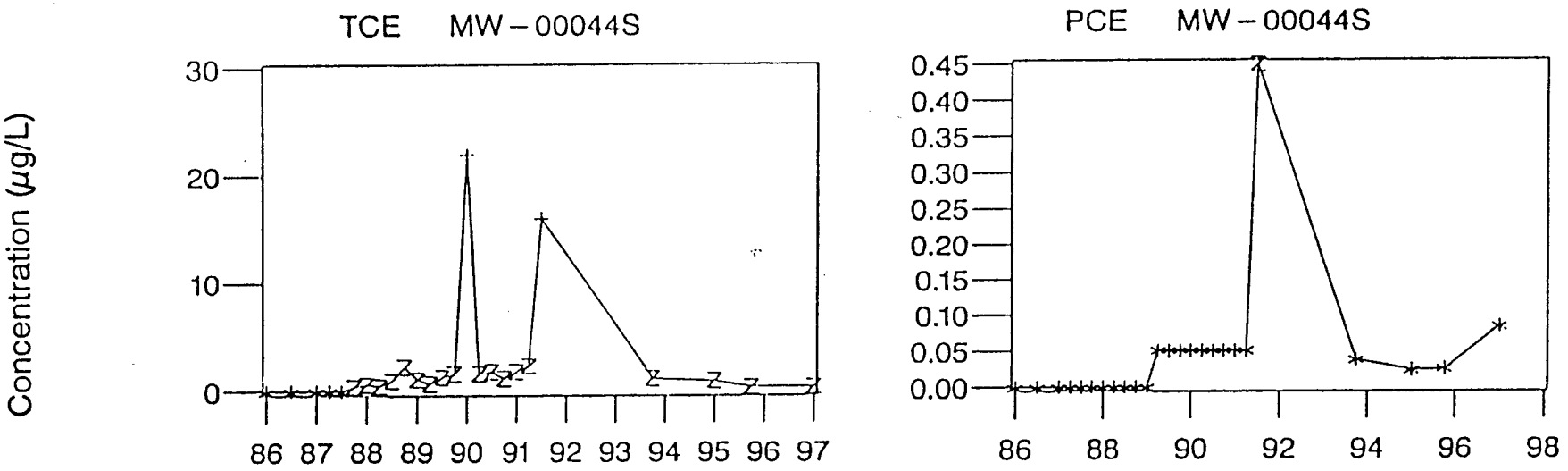
PROJECT OU C Remedial Investigation Phase 2 (North) LOCATION McClellan Air Force Base

Depth Below Surface (ft)	Sample Interval	PID borehole/ breathing zone	NaI Reading (cpm)	Lithologic Description (Color, Texture, Moisture, etc.)	Lithologic Log	Permeability Log	Concentrations ppbv (TCE, PCE, VC; 1K, 10K, 100K, 1M)	Well Construction Details
190								Total depth of borehole = 190'
195								
200								
205								

APPENDIX B

CONTAMINANT TIME SERIES PLOTS

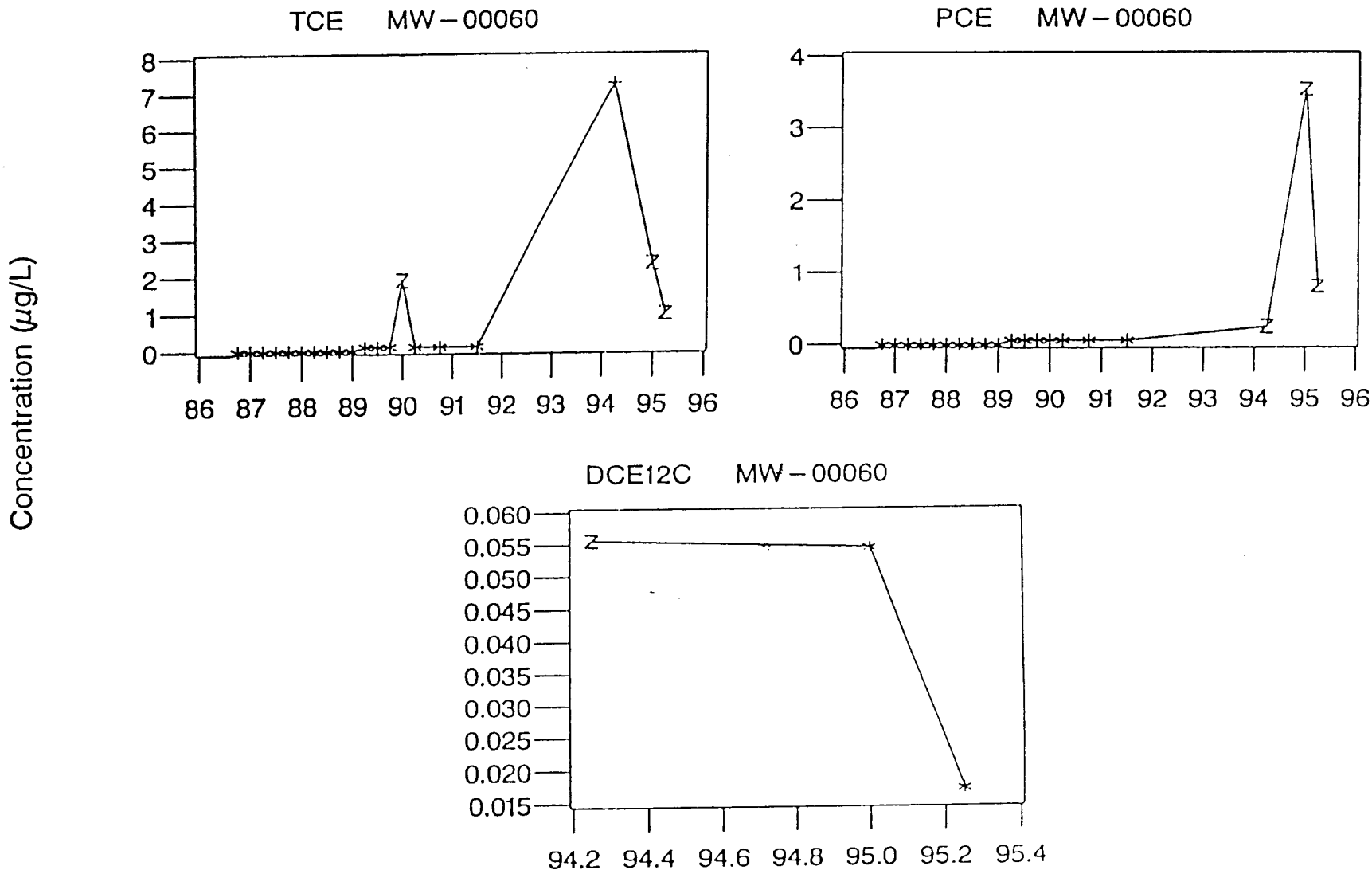
McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW44S



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

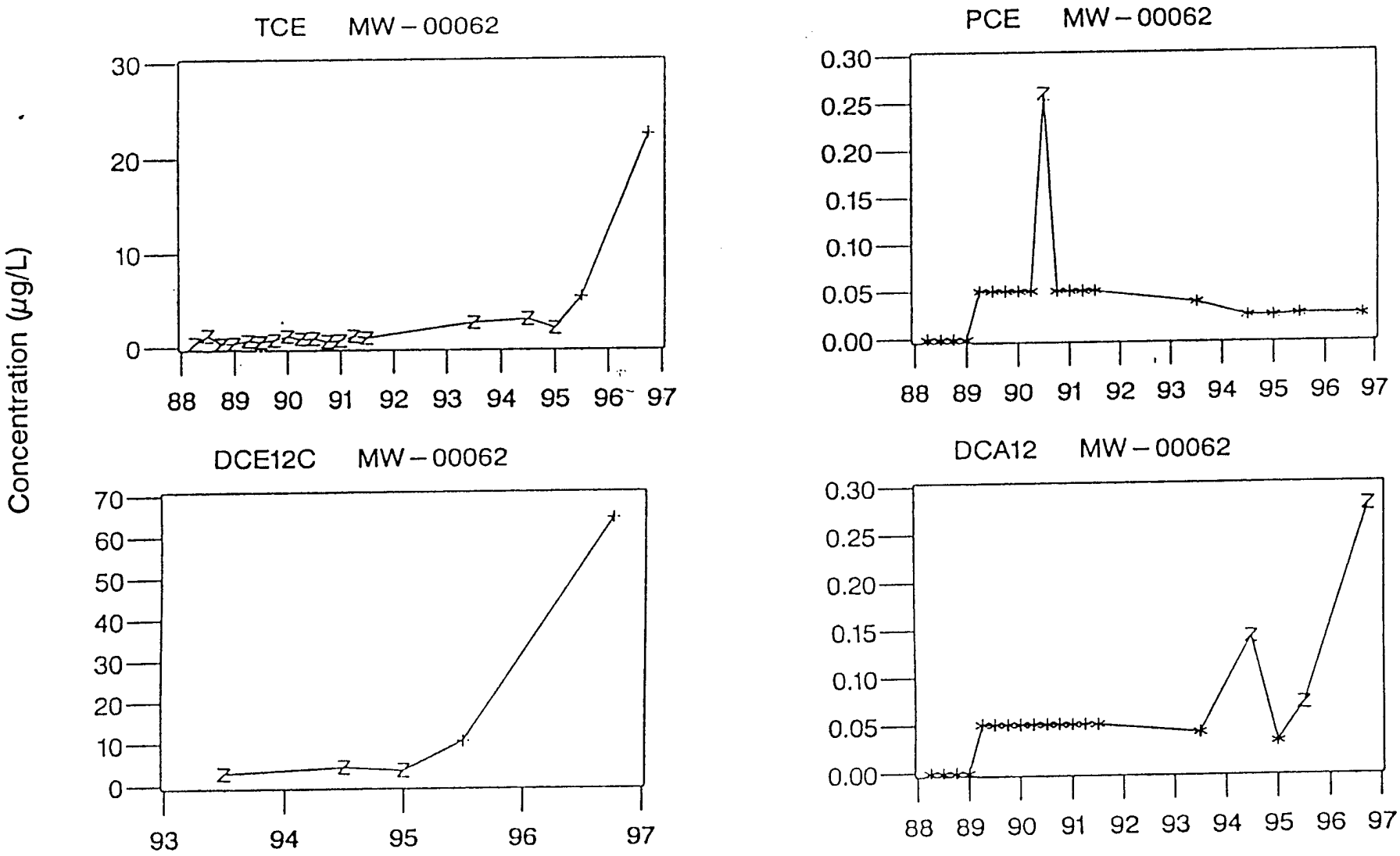
McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW60



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

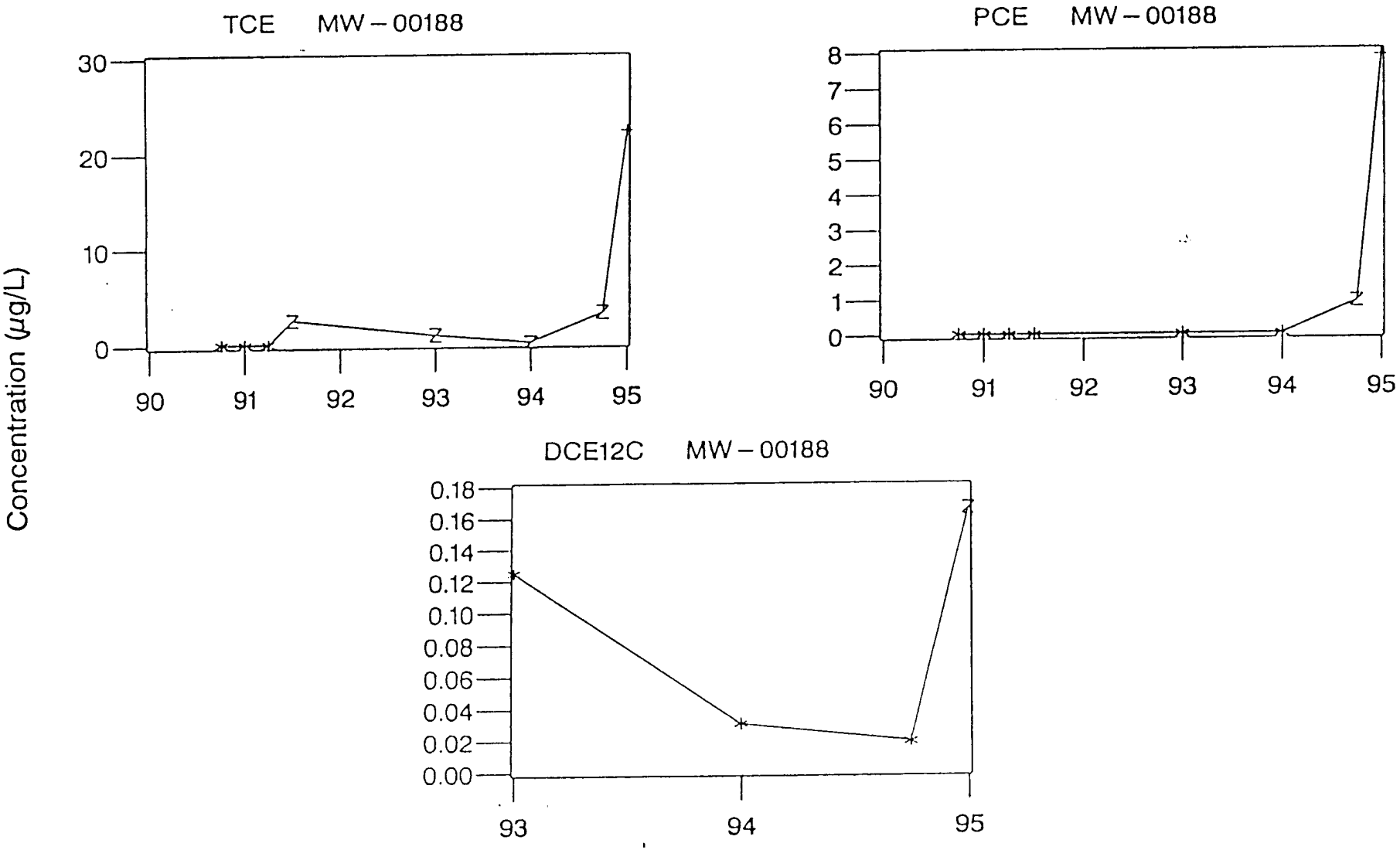
McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW62



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW188

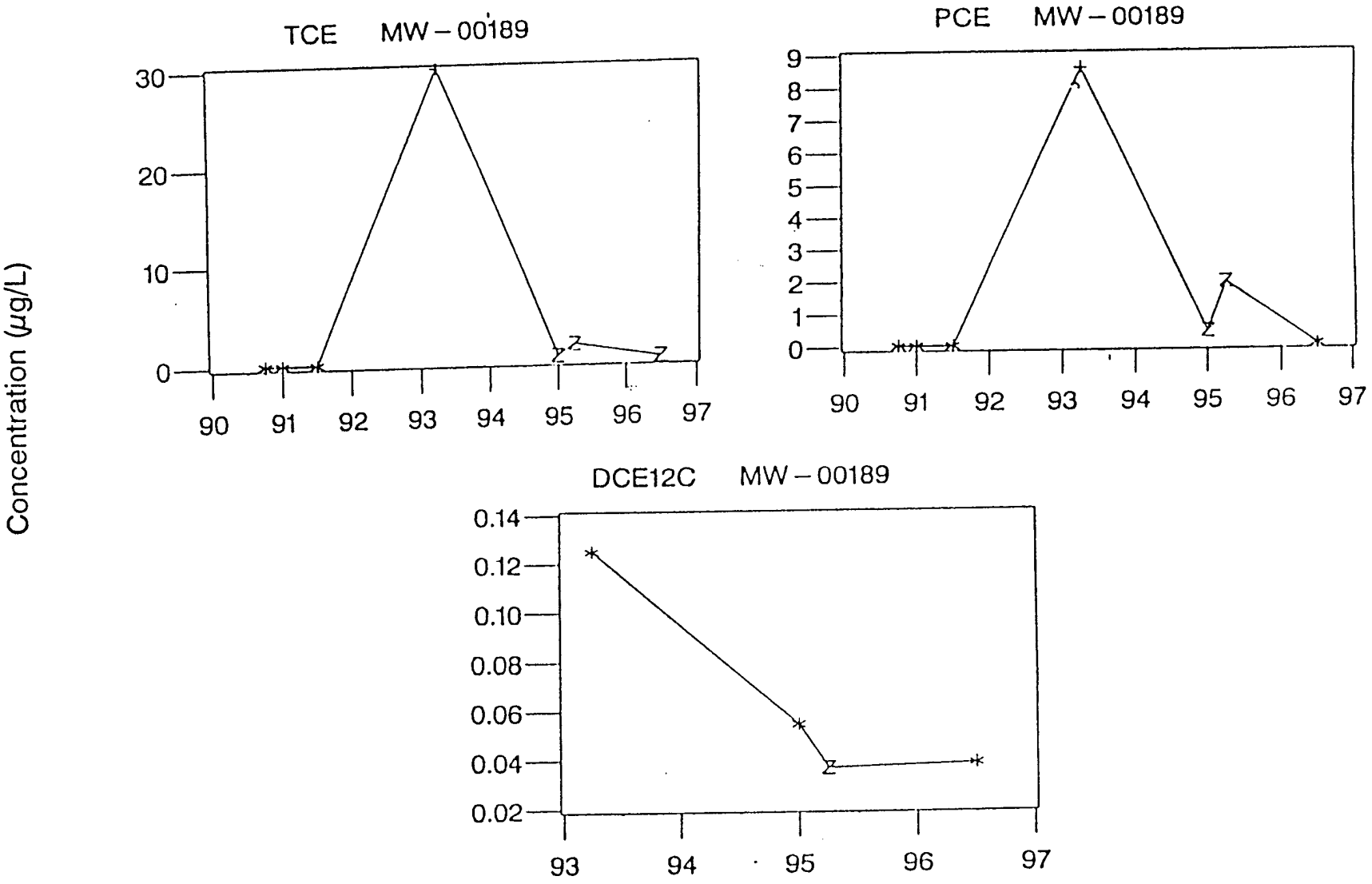


z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.

Source: Radian, 1997(f)

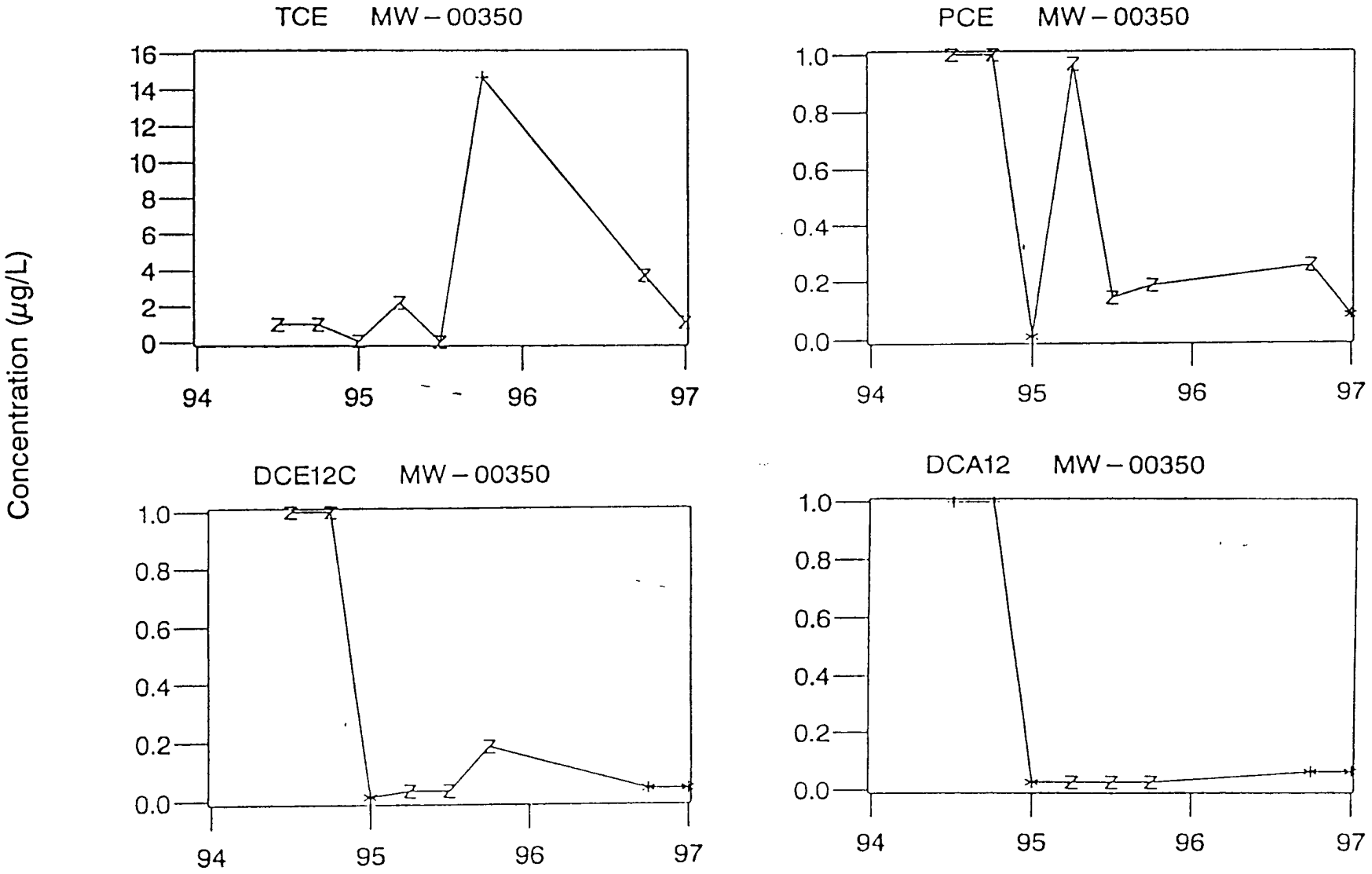
McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW189



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW350

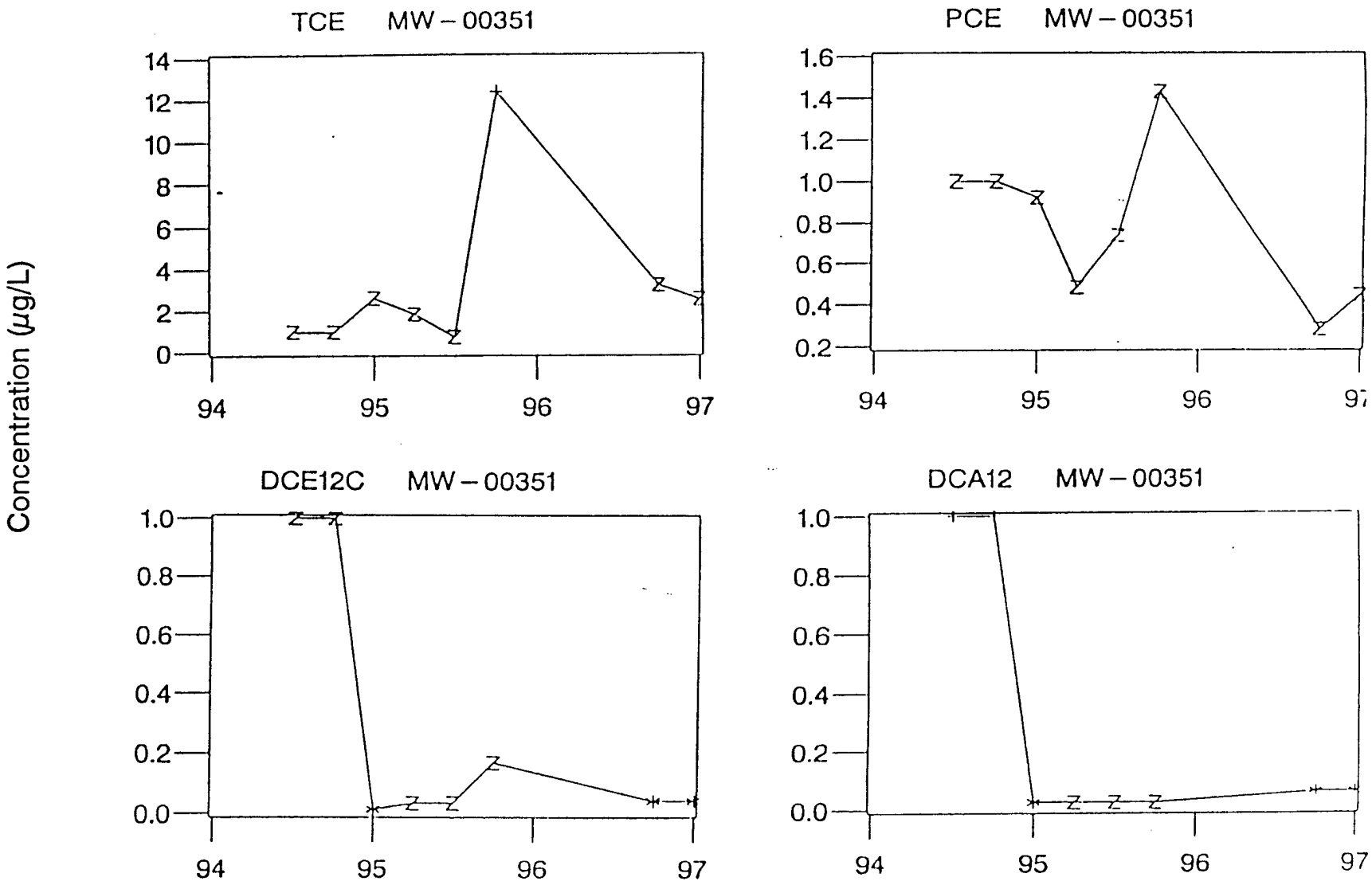


z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.

Source: Radian, 1997(f)

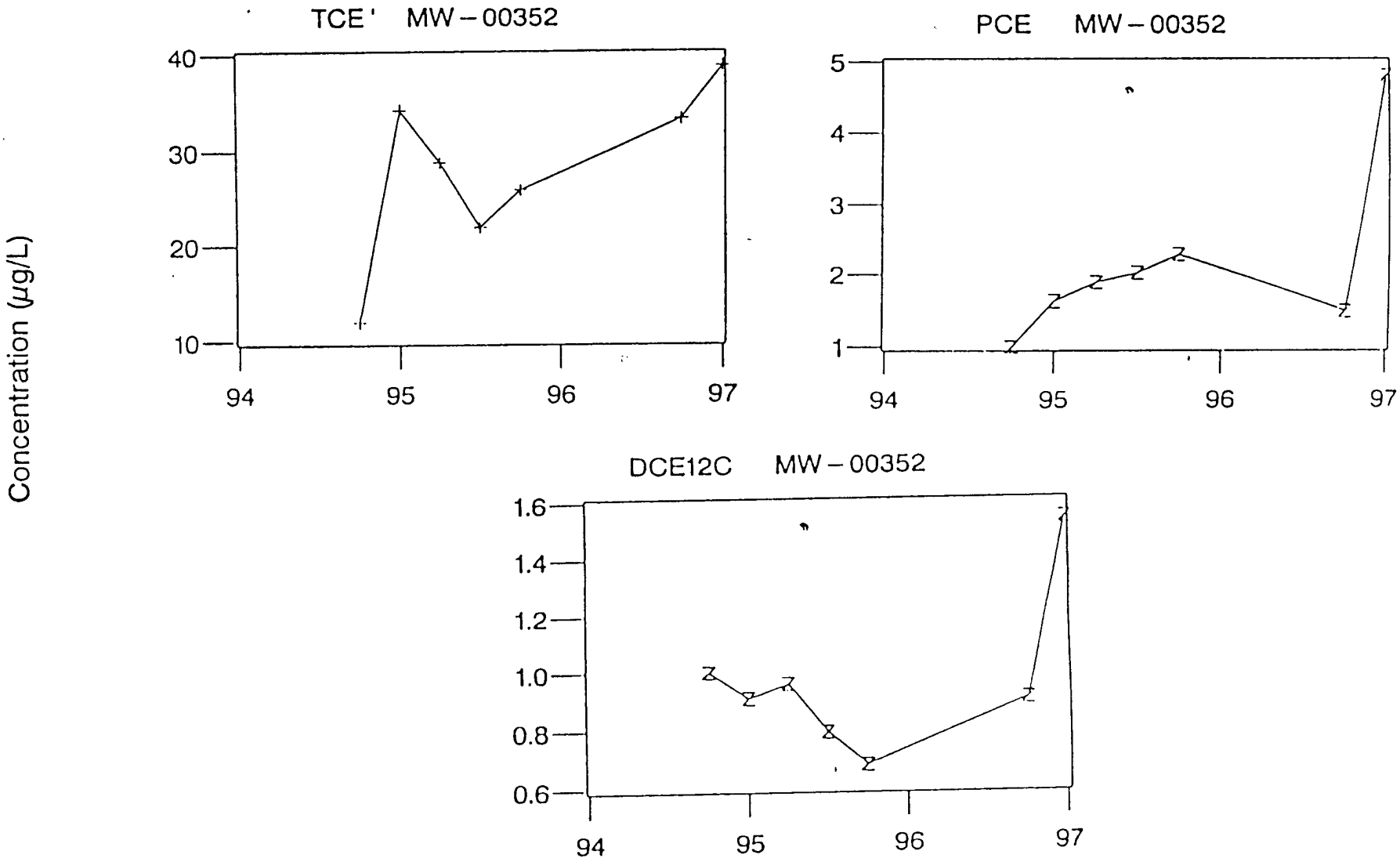
McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW351



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW352

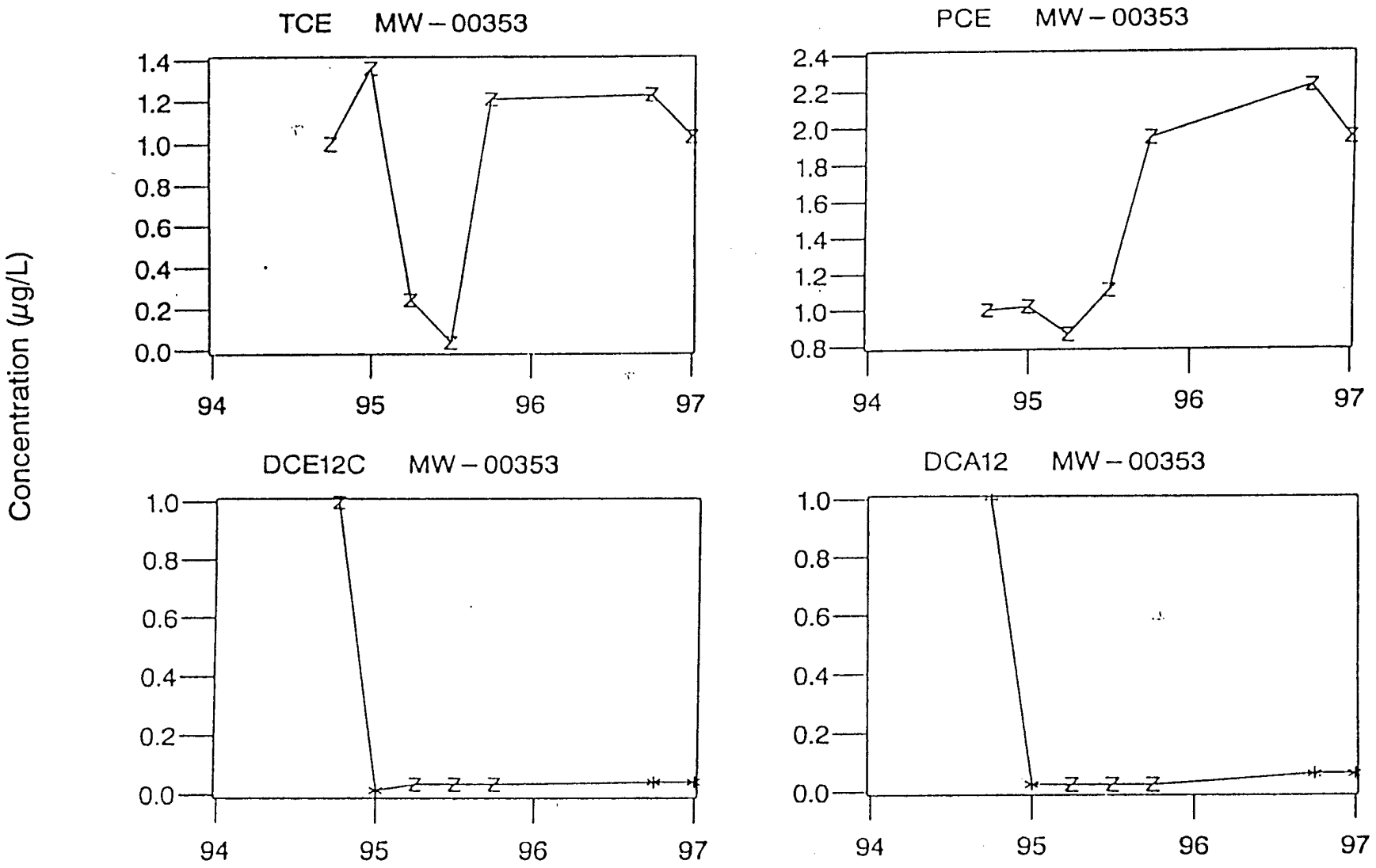


z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.

Source: Radian, 1997(f)

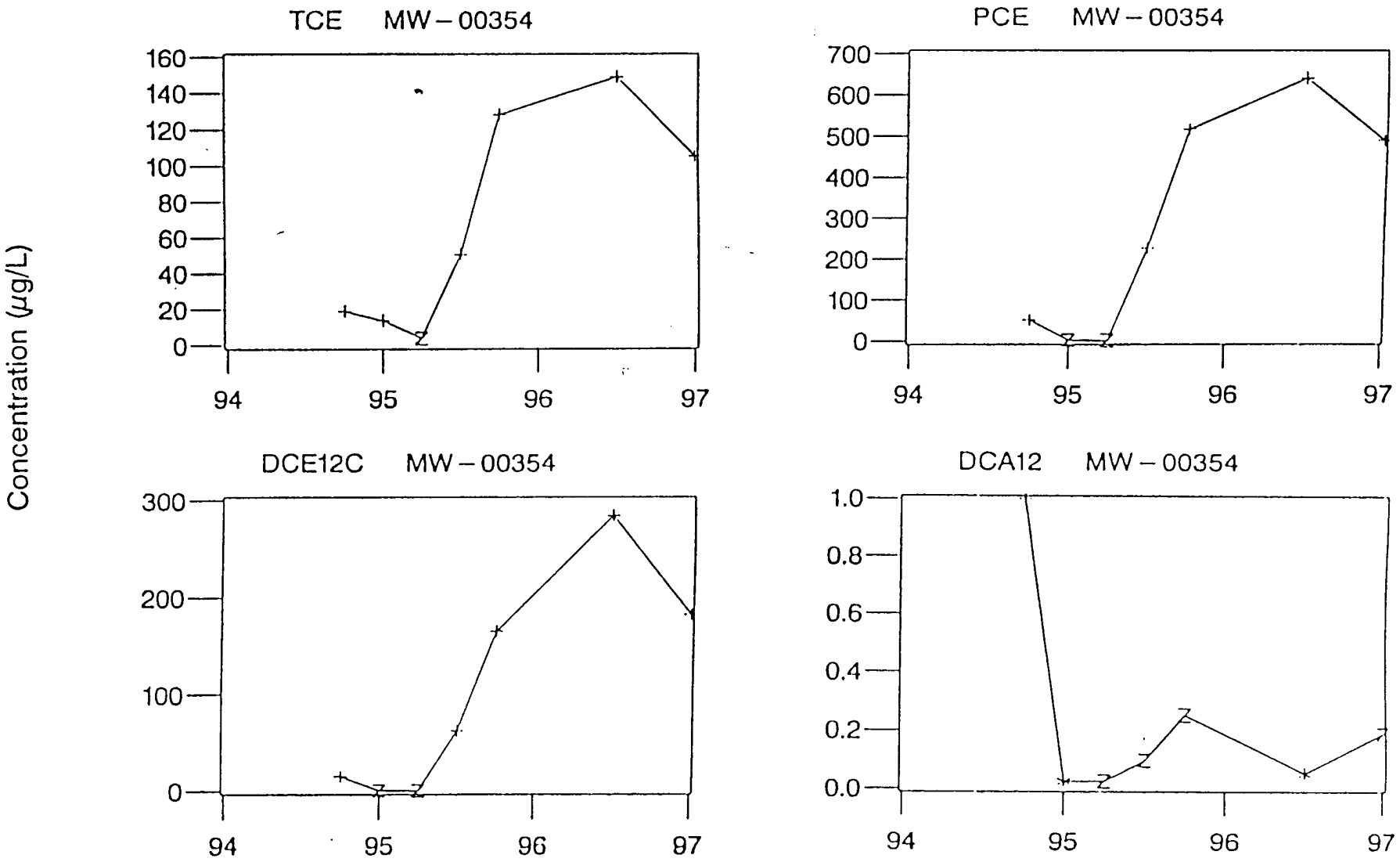
McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW353



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW354

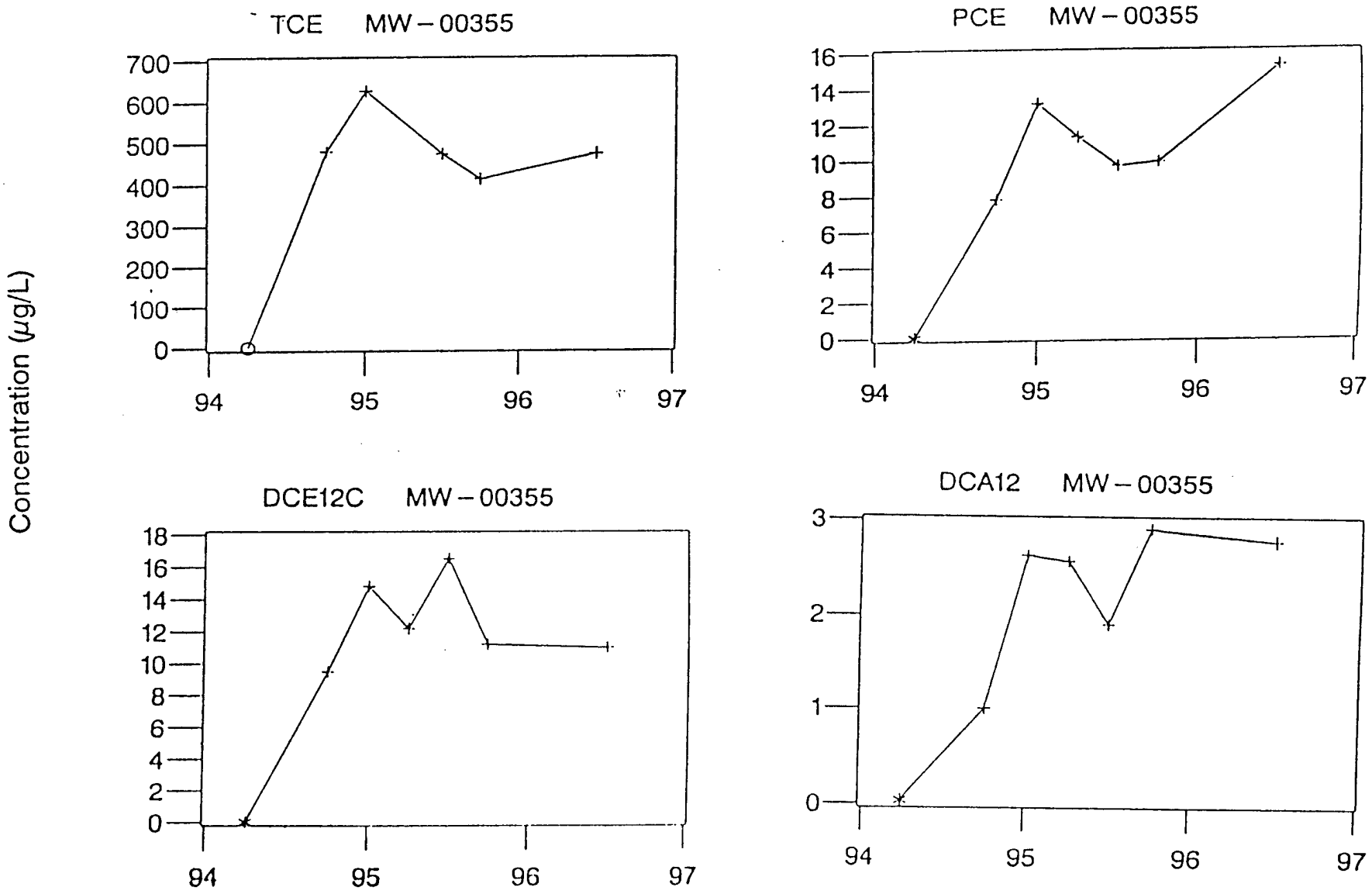


z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.

Source: Radian, 1997(f)

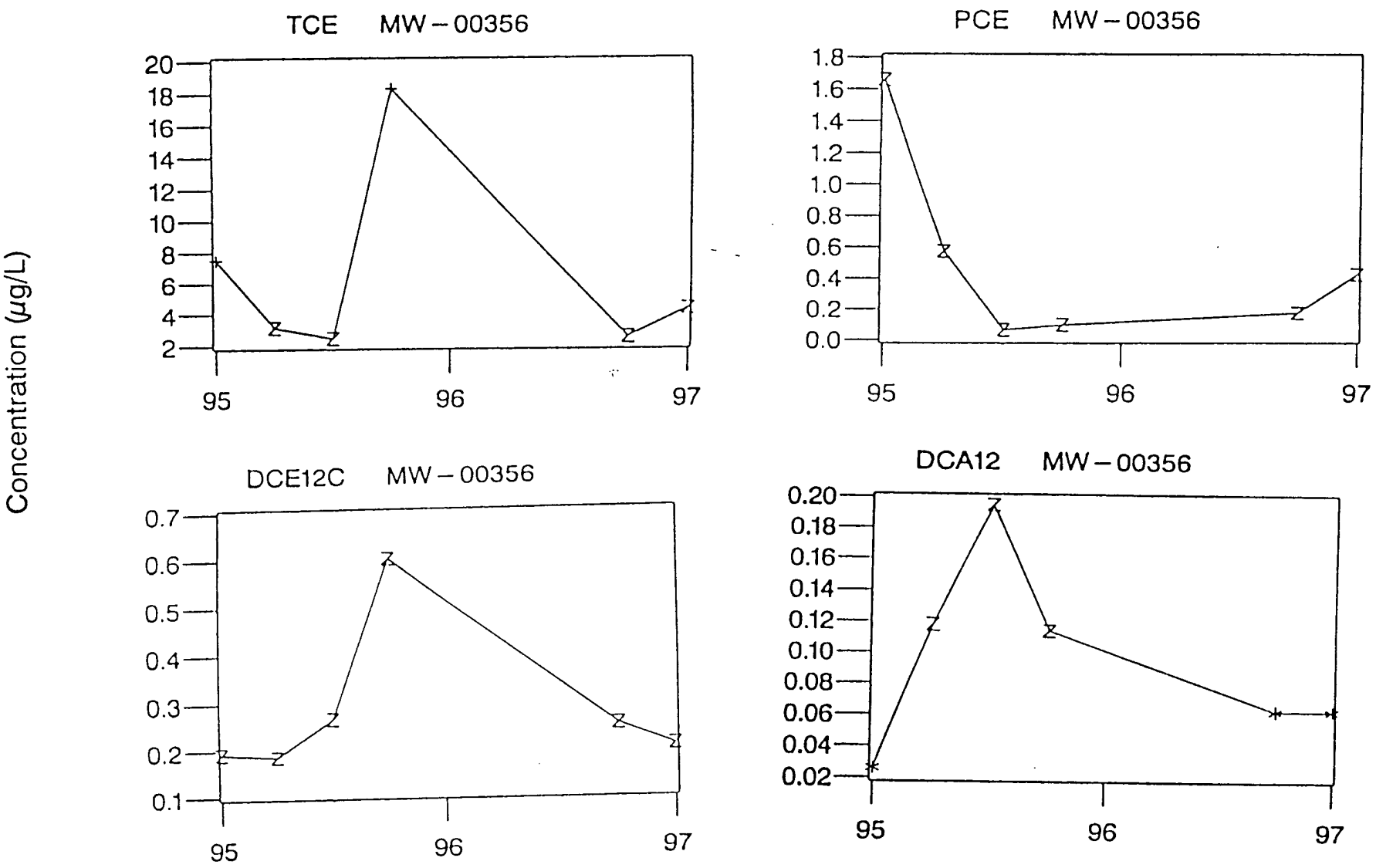
McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW355



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW356

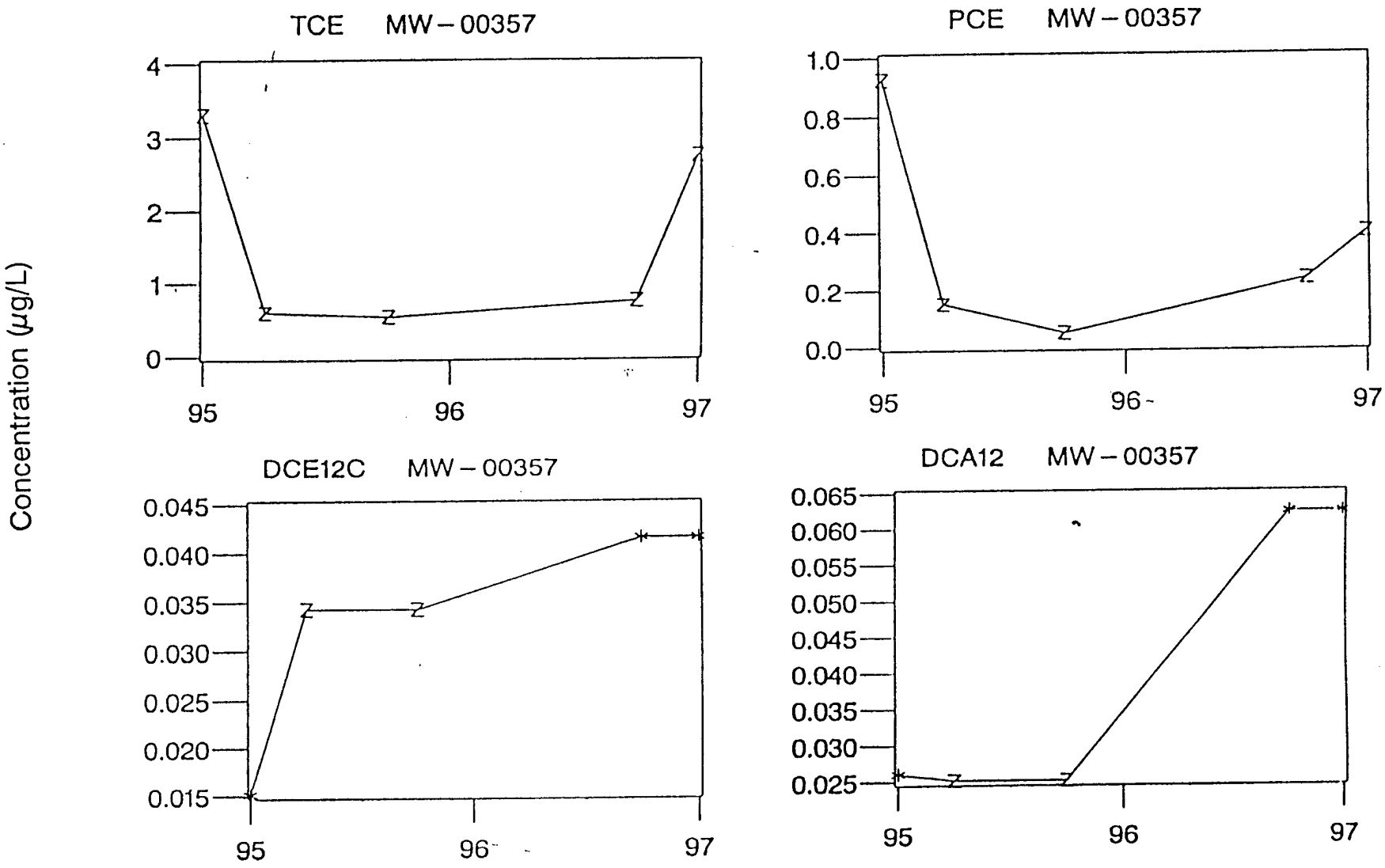


z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.

Source: Radian, 1997(f)

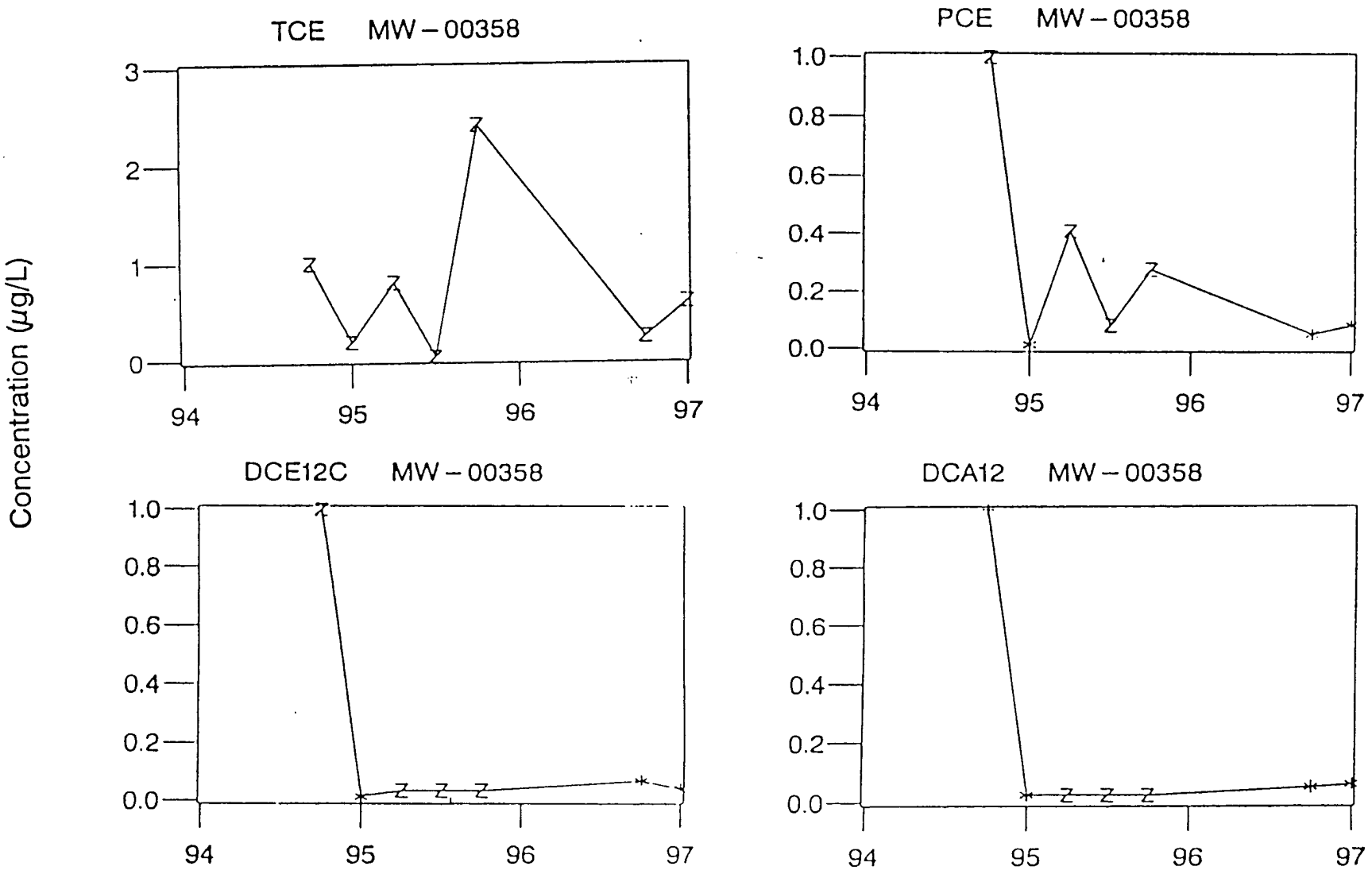
McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW357



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW358

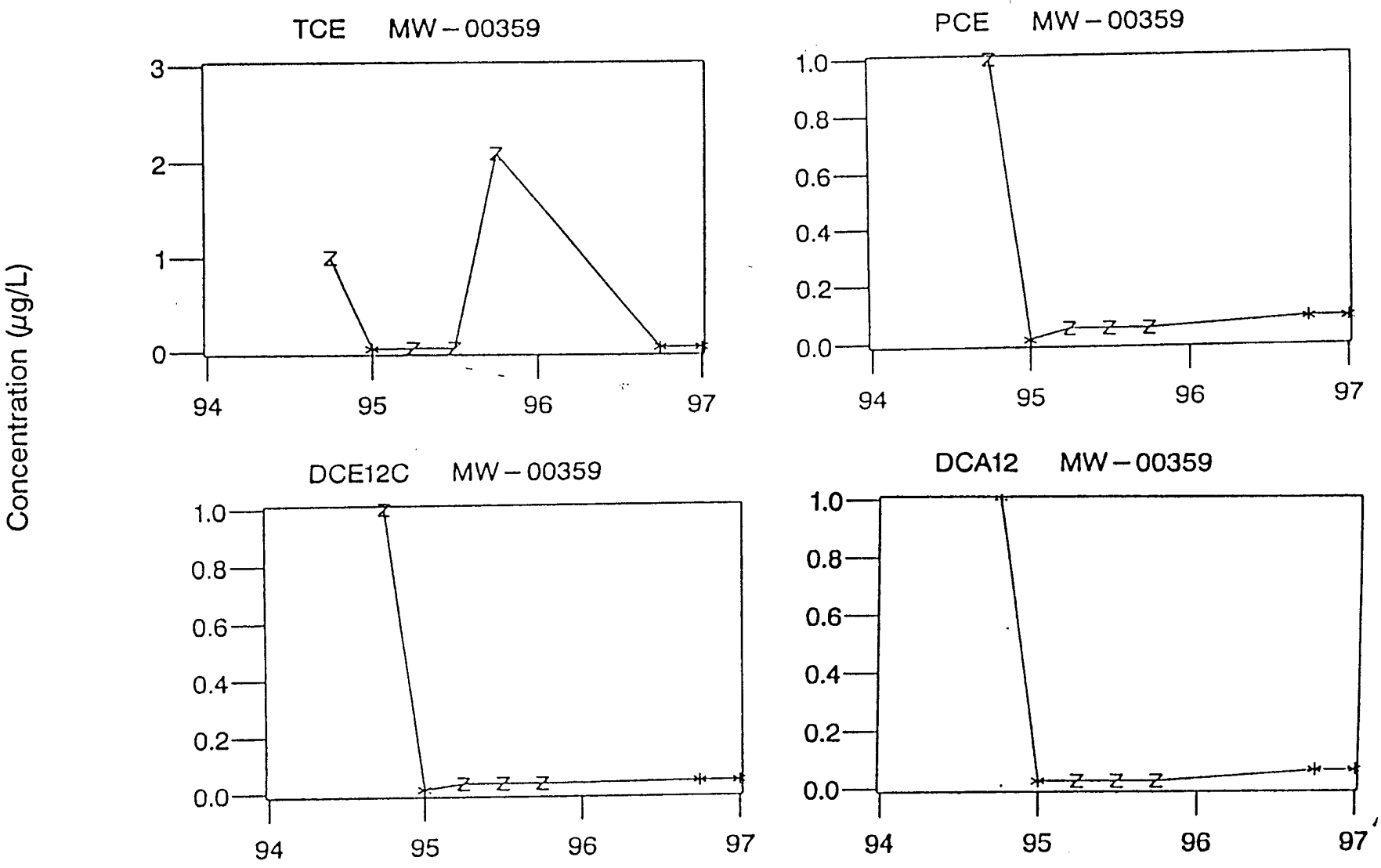


z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.

Source: Radian, 1997(f)

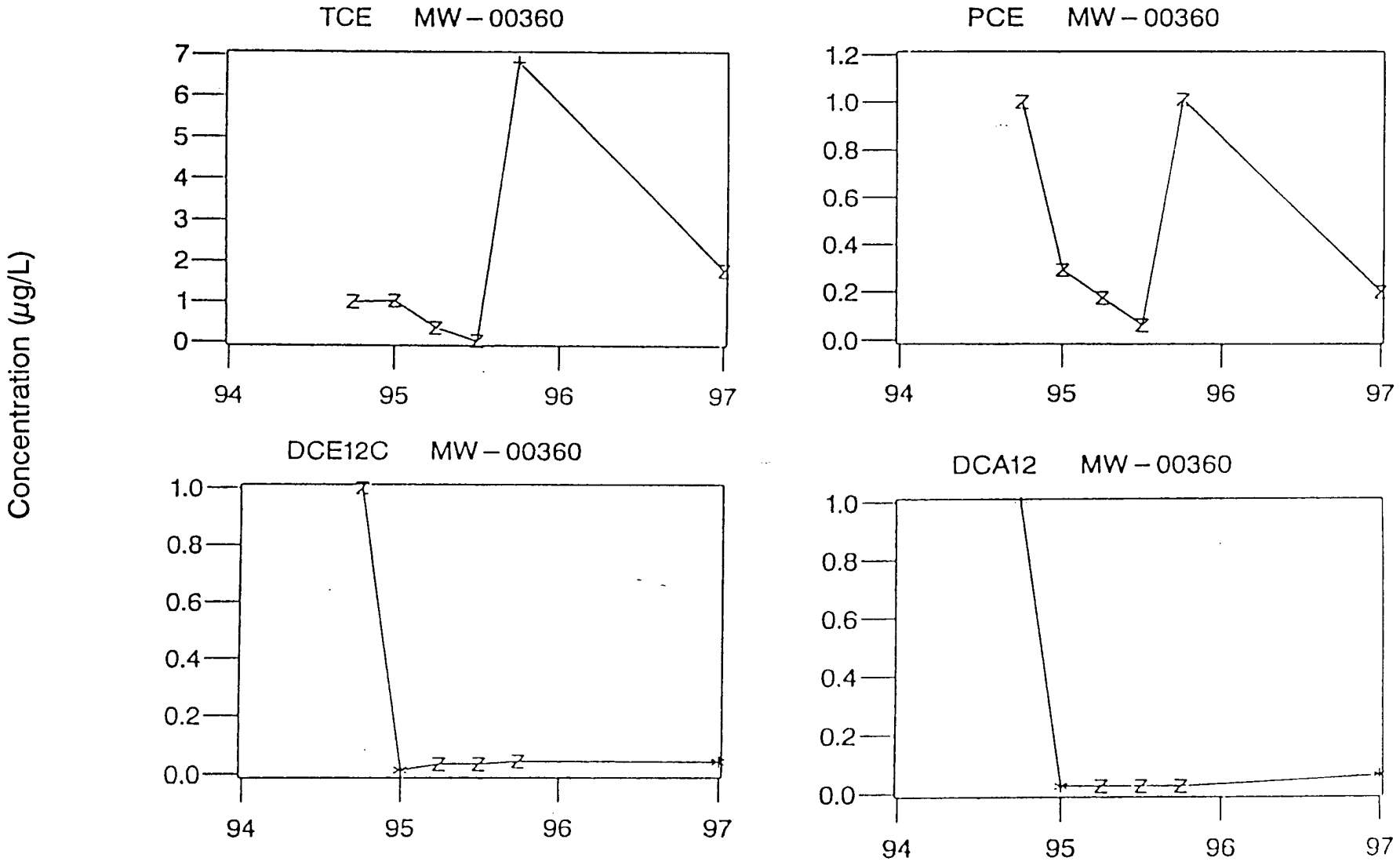
McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW359



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

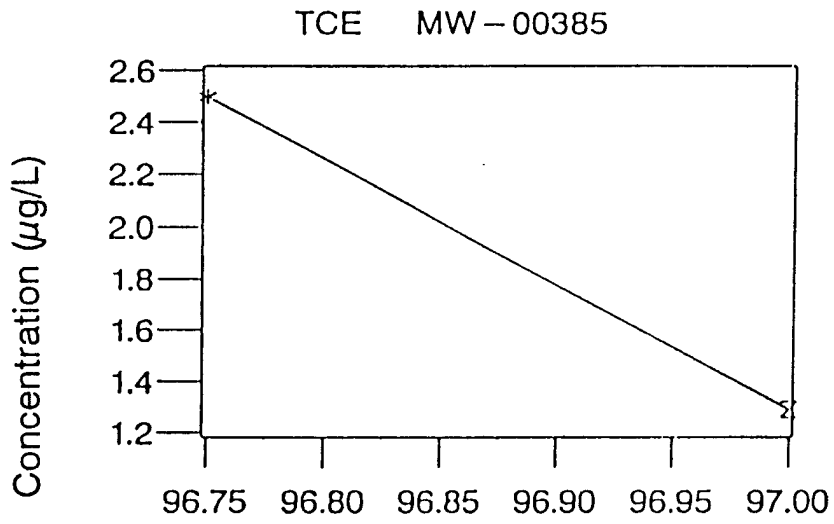
McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW360



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

McClellan AFB Groundwater Monitoring Program Through 1Q97
Time Series Plots
MW385



z - Detected below MCL + - Detected at or above MCL * - Not detected o - Outlier

Note: Time series plots are shown for each well and analyte that was detected in at least one sample collected since 1985; no plot is included if all results were not-detected.
Source: Radian, 1997(f)

APPENDIX C

SOPS AND EQUIPMENT CALIBRATION FOR FIELD AND LABORATORY METHODS

APPENDIX C

SOPS AND EQUIPMENT CALIBRATION FOR FIELD AND LABORATORY METHODS

Intertek Testing Services
Environmental Laboratories

Standard Operating Procedure for DISSOLVED GAS ANALYSIS USING A GC HEADSPACE EQUILIBRATION TECHNIQUE RSK-175 MODIFIED

1.0 DESCRIPTION

This method is applicable to the preparation of water samples for analysis of the headspace to quantify part-per-billion levels of dissolved gases in the water sample. This method is specifically for determining methane, ethane, ethene, propane, vinyl chloride, nitrogen, oxygen, carbon dioxide and hydrogen.

This method is restricted to use by or under the supervision of analysts experienced in sample preparation and in the use of gas chromatography and the interpretation of chromatograms.

2.0 THEORY AND PRINCIPLES

A water sample is collected in a serum bottle and capped using a Teflon faced septum and a crimp cap of the appropriate size to fit the bottle. An ordinary VOA vial and duplicate samples are recommended. A headspace is prepared using high purity argon. The bottle is heated to 95°C for 5 minutes and a sample is taken of the headspace and injected onto a gas chromatographic column where the gaseous components are separated and detected by flame ionization detector (FID), thermal conductivity detector (TCD) or mass spectrum detector (MSD). By using Henry's Law, the concentration of the gas in the headspace, the bottle volume and temperature of the sample, the concentration of dissolved gas in the original water sample can be determined.

3.0 INTERFERENCES

The purity of the argon will affect the headspace results. Leakage of the headspace will result in falsely elevates concentrations of oxygen and nitrogen.

4.0 QUALITY CONTROL

The QC of the method includes the following:

4.1 Initial Calibration

A three-point initial calibration is made during instrument setup, whenever system components are changed or when continuing calibration fails. The Relative Standard Deviation (RSD) of the Response Factors (RFs) of the initial calibrations should within 20% for FID, 25% for TCD and 30% for MSD.

4.2 Continuing Calibration

Intertek Testing Services NA Inc.
1088 East Collins Boulevard Richardson, TX 75081
Telephone (972) 238-5591 Fax (972) 238-5592

The continuing calibration is verified daily before any samples are run. The Percent Difference (PD) of RFs between continuing and initial calibration should be within 20% for FID, 25% for TCD and 30% for MSD. If continuing calibration fails, a new initial calibration must be made.

4.3 Method Blank

The method blank is analyzed daily immediately following initial or continuing calibration. All the target components should be less than detection limit.

4.4 Laboratory Control Spike (LCS)

The LCS is made by spiking a standard gas mixture into the degassed DI water to generate a spiked headspace. Degassing is best accomplished by bubbling argon through the water for 5-15 minutes. The recovery of the target compounds for FID should be within 80-120%, for TCD should be 75-125%, and for MSD should be 70-130%.

5.0 EQUIPMENT AND MATERIALS

5.1 GC/FID - Methane, Ethane, Ethene

Varian GC 3700 for GC/FID

Temperature Program:	Initial 30°C, Hold 1.0 min 35°C/min to 100°C Final Temperature 100°C, Hold 2.0 min.
Carry Gas:	Argon
Column:	6 ft X 1/8 OD Chemipack C18,80/100.

5.2 GC/TCD - Hydrogen, Methane, Carbon Dioxide, Oxygen, Nitrogen

Varian GC 3600 for GC/TCD

Temperature Program:	40°C Hold 8 min.
Carry Gas:	Argon
Column:	Alltech STR I 6ft/Inner with Porous polymer and 6 ft/Outer with molecular Sieve.

5.3 GC/MSD

GC/MSD for vinyl chloride and/or other compounds. The GC/MSD setup and working conditions are the same as used for TO-14.

6.0 REAGENTS

6.1 Gas cylinders of ultrahigh purity helium, nitrogen, and zero air.

6.2 Cryogens - ITS-Dallas utilizes liquid nitrogen for the cryogenic trap and other cryogenic points.

6.3 4-Bromofluorobenzene (BFB) - introduced as a gaseous standard through the sample transfer system for monitoring mass spectrometer tuning.

6.4 Perfluorotributylamine (PFTBA) - introduced through a batch inlet system; used for mass spectrometer tuning.

6.5 Methanol, ACS reagent grade

7.0 STANDARDS

Scott Mix 219 for GC/FID.
Scott Mix 237 for GC/TCD.
Scott Mix for EPA TO-14.
Scott Mix 701 for GC/TCD Hydrogen.

8.0 PRESERVATION AND HOLDING TIMES

8.1 Water samples should be maintained at 4°C during transportation and in a refrigerator set to maintain 4° ± 2°C while in the laboratory.

8.2 A sample should be analyzed within 20 days after sample collection.

9.0 PROCEDURES

9.1 Sample Collection and Preparation

9.1.1 Water samples should be collected in the field or prepared in the lab by placing the water in a glass bottle. Typically, a 40 mL VOA vial is used. Add the water down the side of the bottle so as not to agitate or contaminate the sample. Fill to the top and cap using a butyl rubber Teflon faced septum and the appropriate size aluminum crimp cap. Care should be taken so there are no bubbles in the bottle.

9.1.2 Field samples should be fixed with 1:1 HCl to a pH less than 2 before they are capped. Do not add acid if carbon dioxide analysis is to be performed since acid may convert inorganic carbon to carbon dioxide.

9.2 Sample Analysis

9.2.1 Remove samples from the refrigerator and allow them to come to room

temperature. To generate headspace in the sample bottle, place the bottle upside down in a three-finger clamp attached to a ring stand. Next, insert through the septum a 20 gauge needle.

9.2.2 Using a second syringe, inject 10 mL of high purity argon into the vial. The argon forces an equal volume of water out of the bottle. If a large volume of water is used, 10% of the water volume should be forced out of the bottle in order to generate 10% headspace volume. Pull both the injecting syringe and the needle from the septum.

9.2.3 Heat the sample bottle to 95° - 100°C for 5 minutes to allow the gases to equilibrate between the headspace and the liquid phase. A portion of the headspace is then immediately withdrawn for analysis.

9.2.4 Use a 1.0 mL gas tight syringe to take a 0.01 - 1.0 mL sample of the headspace. This is done by inserting the syringe needle into the septum so that the side port of the needle is in the headspace. Close the syringe and withdraw the needle from the septum. Inject the syringe's contents into a gas chromatograph for analysis.

9.2.5 After the analysis is successfully completed, remove the cap from the bottle. Excessive handling of the bottle should be avoided.

9.2.6 Along with the samples a method blank should also be analyzed. The method blank consists of degassed, deionized water prepared in the same type of bottle used for the samples.

10.0 CALCULATIONS

10.1 GC/FID/TCD

For GC/FID/TCD, external calibration is used for headspace concentration calculation:

$$RF_i = \frac{C_{i,std}}{A_{i,std}}$$

$$C_{i,sample} = RF_i \; X \; A_{i,sample} \; X \; DF$$

$RF_{i,std}$ = Response Factor of compound i on FID or TCD.

$C_{i,std}$ = Concentration of compound i in calibration standard.
$A_{i,std}$ = Peak Area of compound i in calibration.
$C_{i,sample}$ = Concentration of compound i of sample in headspace.
$A_{i,sample}$ = Peak Area of compound i of sample in headspace.
DF = Dilution Factor of Injection.

For concentration in water phase:

$$C_{i,sample,aq.} = \frac{C_{i,sample} \; X \; V_{headspace}}{V_{water}} + \frac{C_{i,sample} \; X \; 55.5 \; X \; MW_i}{H}$$

$C_{i,sample,aq}$ = Concentration of compound i in water phase.
$V_{headspace}$ = Volume of sample headspace.
V_{water} = Volume of sample water phase.
H = Henry's Constant.
MW_i = Molecular Weight of Compound i
55.5 = g mole / L of Water

11.0 REFERENCES

11.1 Kampbell, D.H., J.T. Wilson, S.A. Vandegrift, Dissolved Oxygen and Methane in Water by a GC Headspace Equilibration Technique, International Journal of Environmental Analytical Chemistry, Volume 36, pp 249-257, 1991.

11.2 SW-846, Method 3810, Headspace, Volume IB, Chapter 4, Section 4.4, Revision 0, September 1986.

11.3 RSKSOP-175, Revision 0, August, 1994.

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Modified Bligh & Dyer Lipid Extraction

A. Background

Phospholipid fatty acid analysis can be useful to the microbiological researcher by providing:

1. an estimate of viable microbial biomass
2. a description of microbial community structure
3. an indicator of microbial physiological status

This procedure uses the single-phase chloroform:methanol:Phosphate Buffer extraction system of Bligh and Dyer [1959] as modified by White *et al.* [1979] to quantitatively extract microbial lipids for further analysis. Samples may be bacterial cells, animal or plant tissue, soils, sediments, filters, or other material.

B. Safety

Reagents for this procedure include chloroform, methanol, phosphate buffer, and glutaraldehyde/ formaldehyde. Always review the MSDS literature located in the lipid laboratory for proper personal protective equipment before working with any hazardous chemical.

When handling radioactive samples, the following safety precautions are mandatory:

1. wearing laboratory coats
2. approved solvent resistant gloves
3. protective eyewear

Avoid skin contact and always wash hands thoroughly after working with radiolabeled samples.

C. Apparatus

1. Glass separatory funnels (250 ml standard) with teflon stopcocks and ground-glass apertures. If a separatory funnel is suspected to leak, a glass test tube is taped under the stopcock to prevent sample loss.

2. Round-bottom flasks (choose a size appropriate to the volume being reduced, usually 250 ml) with cork ring seats.

3. Glass funnels packed with muffled glass wool.

4. Pyrex test tubes (16ml) with teflon-lined screw caps.

5. Glass centrifuge bottles with teflon lined screw caps for extraction of sediment samples.

6. Filtering apparatus consisting of a glass side-arm flask, glass fritted filter, glass funnel, rubber stopper, and a metal clamp for use with water samples.

7. Rota-vap solvent evaporator with temperature-controlled water bath at 37°C.

8. Nitrogen gas blow-down with temperature controlled environment at 37°C for solvent removal from test tubes.

9. The only material to come in contact with solvents or sample are muffled glass and teflon. This includes all bottle caps (teflon-tape can be used to line tops if not available), repipet tubes, pipets, individual extraction containers, etc.

D. Reagents

1. Organic solvents include chloroform and methanol. Solvents should be of the purest grade possible (GC^2 or GC Grade). An aliquot of each new lot of chromatography solvents are concentrated by a factor of 1000 and analyzed by capillary gas chromatography to ensure it meets the manufacturer's specifications for organic residue (see SOP# SLVCK).

2. Nanopure filtered organic-free deionized water (NPW) is used to make all aqueous solutions. Prior to use, water is filtered through an anodisc (0.2μm) filter, then chloroform-extracted using approximately 200 ml chloroform per 4 L DIW.

3. Phosphate buffer - 50 mM, pH 7.4: preparation: 8.7 g K_2HPO_4 (dibasic) in 1 L Nanopure distilled water and adjusting to pH 7.4 with approximately 3.5 ml 6 N HCl, measured with litmus paper. Phosphate buffer should be stored over 50 ml of $CHCL_3$ per 1 liter of buffer and kept refrigerated (4°C).

E. Procedures

Extraction:

1. Lyophilized cells are weighed and added directly to a separatory funnel after solvents. Once all samples have been weighed and transferred to the separatory funnel, the first phase The first phase solvents are then added and they are extracted with the first phase solvents in the ratio of 2/1/0.8 (methanol: chloroform: buffer (v/v/v)). The ratio of 1.0 mg lyophilized cells to 1.0 ml of chloroform in the first phase mB/D extraction should be observed (i.e. 37 mg cells in 75 ml methanol, 37.5 ml chloroform, 30 ml phosphate buffer).

2. Aqueous samples containing sediment - are filtered through a 2.7μm glass fiber filter, being careful not to disturb the sediment that has settled to the bottom of the container. Sufficient water should be left in the container to thoroughly wash the sediment into a glass centrifuge bottle, where it is centrifuged at 2000 rpm for 15 minutes to ensure a good pellet. The supernatant and remaining water are filtered through a series of glass fiber filters of decreasing pore size (2.7μm, 0.7μm, 0.2μm). The filters are added to the centrifuge bottle containing the sediment pellet. The first phase solvents are then added in the ratio of (2/ 1/0.8) The bottle is shaken vigorously, vented, then sonicated for no more than 2 minutes. Once the extraction is complete, the bottles are centrifuged at 2000rpm for 15 minutes to separate the sediment and filters from the solvent, and the mB/D first phase decanted into a separatory funnel.

2. Aqueous samples containing little or no sediment are filtered through a series of glass fiber filters of decreasing pore size (2.7μm, 0.7μm, 0.2μm), and the filters added directly to the separatory funnel, where the first phase solvents are added at a ratio of (2/1/0.8).

3. Sediments should be lyophilized and thoroughly homogenized before extraction. Samples are weighed and transferred to glass centrifuge bottles where they are extracted. The ratio of 1.0 g lyophilized sediment to 1.0 ml chloroform in the first phase mB/D extraction should be observed (i.e. 37 g sediment in 75 ml methanol, 37.5 ml chloroform, and 30 ml buffer). If lyophilization is not possible, the amount of water in the sample should be estimated and subtracted from the amount of buffer required. Sediments are vigorously shaken and vented, then sonicated for no more than 2 minutes. Once the extraction is complete, the bottles are centrifuged for 15 minutes at 2000 rpm to separate sediment from solvent. The supernatant (mB/D first phase) is decanted into a separatory funnel.

Separation:

2.1 a. First phase extraction in a separatory funnel (4-18 hours), additional chloroform and NPW are added to separate the aqueous and organic phases. The volumes of water and chloroform are equal to volume in first phase [Guckert et al., 1985, Guckert and White, 1988]. This results in a final solvent ratio of 1/1/0.9 for chloroform:methanol:aqueous. The separatory funnel is shaken gently, cautiously vented through stop cock end, shaken vigorously, vented and allowed to separate overnight (approximately 18 hours) or until the aqueous (upper) phase is clear.

b. First phase extraction in a glass centrifuge bottle: Upon completion of first phase extraction (4-18 hours) decant into the separatory funnel, the remaining solid (sediment, filters, etc.) is re-extracted with volumes of chloroform. The centrifuge bottle is shaken, vented, and again centrifuged at 2000 rpm for 15 minutes precipitate a pellet. The solvent is then decanted into the appropriate separatory funnel containing the first phase extraction, and an equal amount of NPW (as chloroform) is added to give a final solvent ratio of 1/1/0.9 (methanol: chloroform: aqueous). The separatory funnel is shaken gently, cautiously vented, shaken vigorously, vented, and allowed to separate overnight (approximately 18 hours) or until the aqueous (upper) phase is clear.

2.2 If the aqueous phase of the extraction system is to be counted for radiolabel incorporation, 1 ml aliquot is taken to scintillation vial containing 5 ml of Ultima Gold XR scintillation fluid, and the cap is labelled (all operations involving scintillation cocktail are performed in the hood). Liquid scintillation counting is covered in SOP #LSC.

2.3 The organic phase is drained until the interface between water and solvent just meets the stopcock, making certain none of the aqueous phase contaminates the solvent. If the sample requires filtering, use a Whatman 2^V filter supported by a glass funnel and filter the lower (organic) phase into a glass round-bottom flask. If the colorimetric assay is to be performed, do not use the Whatman filters due to an increase in phosphate contamination. If sample needs to be filtered, use a muffled glass funnel stuffed with a small piece of glass wool supported by a glass round bottom flask and allow the organic phase to drain through. Wash the glass funnel containing the filter/glass wool with 3x 2 ml washes of chloroform to rinse any remaining organic material into the round bottom flask.

Solvent Reduction:

3.1 Solvent Reduction is achieved through rotary evaporator under vacuum via rotary evaporator. Care must be taken to ensure that the water bath does not exceed 37°C due to thermally labile unsaturated fatty acids. In addition, lipids should have minimal exposure to air, due to the reactivity of O_2 with the double bonds, further breaking down the unsaturation. Christie [1989] and Kates [1986] recommend using nitrogen gas to evacuate the rotary evaporator.

3.2 The dried total lipid in the round-bottom flask is transferred to a test tube with 2 x 2 ml washes of $CHCl_3$:MeOH (1:1) and a final wash of 2 mls of $CHCl_3$ (for dirty samples, additional washes may be necessary). Once transferred, the solvent is removed from the test tube under constant nitrogen flow using the blow-down with a water bath temperature of 37^0C.

3.3 If the total lipid extract is to be counted for radiolabel incorporation, the total lipid is resuspended in a known volume of chloroform, and a 10% aliquot of this total lipid is removed for liquid scintillation counting (see SOP #LSC-1).

3.4 The total lipid is stored in $CHCl_3$ at -20°C until lipid class separation.

F. Notes

1. Organic-free technique differs from sterile technique. Meticulous technique must be practiced to ensure contaminate-free analyses. No materials other than fired glass and solvent-rinsed teflon may come into contact with lipid solvents or samples. Skin lipids, hair, stopcock grease, oils, and hydrocarbons are all potential contaminants.

2. All glassware used for lipid analysis must be free of organic matter. Scrupulous cleaning of all glassware is necessary for contaminant-free analysis (this includes washing and firing in a muffle furnace at 450^0C for 4 hours - see SOP # GW2). Disposable glassware such as pipets and silicic acid columns need not be washed but fired. Care must be taken not to re-contaminate fired glassware. Items which will not tolerate muffle furnace temperatures are rinsed with methanol:chloroform (1:1 v/v) and allowed to air dry.

G. References

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Approved by:_____ Date:_____

Issue Date: 8/9/94 SOP #GCLIP-1

Gas Chromatographic Analysis of Lipids

A. Background

The purpose of this procedure is to separate, quantify, and identify lipid compounds by gas chromatography (GC). Preliminary identification of compounds will be based on comparison to retention times of standards. Mass spectrometry will be used for verification of compound structure in a collaborative arrangement with the Center for Environmental Biotechnology.

B. Safety

Reagents for this procedure include hexane, cholestane, and nonadecanoic acid. Safe handling of these materials will be followed as described in the MSDS literature located in the laboratory.

C. Sampling:

Samples will be either: fatty acid methyl esters (FAME, SOP #METH), poly-ß-hydroxyalkanoates (PHA, SOP #PHA), trimethyl-silyl (TMS)derivatives of 3ß-ol sterols (SOP #STER-1), TMS derivatives of lipopolysaccharide hydroxy fatty acids (LPS OH-FA, SOP #OHFAM), or DMDS derivatives of monounsaturated FAME (SOP #DMDS).

D. Apparatus

1. Hewlett-Packard gas chromatograph model 5890 series II with a 7673A auto injector. The instrument is controlled with an IBM-compatible PC using HP-IB Chemstation software for Windows and DOS.

2. Gasses: Carrier gas - the purest available hydrogen (99.999% pure or above), flame hydrogen - industrial grade, flame air - breathing grade, make-up nitrogen - UHP grade.
3. Nitrogen gas blow-down.
4. Volumetric pipets.
5. Injection syringes.

E. Reagents

1. Hexane of the purest grade possible, Burdick & Jackson GC^2 or equivalent. An aliquot of each new lot will be concentrated by a suitable factor (e.g. 1000) and analyzed by capillary GC for any organic contaminants.

2. 50 pmol/μL nonadecanoic acid methyl ester (C19:0, internal standard). 15.6 mg C19:0 (M.W. 312) per L hexane.

F. Procedures

1. Preparation

1.1 The GC is turned on by a switch on it's right side. The autosampler is turned on at its controller, a white box sitting next to the GC. The gases are turned on, at the following pressures: H_2 (flame) 20 psi, H_2 (carrier) 40 psi, N_2 40 psi, Air 30 psi. (**Caution:** If the GC is to remain on, do not turn off the carrier gas. Without the carrier gas, the column will deteriorate quickly.) Ignite the flame on the flame ionization detector (FID) by pressing the FID ignitor button located on the upper left corner of the GC.

1.2 Optional - if autoinjector is to be used. Slide the injector onto the post over the injection port. Make sure that the solvent levels in the wash vials in the injector are satisfactory. Turn on the computer which will be used for data acquisition.

1.3 The HP 3365 Series II Chemstation software is accessed through Windows. Clicking on the Chemstation icon brings up the Chemstation dialogue boxes. The method menu is brought up, and the method to be used, e.g. PLFA method, is loaded. (See Note 1 for temperature programs.)

2. Estimation of Sample Dilution Volume. The concentration injected should be maximized to allow accurate quantitation of minor peaks, and the concentration must be low enough that the linear range of the GC and it's FID detector is not exceeded. 3 methods are given, in decreasing order of accuracy.

2.1 Method #1, Estimation from Lipid Phosphate Data. If the total lipid phosphate or polar lipid phosphate has been determined for the sample, this data can be used to estimate the appropriate dilution volume. (It is assumed that the total lipid phosphate and polar lipid phosphate are equal.) Since

$$\text{moles LP} \times 2 \cong \text{moles PLFA},$$

the largest peak in a profile is often half or more of the total, and 5 times the C19:0IS is near the maximum properly integrated peak height, therefore

$$[\text{nmoles LP} \times (2\ \text{FA/LP} \times 5)]/(50\ \text{nmole/mL}) = \text{mL solvent, or}$$

$$\text{nmoles LP} \times 0.2 = \text{mL solvent.}$$

2.2 Method #2, Estimation from Known Samples. A sample of 50 mg wet weight of of bacterial cells, or 10 mg dry weight of cells, is diluted to XXX mL for injection.

2.3 Method #3, Estimation by Injecting a Range Finder. The dried sample is dissolved in 1 mL hexane. 1 µL is shot, . The solvent is removed with the nitrogen gas blow-down, and the dried lipid is redissolved in the correct amount of internal standard solution. 100 µL of the sample is transferred to a crimp-top vial with insert, crimped tightly, and stored at -20°C until ready to shoot on the GC.

3. Injection.

3.1 The samples to be shot on the HP 5890 GC are placed into narrow-mouthed crimp-top vials. The seal around the top must be tightened three times, rotating the vial one-third of a turn each time, so that the solvent doesn't evaporate out of the vial. These vials are placed into the autosampler rack sequentially. A vial containing the GC mix an 12-24 are placed in the first and second position for each sample set, with the other vials following.

3.2 To make a single shot, click on RunControl, click on Sample Info, and enter the operator name, file name, vial position, and sample name (Make sure that the vial to be shot is in the same position as the vial position that was entered.) Click on OK. Click on RunControl, select Start Run. If this does not work, re-set the instrument and this time start the run from the start button on the GC.

3.3 To run a sequence, click on Sequence. Load the default sequence. Click Sequence, and select Edit Sample Log Table. Enter in the Vial Number, Sample Name, Method Name, Inj/vial, and Sample Info for the first vial. Click ENTER. Then click INSERT for the next vial. Continue entering the sample information until they are all in the sequence table. Click OK. Click Sequence and select Edit Sequence Parameters. Enter in the Operator Name, Subdirectory to store the data in, Sequence Comment, then click OK. Click Sequence, and Save the sequence. Click on RunControl, and select Run Sequence. The data will be stored in the subdirectory that was entered in the Sequence Parameters Table.

Note: if a ready light does not appear then, edit the entire method and make sure that both detectors are selected.

4. Separation

The compounds to be analyzed will be separated for quantification using capillary gas chromatography with flame ionization detection. A 50 meter non-polar cross-linked methyl silicone column (e.g. HP-1) will be used with a suitable temperature program (see Note 1). Generally, 1 µL is injected.

5. Quantification

Quantification will be based on a comparison to an internal standard (FAME - C19:0, LPS OH-FA - C19:0, sterols - cholestane, PHA's - malic acid). Equi-molar responses are generally assumed within the range of microbial FAME (12:0-24:0) and sterols (22C-30C); however, tables of molecular weight correction factors are available (Christie, 1989).

Results obtained from the GC will be quantified areas under each sample peak, including the internal standard. For each peak, the following calculation is done to obtain molar or weight amounts per sample.

The calculations done for each compound are:

$$C_X = (A_X/A_{ISTD}) * C_{ISTD} * D,$$

where C_X is the calculated concentration of compound X (pmoles per sample), A_X is the peak area of compound X, A_{ISTD} is the peak area of the internal standard, and C_{ISTD} is the concentration of the internal injection standard (pmole/ µL, and D is the sample dilution (µL). Data may also be expressed as pmole/gdwt by dividing C_X by grams dry weight of sample, and as mole % by dividing by total pmoles of all compounds in sample then multiplying by 100. .

Assuming an average phospholipid content of 10^{-4} moles of PLFA per 5.9×10^{12} bacterial cells (based on *E. coli*), and 10^{-4} moles PLFA per 1.2×10^{10} algal cells (based on *Chlorella*), an estimate of bacterial and algal cells may be obtained by multiplying calculated picomolar concentrations of PLFAME by the appropriate factor (2.0×10^4 cells/pmol for bacteria, 1.2×10^2 cells/pmol for algae), yielding cells per gram.

6. Identification

6.1 FAME. The use of a linear temperature program for the separation of FAME permits the use of Equivalent Chain Length (ECL) analysis for FAME identification. This technique, detailed by Christie [1989], is based on the linear relationship between the retention times of a homologous series of straight-chain saturated FAME against the number of carbons in the FAME chain. ECLs are a constant property of a specific FAME as long as the temperature program is linear. This provides the ability to utilize published ECLs in a library of FAME to help identify specific FAME.

This identification is preliminary, however, and selected samples from a sample set should be further analyzed by (1) GC/MS as detailed in Guckert *et al.* [1985], and (2) DMDS derivatization of monounsaturated double bonds [Nichols *et al.* 1986].

Fatty acid nomenclature will be of the form **'A:BwC'** where **'A'** designates the total number of carbon atoms, **'B'** the number of double bonds, and **'C'** the distance of the first unsaturation from the aliphatic end of the molecule. The suffixes 'c' for *cis* and 't' for *trans* refer to geometric isomers of double bonds. The prefixes 'i' and 'a' refer to iso and anteiso methyl-branching respectively [Kates 1986]. The prefix "Cy" refers to a cyclopropyl moiety, "NMe" to a methyl branching N carbons from the carboxylate end of the molecule, "Br" to a methyl branching of unknown position, and "NOH-" to a hydroxyl group N carbons from the carboxylate end..

6.2 PHAs. Comparison of unknown peaks to a prepared standard (usually poly-ß-hydroxybutyrate) allows preliminary identification of PHAs. However, structural identification requires GC/MS analysis as detailed by Findlay and White, [1983].

6.3 Sterols. Due to variations in chromatographic variables, identification of sterols requires the calculation of relative retention times (RRT) based on cholesterol and sitosterol [Nes 1989]. The RRT for each peak is calculated by the following formula:

$$RRT_X = 1 + [0.63 * (RT_X - RT_C)] / (RT_S - RT_C),$$

where RRT_X is the relative retention time of the unknown peak, RT_X is the retention time of the unknown peak, RT_C is the retention time of cholesterol, and RT_S is the retention time of sitosterol. By comparing the calculated RRT_X of an unknown sterol to a library of RRT's for known sterols under the given chromatographic conditions, preliminary identification of individual compounds is possible. This identification is preliminary, however, and selected samples should be further analyzed by GC/MS as detailed in Nichols et al. [1983].

6.4 LPS OH-FA. A bacterial fatty acids standard mixture containing α- and ß-hydroxy fatty acids may be obtained from Matreya (cat# 1114) and preliminary identification of hydroxy fatty acids achieved by comparison to the standard mixture. Identification should be considered tentative, however, and GC/MS analyses performed according to Parker et al. [1982].

G. Notes

1. PLFA temperature program: 100°C for 0 min., 10°/min. to 150°C for 1 min., 3°/min. to 282°C for 5 minutes. Injector temperature = 270°C, detector temperature = 290°C. Total run time = 55 minutes.

Sterol temperature program: 200°C for 0 min., 10°/min. to 280°C for 0 min., 2°/min. to 310°C for 5 minutes. Injector temperature = 290°C, detector temperature = 290°C. Total run time = 28 minutes.

PHA temperature program: 45°C for 10 min., 10°/min. to 285°C for 5 minutes. Injector temperature = 270°C, detector temperature = 290°C. Total run time = 39 minutes.

LPS OH-FA temperature program: same as FAME temperature program.

2. Rangefinders are shot to insure the internal standard is within a factor of the sample peaks. Generally, for 37 mg lyophilized bacterial isolate or 37 g dry sediment, a rangefinder is shot at 1:1000 µl hexane (no internal standard). Adjustments are made and the sample diluted in internal standard only when the proper dilution is determined.

H. References

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SOP #SAC-3

Silicic Acid Column Chromatography

A. Background

Silicic acid chromatography is the method utilized to separate total lipid extracts into three general lipid classes based on the increasing polarity of both solvent and class: neutral lipids (NL), chloroform < glycolipids (GL), acetone < polar lipids(PL), methanol. The following flow chart illustrates analytes which are detected in the specific fractions.

B. Safety

Reagents for this procedure include chloroform, acetone, methanol, hexane, silicic acid (powder), and glutaraldehyde. Safe handling of these materials is described in the MSDS literature located in the lipid laboratory.

If samples are determined to be radioactive, safe handling procedures will be followed as described in SOP #B&D-1.

C. Sampling

Samples will be the total lipid extract obtained from the lipid extraction (SOP #B&D-1). These will have been stored in a test tube at -20^{0}C until use. The test tubes must warm slowly to room temperature before the caps are opened.

D. Apparatus

1. Glassware includes: test tubes with teflon-lined screw caps and pasteur pipets. All glassware is fired in the muffle furnace.

2. Chromatography columns are constructed from large volume dispo-pipets (e.g. Fisher #13-678-8) packed with glass wool and muffled.

3. Suitable racks to hold the assembled columns.

4. Nitrogen gas blow-down for solvent removal from test tubes with water bath temperature controlled at 37^{o}C. .

E. Reagents

1. Organic solvents include chloroform, methanol, acetone, and hexane.

2. Silicic acid, 100-200 mesh powder. Unisil (Clarkson Chemical Co., Williamsport, PA) or equivalent. Silicic acid is activated at 100°C for a minimum of 1 hour in a fired test tube or flask with aluminum foil over the top (See Note #1).

F. Procedures

1. Before setting up the silicic acid columns, the test tubes to recieve the lipid fractions should be labeled, to avoid delay during lipid elution. For example: "NL", "GL", and "PL" for neutral lipid, glycolipid, and polar lipid, respectively, and the sample name.

2. A suitable column can be constructed from a dispo-pipet. Wet the glass wool in the bottom of the dispo-pipet with chloroform. Slurry 0.5 g silicic acid in 6-8 mL chloroform in a test tube. The silicic acid/chloroform slurry should be agitated to release trapped air bubbles (visually apparent). Transfer the slurry to the dispo-pipet using a Pasteur pipet. 1-2 mL additional chloroform is added to the column and allowed to flow through the silicic acid while tapping the column with a pipet in order to pack the silicic acid. There should be no sign of air pockets within the bed of the column. If there are, additional chloroform may be added and the bed agitated with a Pasteur pipet until the air bubbles rise to the surface. You should not allow the packing to dry or disturb the surface of the bed once the procedure has begun (see Note 2).

3. If saving the NL fraction, place the test tube under the column before loading the total lipid. The total lipid is dissolved in a minimum volume of chloroform (≤100 µL), vortexed, and loaded onto the top of the silicic acid bed with a Pasteur pipet. This is repeated twice more, rinsing the inside of the test tube to ensure a quantitative transfer. If the NL fraction is not being saved, a waste collection vessel may be placed under the column to catch the chloroform while loading the sample. Keep the waste jar underneath the column until the desired fraction is to be collected, then replace it with the appropriate test tube.

4. Once the column is loaded, a series of three solvents of increasing polarity are used to separate the lipid classes. The ratio between grams of silicic acid to mL's of eluting solvent must be kept constant at 1:10. For example: if using a column with a 0.5 g slurry, elute the NL 5 mL chloroform, GL with 5 mL acetone, and PL with 5 mL methanol [Guckert *et al.*, 1985]. Lipid classes are collected in separate test tubes set up below the column.

5. If the lipid classes are to be counted for radiolabel incorporation, then they are re-suspended in a known volume (e.g. 1 mL) of the respective elution solvent. 40% of the

neutral lipid, 40% of the glycolipid, and 20% of the polar lipid are transferred to separate scintillation vials. 5 mL of Ultima Gold XR will be added to each vial, and the vials will be capped and labeled (label the caps). All corresponding disposable glassware (pipettes and columns) should be collected in a bucket marked "radioactive" , decontaminated, and disposed of properly (see SOP # DECON-1).

G. Notes

1. Silicic acid is slightly acidic precipitated silica. Silanols (active sites on the silicic acid granules) contain -OH groups directly bound to the silicon atom. The silanols interact with the polar groups of the lipid classes, while the non-polar end of the lipid molecule contributes little to separation. As the polarity of the solvents increase, the lipid classes are selectively eluted from the silanols, thereby effecting separation. Silicic acid is easily hydrated and must be dehydrated at 100^0C for at least one hour prior to use.

2. Do not overload the silicic acid columns. By saturating the active sites with lipid, quantitative recovery of lipid fractions is diminished and a lower biomass estimate will result. It may be necessary to increase the amount of silicic acid if the samples are of exceptionally high biomass or highly pigmented. The maximum load for silicic acid chromotography is approximately 20 mg of total lipid per 1.0 g of silicic acid. If the mass of silicic acid is increased, volumes of eluting solvents must also increase accordingly to retain a 1:10 ratio (g silicic acid : mL eluting solvent).

H. References

Guckert, J.B., C.P. Antworth, P.D. Nichols, and D.C. White. 1985. Phospholipid, ester-linked fatty acid profiles as reproducible assays for changes in prokaryotic community structure of estuarine sediments. *FEMS Microbiol. Ecol.* **31**:147-158.

Approved by:_____ Date:_____

Preparation of fatty acid methyl esters from esterified lipids

A. Background

This procedure outlines the preparation of FAME from the esterified lipids located in either total lipid extracts or the individual lipid classes. Mild alkaline methanolysis is utilized to cleave the fatty acids from the phospholipid glycerol backbone and replace the glycerol bonds with methyl groups, creating fatty acid methyl esters (FAME).

B. Safety

Reagents for this procedure include chloroform, hexane, methanol, toluene, NPW, acids and bases. Safe handling of these materials will be followed as described in the MSDS literature located in the lipid laboratory.

C. Sampling

Samples will be either the total lipid extract or the individual lipid classes obtained from the total lipid extract. Most commonly, the polar lipid fraction will be used.

D. Apparatus

37°C heating block for incubation, table-top centrifuge, vortex mixer, nitrogen gas blow-down, litmus paper.

E. Reagents

1. Methanolic potassium hydroxide: 0.2M KOH in methanol is made fresh before each use. To make 0.2M KOH in methanol, weigh accurately the amount of KOH to be used. Rule: 1 tablet is 0.1g therefore 1 tablet results in approximately 1mL of MEOH. Multiply g of KOH by 89.2857, which results in mLs of MeOH (1mL of 0.2M KOH is required per sample). Sonicate the KOH in methanol for approximately 2 minutes, or until the KOH is completely dissolved in solution. The grams of KOH and the molarity must be recorded in the lab notebook. Molarity must be within $\pm$ 0.05M. Guard against aqueous contamination (see note 1).

2. 1N Acetic acid in nanopure water. Preparation: 5.72mL Acetic Acid (17.5N) in 100ml nonopure water. Add **acid to water** slowly down the side of vessel constantly swirling.

3. Toluene:Methanol (1:1, v/v)

4. Hexane:Chloroform (4:1, v/v)

5. Nanopure distilled water. Reagents, item 2.

F. Procedures

1 Preparation:

1.1 The dried lipid is redissolved in 1 mL Toluene:MeOH (1:1) and 1 Ml methanolic KOH.

1.2 The mixture is vortexed briefly and incubated for at least 30 minutes at 37°C.

2. Methanolysis:

2.1 Cool the samples to room temperature.

2.2 Add 2mL of hexane:chloroform (4:1 v/v)

2.3 Neutralize (pH 6-7) with approximately 200 µL 1N acetic acid and measure pH with litmus paper (see note 2).

2.4 Add 2mL NPW

2.5 The mixture is vortexed for at least 30 seconds, and the phases (upper is the organic containing the FAME; lower is the aqueous) are separated by centrifugation (5 minutes, approximately 2000 rpm).

2.6 The upper phase is transferred to a clean test tube labeled FAME (see note3). The lower phase is re-extracted with 2 mL hexane:$CHCL_3$ (4:1 v/v), centrifuged, and transferred as above, twice more.

2.7 The solvent is removed with the nitrogen gas blow-down. If storing, DO NOT remove solvent and store at approx. -20°C until quantification.

G. Notes

1. Any water in the reaction will act as a reagent by attacking double bonds in the long-chain fatty acids. Water will also compete with the methanol for the fatty acid, yielding free fatty acids rather than methyl esters. Potassium hydroxide is very hygroscopic and will absorb water out of the air, therefore is stored in a sealed container and a quick transfer from the balance to the methanol is required.

2. Neutralization is required: (1) methanolysis is incomplete at a higher pH, and (2) FAMEs have a higher affinity for water at a higher pH. Usually, 200µL 1N acetic acid is sufficient to neutralize the KOH. The blank from the set is pH analyzed by drawing a small amount of the lower phase into a pasteur pipet and spotting the sample onto litmus paper. The litmus paper should indicate pH=7.

3. For this operation, it is best to hold both test tubes in one hand while pipetting with the other hand. Care must be taken to avoid transferring any water with the organic phase. It is not necessary to retrieve all of the organic phase each time, since the aqueous phase is rinsed three times.

H. References

Guckert, J.B., C.P. Antworth, P.D. Nichols, and D.C. White. 1985. Phospholipid,ester-linked fatty acid profiles as reproducible assays for changes in prokaryotic community structure of estuarine sediments. FEMS Microbiol. Ecol. **31**:147-158.

Approved by: _____ Date:_____

Sampling protocol for collecting water or soil samples for the Lipid and DNA analysis performed by Microbial Insights, Inc.

Water for PLFA Analysis:

At least 1 liter of water should be collected in a clean glass or semi transparent or transparent plastic jug. The amount of sample depends on the transparency of the water. For crystal clear water we will require 2 liters of water, but for water with visible pigment or turbidity we will only need 1 liter. For each liter collected place 10mls of formaldehyde as a preservative directly in the water sample**. Close the container tightly and shake the sample to disburse the formaldehyde. The sample container should be clearly labeled with the sample identification and tightly sealed to prevent leakage. The samples should be shipped on ice (4°C) overnight directly to the address below.

Water for DNA, Methanotrophs and Heterotrophs Analysis:

Same as for the PLFA analysis except for no preservative (formaldehyde) should be added to the sample. A separate sample is required for the DNA analysis.

Soil for PLFA and DNA Analysis:

30-75 grams of soil is required as a sample for the lipid and DNA analysis. Place the soil in a clean jar, plastic container, or whirl-pack bag. Immediately place the samples on ice (4°C) and ship overnight to the address below. These samples are not preserved.

** If Microbial Insights provided the bottles the formaldehyde is already added.

Ship to:

Microbial Insights, Inc.
2340 Stock Creek Blvd.
Rockford, TN 37853-3044
phone: (423) 573-8188
fax: (423) 573-8133

Sample Reception Procedure

A. Background

Sample reception is the first stage of the data generation process. A consistent sample handling procedure should be followed and all relevant actions taken should be recorded in the appropriate client notebook.

B. Safety

There are no reagents or other hazardous materials used in these procedures.

C. Sampling

All sampling is done by the client and shipped directly to MI. Matrices include: soil, water, filters, plant material, non-organic surfaces, or samples in any stage of the extraction procedure. It is necessary (dependent on desired analysis) to refrigerate, freeze, lyophilize or preserve (1% formaldehyde) samples in order to prevent any change in the physiological status of the microbial community.

D. Procedures

Initial Reception:

1. The samples usually arrive in coolers by overnight delivery. Sign for the package and place it in the sample receiving area. Examine the container closely for damage and note in the log book all relevant observations. Note any discrepancies with the chain of custody and the actual samples.

2. A client/sample notebook containing copies of all documentation is required. This notebook must be labeled with the proper MI set name and number. The original chain of custody and accompanying sample information is given to the project manager for review.

3. Some samples may arrive at room temperature. Be sure to note "Room Temp" in the sample notebook. For frozen or chilled samples, measure the temperature by placing a thermometer in the center of the samples and closing the lid to ensure accuracy. After 5 minutes record the temperature in the notebook.

4. Review chain-of-custody for requested analysis. If the modified bligh dyer extraction process is unable to be performed within the first 24 hours, follow the rules below for proper sample storage.

Desired analysis:

A. PLFA, PHA, DMA, DG, and Lipid Biomass

1. soil - freeze at -4°C or below
2. water - preserve with 1% formaldehyde and refrigerate at 4-6°C

B. TCH

Note: Must begin analysis within 3-4 days of reception and have a minimum of 5.0 grams. of soil or 5.0 mls of water. If other analysis are requested transfer necessary amount to a clean test tube, label and store remaining original sample as needed for specified analysis.

1. soil - refrigerate at 4-6°C **(Do Not Freeze)**
2. water - refrigerate at 4-6°C **(Do Not Add Preservative)**

C. DNA

Note: Must have a minimum of 5.0 grams. of soil or 50 mls of water.

1. soil - freeze at -4°C
2. water - refrigerate at 4-6°C (Do Not Add Preservative)

Documentation:

1. Sign and date the chain of custody and fill-out any other relevant information requested. Place one copy in the client communication notebook, and other copy in the project notebook. The project manager will mail the original chain of custody back to the client. For clients without a chain of custody form, note all sample reception information on the shipping paper and notify the project manager.

2. Have the project manager review requested analyses and sign the client notebook to ensure all necessary analyses will be performed.

Approved by:_____ Date_____

Laboratory Quality Assurance Management Plan

The Microbial Insights quality assurance management plan is based on the good laboratory practices (GLP) detailed in the Toxic Substances control act CFR 40 part 792. GLP's for each study or sample set analyzed by Microbial Insights, Inc. will contain the following. a designated study director, a quality assurance unit, and assure that the resources and personnel necessary to perform the requested analyzes are available. The duties of the study director and quality assurance unit are the same as those outlined in the CFR 40 part 792.

Equipment calibration:

Each piece of equipment that is used in the sample analysis process shall be calibrated according to the equipment calibration SOP # EQ-1. From the calibration it will be determined if each piece of equipment is operating within acceptable parameters.

Sample processing:

Each analysis shall be performed under the strict guidelines detailed by the appropriate SOP. Any deviation from the SOP must be noted in the Laboratory notebook and approved by the study director.

Solvents and reagents:

A separate laboratory notebook for each sample set will contain documented lot numbers for all solvents, reagents, and gases, used in the sample analysis process.

Data:

All raw data from the analysis shall be kept in the sample set folder. Ten percent of the analysis must be checked against the raw data to assure the calculations are accurate. Data folders that contain the laboratory notebooks and raw data shall be archived and easily assessable.

Limits of Detection:

The analytical limit of the Gas Chromatograph is between one and five picomoles of the fatty acid C19:0. However, the method limit of detection is determined by the amount of fatty acids detected in the laboratory blank. The amount of fatty acids picked up during the processing of the samples ranges from undetectable to thirty picomoles of Fatty acids.

Sample Set Spikes:

Each sample set has a Phospholipid recovery standard process with it to be used as a calibration for the percent of the phospholipid fatty acids recovered. In addition, each sample has an internal standard spiked for quantifing the microbial phospholipid fatty acids.

Gas Chromatograph Calibration:

Each sample set has a standard set of normal saturated fatty acids processed during their analysis. These standards are used to calibrate the linearity of the retention times and the carbon chain length. The response factor is also checked for each sample set using a known amount of the C19 fatty acid standard. Sample sets are processed daily so the instrument is continuously being calibrated and checked for adequate response.

Glassware Cleaning Procedures

A. Background

In order to provide accurate and reproducible results from our analyses, clean, lipid-free glassware is a must. The overall integrity of our results is dependent upon the cleanliness of our technique. All glassware used for lipid analysis must be ion- and organic-free.

B. Safety

MICRO* liquid lab cleaner (a phosphate-free detergent) is the only general laboratory cleaner used. The effects of chronic exposure to MICRO* have not been determined cause drying of the skin. Waterproof gloves are recommended because MICRO* can cause drying of the skin

Samples may contain radioactive ^{3}H and ^{14}C. Special care must be taken not to touch any glassware or solvents that have been in contact with radiolabeled samples until they have been decontaminated and cleaned well with Count-Off™, which is used in place of MICRO*. When washing this glassware, wear disposable gloves and follow the directions on the Count-Off™ A scintillation count must be taken of each tub containing radioactive glassware prior to disposal (see SOP# LSC-3).

Any material unable to be decontaminated must be treated as radioactive waste and discarded in the appropriate waste container. Review "Waste Disposal" in the Chemical Hygiene Plan for requirements and limitations.

C. Apparatus

Wash tubs, waterproof gloves, sinks, deionized water, drying oven, muffle furnace and aluminum foil.

D. Reagents

MICRO* liquid laboratory cleaner or Count-Off™

E. Procedures

Washing:

1. For general glassware, a generous amount of MICRO* is squirted into a washtub (follow directions on bottle for appropriate detergent to water dilutions). The washtub is then filled with the hottest tap water possible. The glassware is placed in the soapy water, being careful not to overload the tub because breakage may occur. This should occur within an hour after the glassware has been used. The glassware is tediously scrubbed with a brush, making sure all openings are free of sample contamination. It is then rinsed at least five times in both cold tap water and in de-ionized water. The glassware is placed in the 100°C drying oven and allowed to dry completely.

2. Radioactive glassware will be cleaned in a separate tub labeled "radioactive". The Count-Off™ detergent is used instead of MICRO* (follow directions on the bottle for the appropriate detergent to water dilution). This glassware must soak for a minimum of **24 hours** before being washed following same procedure as for non-radioactive glassware.

Muffle Furnace:

1. Clean, dry glassware is wrapped in aluminum foil and heated in the muffle furnace for a minimum of four hours at 450°C. Only openings, stems and parts of glassware that are exposed to air need to be completely covered with foil. Test tubes need not be wrapped individually, but in bundles making sure no part of the bundle is exposed to air. Disposable glassware such as pipets and silicic acid columns need not be washed, only wrapped in foil and muffled. Care must be taken not to re-contaminate fired glassware. Items which will not tolerate heating to 450°C are solvent-rinsed with a methanol : chloroform (1:1) mixture and allowed to dry.

Issue Date 7/15/97

SOP #GW-3

Approved by: _____ Date: _____

Equipment Maintenance Procedures

A. Background

To insure consistent and reliable results from the equipment used, it is necessary to detail the specific maintenance requirements for each piece of equipment.

B. Safety

There are no reagents or other hazardous materials used in these procedures.

C. Sampling: None

D. Apparatus

Sartorius 110 gram balance, CAS #67
Troemner 100 g calibration weight sets, serial numbers 18295 and 18292
Sartorius table-top balance, CAS #51
table top centrifuges, CAS #1, CAS #6, and CAS #75
thermometers, MITh1- 3
muffle furnace, CAS #7
freezer, CAS #27
Fluke model 51 standard digital thermometer
Monarch pocket Tach 10 standard tachometer

The manuals and opearating procedures for the pocket tachometer and Fluke thermometer are kept in the same drawer as the respective instruments.

E. Reagents: None

F. Procedures - The following procedures are executed at the beginning of each month. After each procedure the results are recorded in the equipment calibration log note book.

1. 110 Gram Balance CAS #67, calibration.

1.1 Uncover the balance and ensure it is level by looking at the centering bubble at the back of the balance. If it is level, proceed to section 1.2. If it is not level, adjust the dials on the front of the balance until the bubble is aligned.

1.2 Turn the balance on. Place the glove enclosed in weight case #18295 on your right hand. Touch only the weight with the glove. If something

besides the weight touches the glove, the glove must be visually inspected for damage or attached particles.

1.3 Open the balance door with your left hand and gently pick up the weight with the gloved hand. Slowly place the weight on the center of the weighing surface and record the weight. Remove the weight. Press the "calibrate" button on the balance, place the weight on the center of the weighing surface, and wait for the audible signal. Remove the weight, tare the balance, and then re-weigh the weight.

1.4 Every three months, repeat this calibration procedure with the calibration weight in case #18292.

2. Table-Top Balance CAS #51, calibration.

2.1 This balance will be calibrated each day of use. If it is not level then adjust the dials on the front of the balance until the bubble is aligned. Turn the balance on. Place the glove enclosed in weight case #18295 on your right hand. Touch only the weight with the glove. If something but the weight touched the glove then the glove needs to be visually inspected for damage or attached particles.

2.2 Slowly place the weight on the center of the weighing surface and record the weight. Remove the weight. Press the "calibrate" button on the balance, place the weight on the center of the weighing surface, and wait for the audible signal. Remove the weight, tare the balance, and then weigh the weight.

2.3 Every three months, this calibration procedure is repeated with the calibration weight in case #18292.

3. Thermometers MITh1 to MITh3, calibration.

3.1 Fluke model 51 standard thermometer has a variation of 1.1°C. It will be used to calibrate MITh1-3. Every 12 months the standard is calibrated against the third party's standard.

3.2 Fill 2/3's of the thermometer calibrating thermos with cold water. Place thermometers MITh1, MITh 2, MITh 3, and the end of the Fluke standard probe in the water bath. Let them sit for 3 minutes.

4. Muffle Furnace, Cas #7

4.1 Heat muffle furnace CAS #7 to 150°C, place the end of Fluke standard air probe through the hole in door of the muffle furnace so the free end is 4 to 6 inches inside. Let it sit for 3 minutes. Read and record temperatures of the muffle furnace gauge and the Fluke standard.

5. Freezer CAS #27, calibration.

5.1 The thermometer on the freezer CAS #27 must be calibrated every month. Calibrate the freezer thermometer by placing the end of Fluke standard wire extention 6-8 inches into the bottom compartment in freezer CAS #27. Close the botttom compartment door and the freezer door. After 3 minutes, read the temperature on the fluke standard thermometer and on the freezer thermometer and record the findings in the CAS #27 log. The freezer temperature needs to stay below -35°C. If it does not, then all contents need to be placed in a another -35°C or colder storage container until CAS #27 can be fixed.

6.

6.1 The standard for calibrating the centrifuges is a Monarch Pocket Tach 10. It is calibrated before each use by pointing it at a fluorescent light and reading the number. The fluorescent light is at a frequency of 7200. Record the reading in log # 5.

6.2 Calibrating CAS #1. Run centrifuge at setting 100 for 2 minutes or until reading on tachometer is constant.

6.3 Hold tachometer 6 inches away from spinning centrifuge and aim the open window at the spinning centrifuge. Record the standard reading.

6.4 Calibrating CAS #6. Run centrifuge at the number 6 setting until standard reading is constant. Follow procedure 6.3

6.5 Repeat 6.4 for settings 5 and 4.

6.6 Calibrating CAS #75. Run centrifuge at the marked setting until standard reading is constant. Follow procedure 6.3

Approved by:_____ Date:_____

ORTECH		PROCEDURE No. : 97-B21-SP-007 REVISION No. : Original
PROCEDURE	Corporate __ General X Specific __	DEPARTMENT : Pharm. & Consumer Products First Issued : 1997-09-25 Current Issue : 1997-09-25 Effective Date : 1997-09-25
TITLE **Analysis of volatile organic acids in aqueous samples**		PAGE 1 OF 6 PAGES

SCOPE

This method is used for the analysis of volatile organic acids, namely Formic, Acetic, Butyric, Propionic and n-Valeric acids in aqueous sample matrices. The analysis is performed using High Performance Liquid Chromatography (HPLC) with UV detection and allows for a detection limit of 5 ppm.

RESPONSIBILITY

Trained Lab Analyst

PROCEDURE

1 Apparatus and Glassware

1.1 Analytical Balance
Sartorious Research, or equivalent

1.2 High Performance Liquid Chromatograph
Waters LC Module 1 Chromatography System equipped with Millennium Chromatography Manager 2010, or equivalent

1.3 Analytical and Guard Column
Rezex ROA Organic Acid analytical column (7.8 mm x 300 mm) 8 µm or equivalent
Rezex ROA Organic Acid guard column (7.8 mm x 50 mm) 5 µm or equivalent

1.4 Volumetric Glassware
Volumetric flasks and pipets

1.5 GHP Acrodisc GF syringe-tip filters (0.45 µm) or equivalent

1.6 Plastic disposable luer-tip syringes (5 mL)

1.7 Autosampler vials with lids and teflon septa

2 Chemicals

Analytical grade standards:

Formic Acid
Acetic Acid
Propionic Acid
Butyric Acid
n-Valeric Acid

Reagent grade:

Phosphoric Acid (H_3PO_4)

3 Preparation of Mobile Phase

0.0015 M H_3PO_4 is used as the mobile phase and is prepared fresh from a stock solution of 1.5 M H_3PO_4.

3.1 Prepare 1.5 M H_3PO_4 by diluting 11.25 mL of concentrated H_3PO_4 (85%) to 1L with distilled water. Dilute 1 mL of this solution to 1 L to obtain a concentration of 0.0015 M H_3PO_4.

3.2 Filter the mobile phase using vacuum, through a 0.45 µm filter prior to use.

4 Preparation of Standards (see Section 2)

4.1 Two stock standard solutions are prepared as follows:

Stock A – (5000 µg/mL)

Weigh 0.5 g of each standard into a 100 mL volumetric flask and dilute to volume with distilled water.

Stock B – (1000 µg/mL)

Weigh 0.1 g of each standard into a 100 mL volumetric flask and dilute to volume with distilled water.

4.2 Prepare the following working standard solutions (10, 50, 100, 250 and 500ppm) using the above two stock solutions.

for 10 ppm, take 1 mL of 1000 µg/mL stock and dilute to 100 mL
for 50 ppm, take 1 mL of 5000 µg/mL stock and dilute to 100 mL
for 100 ppm, take 1 mL of 1000 µg/mL stock and dilute to 10 mL
for 250 ppm, take 5 mL of 5000 µg/mL stock and dilute to 100 mL
for 500 ppm, take 1 mL of 5000 µg/mL stock and dilute to 10 mL

5 Preparation of samples

5.1 Filter all samples through a 0.45 µm filter prior to analysis.

5.2 If a dilution is necessary, then dilute samples in 0.0015 M H_3PO_4.

6 Analysis

The chromatographic conditions are as follows:

Column:	Rezex ROA Organic Acid analytical column (7.8 mm x 300 mm), 8 µm
Guard column:	Rezex ROA Organic Acid guard column (7.8 mm x 50 mm), 5 µm
Mobile Phase:	0.0015 M H_3PO_4
Flow Rate:	0.8 mL/min
Detector:	UV λ 210 nm
Injection Volume:	50 -100 µL

6.1 Condition column with mobile phase until a stable baseline is achieved.

6.2 Prepare a calibration curve by injecting each of the working standards in duplicate.

6.3 Inject samples.

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7 QA/QC

7.1 Run distilled water as a blank. Verify that there are no peaks eluting in the area of the analyte peaks.

7.2 Spike distilled water at 5 ppm level with a standard solution containing the five acids.
Recovery must be 90% or greater.

7.3 One in every batch of 10 samples is analyzed in duplicate. The duplicate peak responses must agree within 10%.

7.4 Run the standard mixture after every 6 injections.
Check to ensure that the areas are within ±10% of the corresponding calibration standard.

7.5 If any of the parameters in 7.1 to 7.4 fail, do not proceed with the calculations until an explanation is found and approved by the lab supervisor.

8 Calculations

8.1 Regression analysis based on the 5 point calibration curve (standard concentation vs. peak area) is used to calculate the concentration of the volatile acids in the sample using the sample peak area.

8.2 If the peak area of a sample is above the linear range of the working standards, the sample must be diluted and re-analyzed. The appropriate dilution factor should be applied in the calculations.

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8.3 Report the results as ppm (mg acid per litre of sample) for each individual acid.

Prepared By: _____ Date: 1997-09-26

Title: Project Technologist

Pharmaceutical and Consumer Products

Approved By: _____ Date: 1997-09-26

Title: Senior Scientist

Pharmaceutical and Consumer Products

Authorized By: _____ Date: 1997-09-26

Title: Manager

Pharmaceutical and Consumer Products

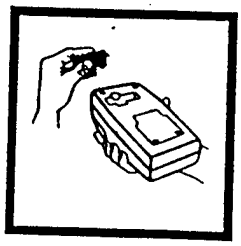
Method Number 8146

IRON, FERROUS (0 to 5.00 mg/L)

For water, wastewater and seawater

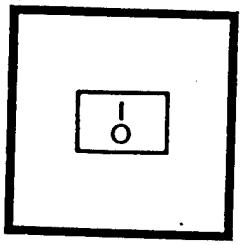
1,10 Phenanthroline Method*
(Powder Pillows or AccuVac Ampuls)

USING POWDER PILLOWS

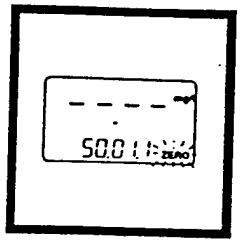


1. Install module 50.01 in a DR/700.

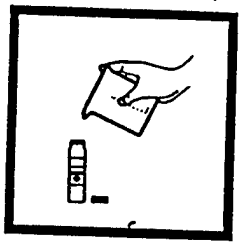
Note: Analyze samples as soon as possible to prevent air oxidation of ferrous iron to ferric iron, which is not measured.



2. Press: I/O
The display will show 500 nm and module 50.01

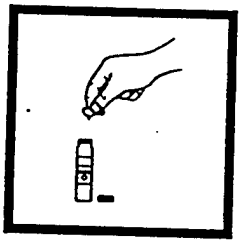


3. After 2 seconds, the display will show a program number, concentration units, decimal position and the zero prompt. If necessary, press ◇ until the lower display shows program number 50.01.1



4. Fill a 25-mL cell to the 25-mL line with sample.

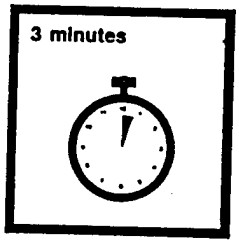
Note: For proof of accuracy, use a 1.00 mg/L ferrous standard solution (preparation given in Accuracy Check) in place of the sample.



5. Add the contents of one Ferrous Iron Reagent Powder Pillow to the sample cell (the prepared sample). Cap and invert to mix.

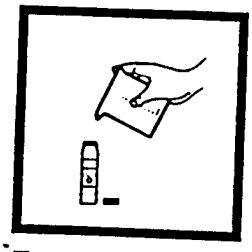
Note: An orange color will develop if ferrous iron is present.

Note: Undissolved powder does not affect accuracy.

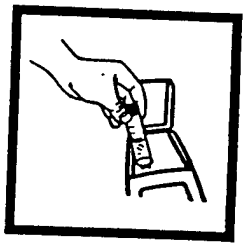


6. Wait 3 minutes.

Note: Steps 7 and 8 can be completed during this reaction period.

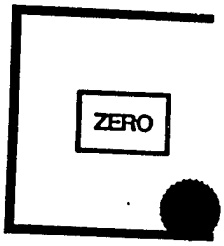


7. Fill a 25-mL cell to the 25-mL line with sample (the blank). Cap.



8. Place the blank in the cell holder.

Note: Typical indoor lighting permits the DR/700 to operate with the cell compartment cover open. In bright sunlight, it may be necessary to close the cell compartment cover. Transfer 10 mL of the blank solution to a 10-mL cell. If the 10-mL cell is used for the blank, another 10-mL cell must be used for the sample.

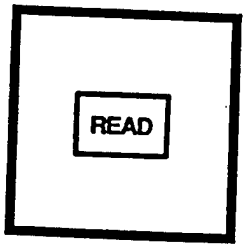


9. Press: ZERO
The display will cour down to 0. Then the display will show 0.0 mg/L and the zero prompt will turn off.



10. Place the prepared sample in the cell holder.

Note: Typical indoor lighting permits the DR/700 to operate with the cell compartment cover open. In bright sunlight, it may be necessary to close the cell compartment cover. Transfer 10 mL of the prepared sample to a 10-mL cell. If the 10-mL cell is used for the blank, another 10-mL cell must be used for the sample.



11. Press: READ
The display will count down to 0. Then the display will show the results in mg/L ferrous iron (Fe^{2+}).

*Adapted from Standard Methods for the Examination of Water and Wastewater

ACCURACY CHECK

Standard Solution Method

Prepare a ferrous iron stock solution (100 mg/L Fe^{2+}) by dissolving 0.7022 grams of Ferrous Ammonium Sulfate, hexahydrate, in deionized water. Dilute to 1 liter. Prepare immediately before use. Dilute 1.0 mL of this solution to 100 mL with deionized water to make a 1.0 mg/L [illegible]ard solution. Prepare this immediately before use.

STATISTICAL EVALUATION

A single operator repetitively tested samples of two laboratory prepared solutions, using one DR/700, matched sample cells and two representative lots of testing reagents. Testing 1.50 mg/L Fe^{2+} concentration samples, the standard deviation was ±0.008 mg/L Fe^{2+}.

Testing zero concentration samples, the limit of detection was 0.007 mg/L Fe^{2+}. The limit of detection was calculated as three times the standard deviation when testing zero concentration samples (Adapted from *Analytical Chemistry,* 1980, *52,* 2242-2249).

Using two representative lots of Ferrous Iron AccuVacs Ampuls, the standard deviation was ±0.012 mg/L Fe^{2+} and the limit of detection was 0.014 mg/L Fe^{2+}.

SUMMARY OF METHOD

The 1,10 phenanthroline indicator in Ferrous Iron Reagent reacts with ferrous iron in the sample to form an orange color in proportion to the iron concentration. Ferric iron does not interfere. The ferric iron (Fe^{3+}) concentration can be determined by subtracting the ferrous iron concentration from the results of a total iron test.

REQUIRED REAGENTS (Using Powder Pillows)

Description	Quantity Per Test	Unit	Cat. No.
Ferrous Iron Reagent Powder Pillows, 25-mL	1 pillow	100/pkg	1037-69

REQUIRED APPARATUS (Using Powder Pillows)

Clippers, large, for opening pillows	1	each	968-00
DR/700 Filter Module Number 50.01	1	each	46250-00

OPTIONAL REAGENTS

Ferrous Ammonium Sulfate, Hexahydrate, ACS	113 g	11256
Water, deionized	3.78 L	272

OPTIONAL APPARATUS

AccuVac Snapper Kit	each	24052
Adapter, AccuVac Vial, DR/700	each	46025
Cap for 10- and 25-mL sample cells	12/pkg	24018
Flask, volumetric, 100 mL	each	547
Flask, volumetric, 1000 mL	each	547
Pipet, volumetric, 1 mL	each	515
Pipet Filler, safety bulb	each	14651
Sample Cell, 10-mL with screw cap	6/pkg	24276
Sample Cell, 25-mL with screw cap	6/pkg	24019

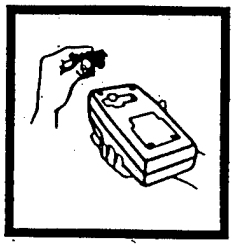
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MANGANESE, HR (0 to 20.0 mg/L)

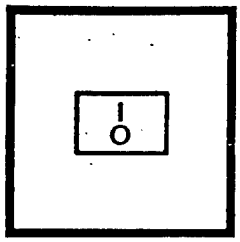
For water and wastewater

Periodate Oxidation Method*; USEPA approved†—Digestion is required; see section 1.



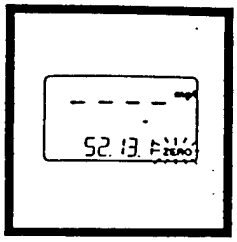
1. Install module 52.01 in a DR/700.

Note: If samples cannot be analyzed immediately, see Sampling and Storage following these steps. Adjust the pH of stored samples before analysis.



2. Press: I/O
The display will show 525 nm and module 52.01

Note: Total manganese determination requires prior digestion; use either the Digesdahl or mild digestion (Section 1).



3. After 2 seconds, the display will show a program number, the concentration units, decimal position and the zero prompt. If necessary, press ◇ until the lower display shows program number 52.13.1



4. Fill a 10-mL cell to the 10-mL line with sample.

Note: A 25-mL sample can be tested by using 25-mL sample cells and optional reagents.



5. Add the contents of one Buffer Powder Pillow, citrate type. Swirl to mix.

Note: For proof of accuracy, use a 5.0 mg/L manganese standard solution (preparation given in Accuracy Check) in place of the sample.

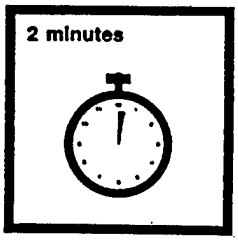


6. Add the contents of one Sodium Periodate Powder Pillow to the sample cell (the prepared sample). Cap and invert several times to mix.

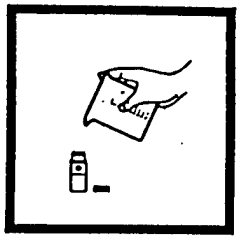
Note: A violet color will develop if manganese is present.

Note: Accuracy is not affected by undissolved powder.

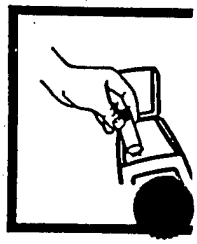
*Adapted from *Standard Methods for the Examination of Water and Wastewater*
†*Federal Register*, June 14, 1979, *44 (116)*, 34193



7. Wait 2 minutes.

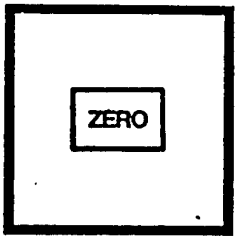


8. Fill a 10-mL cell to the 10-mL line with sample (the blank). Cap.



9. Place the blanl the cell holder.

Note: In bright sunlight may be necessary to clo the cell compartment co



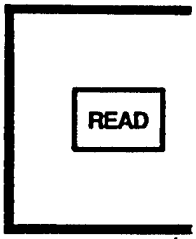
10. Press: ZERO

The display will count down to 0. Then the display will show 0.0 mg/L and the zero prompt will turn off.



11. Within 8 minutes after the 2-minute period, place the prepared sample in the cell holder.

Note: In bright sunlight it may be necessary to close the cell compartment cover.



12. Press: READ

The display will co down to 0. Then t display will show t results in mg/L manganese (Mn).

Note: To convert other units, see

Table 1. Conversion Factors

To convert from	To	Multiply
mg/L Mn	mg/L MnO_4^-	2.16
mg/L Mn	mg/L $KMnO^4$	2.88

SAMPLING AND STORAGE

Collect samples in acid-washed plastic bottles. Manganese may be lost by adsorption to glass container walls. Adjust the pH to 2 or less with nitric acid (about 2 mL per liter). Preserved samples may be stored up to six months at room temperature. Adjust the pH to 4 to 5 with 5.0 N and 1.0 N Sodium Hydroxide Standard Solution before analysis. Do not exceed pH 5, as manganese may be lost as a precipitate. Correct the test result for volume additions; see Sampling and Storage, Volume Additions, (Section I) for more information.

ACCURACY CHECK

Standard Additions Method

a) Snap the neck off a Manganese Voluette Ampule Standard Solution, High Range, 250 mg/L Mn.

b) Use the TenSette Pipet to add 0.1, 0.2, and 0.3 mL of standard to three 25-mL water samples. Mix thoroughly.

c) Analyze each sample as described above. The manganese concentration should increase 1.0 mg/L for each 0.1 mL of standard added.

d) If these increases do not occur, see Standard Additions (Section I) for more information.

Standard Solution Method

Prepare a 5.00 mg/L manganese standard solution by pipetting 5.00 mL of Manganese Standard Solution, 1000 mg/L Mn, into a 1000-mL volumetric flask. Dilute to the mark with deionized water. Or, prepare this standard by diluting 1.00 mL of the contents of a Voluette Ampule For High Range Manganese to 50 mL, using the TenSette Pipet. Prepare these solutions daily.

INTERFERENCES

The following may interfere when present in concentrations exceeding those listed below:

Calcium	700 mg/L
Chloride	70,000 mg/L
Iron	5 mg/L
Magnesium	100,000 mg/L

Highly buffered samples or extreme sample pH may exceed the buffering capacity of the reagents and require sample pretreatment; see Interferences, pH (Section I).

STATISTICAL EVALUATION

A single operator repetitively tested samples of two laboratory prepared solutions, using one DR/700, matched sample cells and two representative lots of testing reagents. Testing 10.0 mg/L Mn concentration samples, the standard deviation was ±0.11 mg/L Mn.

Testing zero concentration samples, the limit of detection was 0.04 mg/L Mn. The limit of detection was calculated as three times the standard deviation when testing zero concentration samples (Adapted from *Analytical Chemistry,* **1980,** *52,* 2242-2249).

SUMMARY OF METHOD

Manganese in the sample is oxidized to the purple permanganate state by sodium periodate, after buffering the sample with citrate. The purple color is directly proportional to the manganese concentration.

If only dissolved manganese is to be determined, filter the sample before acid addition.

REQUIRED REAGENTS

Description	Quantity Per Test	Unit	Cat
Buffer Powder Pillows, citrate type for manganese, 10 mL	1 pillow	100/pkg	2107
Sodium Periodate Powder Pillows for manganese, 10 mL	1 pillow	100/pkg	2107

REQUIRED APPARATUS

Clippers, for opening powder pillows	1	each	9(
DR/700 Filter Module Number 52.01	1	each	4625

OPTIONAL REAGENTS

Buffer Powder Pillows, Citrate, 25 mL (for manganese)	50/pkg	983
Hydrochloric Acid, 6.0 N	500 mL	884
Manganese Standard Solution, 1000 mg/L Mn	100 mL*	12791
Manganese Standard Solution, Voluette ampule, High Range, 250 mg/L Mn, 10 mL	16/pkg	1425
Nitric Acid, ACS	500 mL	152
Nitric Acid Solution, 1:1	500 mL	2540
Sodium Hydroxide Standard Solution, 1.0 N	100 mL MDB	1045
Sodium Hydroxide Standard Solution, 5.0 N	100 mL* MDB	2450
Sodium Periodate Powder Pillows for manganese, 25 mL	100/pkg	984
Water, deionized	3.78 L	27

OPTIONAL APPARATUS

Ampule Breaker Kit	each	21968
Cap for 10- and 25-mL sample cells	12/pkg	2401
Dropper, plastic, 0.5 and 1.0 mL marks	each	2124
Flask, volumetric, Class A, 50 mL	each	1457
Flask, volumetric, Class A, 100 mL	each	14574
Flask, volumetric, Class A, 1000 mL	each	14574
pH Indicator Paper, 1 to 11 pH	5 rolls/pkg	391
pH Meter, Hach One	each	4380(
Pipet, serological, 1 mL	each	532
Pipet, serological, 5 mL	each	532
Pipet, TenSette, 0.1 to 1.0 mL	each	1970(
Pipet Tips, for 19700-01 TenSette Pipet	50/pkg	2185(
Pipet, volumetric, 5.00 mL	each	1451
Pipet Filler, safety bulb	each	1465
Sample Cell, 10-mL with screw cap	6/pkg	2427(
Sample Cell, 25-mL with screw cap	6/pkg	2401

For Technical Assistance, Prices and Ordering

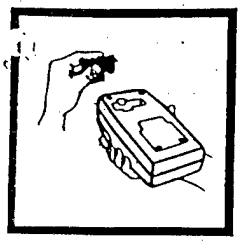
In the U.S.A.—Call 800-227-4224 toll-free for more information.
Outside the U.S.A.—Contact the Hach office or distributor serving you.

Method Number 8131

SULFIDE (0 to 0.600 mg/L S^{2-})

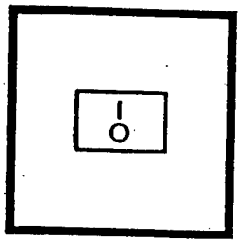
For water, wastewater and seawater

Methylene Blue Method*; USEPA approved for reporting**

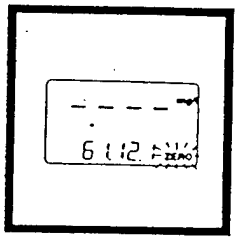


1. Install module 61.01 in a DR/700.

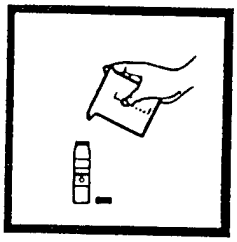
Note: Sample must be analyzed immediately and cannot be preserved for later analysis. Avoid excessive agitation.



2. Press: I/O
The display will show 610 nm and module 61.01

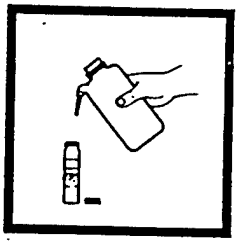


3. After 2 seconds, the display will show a program number, the concentration units, decimal position and the zero prompt. If necessary, press ◇ until the lower display shows program number 61.12.1

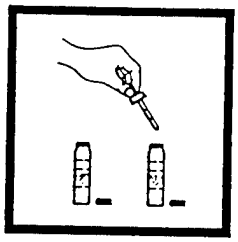


4. Fill a 25-mL sample cell to the 25-mL line with sample (the prepared sample).

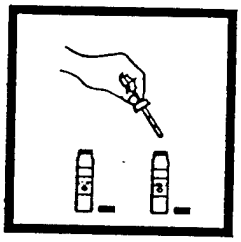
Note: For turbid samples, see Interferences following these steps for pretreatment instructions.



5. Fill another 25-mL cell to the 25-mL line with deionized water (the blank).

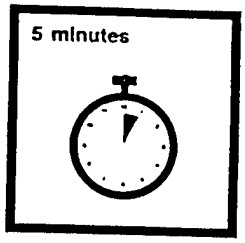


6. Add 1.0 mL of Sulfide 1 Reagent to each cell and cap. Swirl to mix.

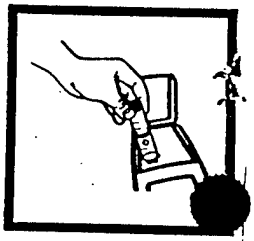


7. Add 1.0 mL of Sulfide 2 Reagent to each cell and cap. Immediately swirl to mix.

Note: A pink color will develop. Then the solution will turn blue if sulfide is present.



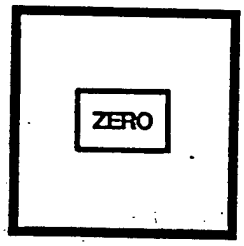
8. Wait 5 minutes.



9. Place the blank in the cell holder.

Note: Typical indoor lighting permits the DR/700 to operate with the cell compartment cover open. In bright sunlight, it may be necessary to close the cell compartment cover. Transfer 10 mL of the blank solution to a 10-mL cell. If the 10-mL cell is used for the blank, another 10-mL cell must be used for the sample.

*Adapted from *Standard Methods for the Examination of Water and Wastewater*
**Procedure is equivalent to USEPA method 376.2 and Standard Method 4500-S^{2-} for wastewater.

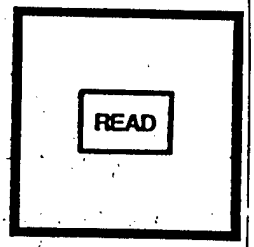


10. Press: ZERO
The display will count down to 0. Then the display will show 0.000 mg/L and the zero prompt will turn off.



11. Immediately place the prepared sample in the cell holder.

Note: Typical indoor lighting permits the DR/700 to operate with the cell compartment cover open. In bright sunlight, it may be necessary to close the cell compartment cover. Transfer 10 mL of the prepared sample to a 10-mL cell. If the 10-mL cell is used for the blank, another 10-mL cell must be used for the sample.



12. Press: READ
The display will count down to 0. Then the display will show the results in mg/L sulfi... (S^{2-}).

ACCURACY CHECK

Standard Solution Method

Sulfide standard solutions are very unstable and should be prepared from sodium sulfide and standardized as described in *Standard Methods for the Examination of Water and Wastewater*, 16th ed., page 475 or in the 17th ed., page 4-195.

STATISTICAL EVALUATION

A single operator repetitively tested samples of two laboratory prepared solutions, using one DR/700, matched sample cells and two representative lots of testing reagents. Testing 0.595 mg/L S^{2-} concentration samples, the standard deviation was ±0.008 mg/L S^{2-}.

Testing zero concentration samples, the limit of detection was 0.010 mg/L S^{2-}. The limit of detection was calculated as three times the standard deviation when testing zero concentration samples (Adapted from *Analytical Chemistry*, 1980, *52*, 2242-2249).

INTERFERENCES

For turbid samples, a sulfide-free blank should be prepared as follows. Use it in place of deionized water in Step 5.

a) Measure 25 mL of sample into a flask.

b) Add Bromine Water drop-wise until a yellow color remains.

c) Add Phenol Solution dropwise until the yellow color just disappears. Use of this blank solution will compensate for turbidity in the sample.

Strong reducing agents such as sulfite, thiosulfate and hydrosulfite interfere by reducing the blue color or preventing its development. High concentrations of sulfide may inhibit full color development, requiring a dilution of the sample. Some loss of sulfide may occur when the sample is diluted.

SUMMARY OF METHOD

Hydrogen sulfide and acid-soluble metal sulfides react with N,N-dimethyl-p-phenylenediamine oxalate to form methylene blue. The intensity of the blue color is proportional to the sulfide concentration.

High sulfide levels in oil-field waters may be determined after proper dilution.

Determine soluble sulfides by centrifuging the sample in completely filled, capped tubes and analyzing the supernatant. Insoluble sulfides are then estimated by subtracting the soluble sulfide concentration from the total sulfide result.

REQUIRED REAGENTS

	Cat. No.
Sulfide Reagent Set (100 Tests)	22445-00
Includes: (2) 1816-32, (2) 1817-32	

Description	Quantity Per Test	Unit	Cat. No.
Sulfide 1 Reagent	2 mL	118 mL MDB	1816-32
Sulfide 2 Reagent	2 mL	118 mL MDB	1817-32

REQUIRED APPARATUS

DR/700 Filter Module Number 61.01	1	each	46261-00

OPTIONAL REAGENTS

Bromine Water, 30 g/L	29 mL	2211-20
Phenol Solution, 30 g/L	29 mL	2112-20
Sodium Sulfide, ACS	114 g	785-14

OPTIONAL APPARATUS

Cap for 10- and 25-mL sample cells	12/pkg	24018-12
Cylinder, graduated, 25 mL	each	508-40
Dropper, for 1 oz bottle	each	2258-00
Flask, erlenmeyer, 50 mL	each	505-41
Sample Cell, 10-mL with screw cap	6/pkg	24276-06
Sample Cell, 25-mL with screw cap	6/pkg	24019-06
Standard Methods for the Examination of Water and Wastewater	each	22708-00

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HOW TO USE THE ENCLOSED STANDARD:

Standard Additions Accuracy Check

The Standard Additions Method checks analysis accuracy by measuring the recovery of a standard.

1.) Analyze a portion of the sample and record the result as Reading No.1.
2.) Carefully break open the standard ampule, withdraw 0.1 cc of standard, add it to a new portion of sample, and repeat the analysis. Record as Reading No. 2. Repeat using 0.2 cc and 0.3 cc of standard and new samples. (see table inside for expected increases)
3.) Determine the Addition Recovery Percentage (AR%) using equation 1.

Recoveries of 100 ± 5% suggest that the original sample analysis is correct.
Recoveries of less than 95%, or more than 105% indicate an error. Measure a standard solution, according to the procedure, to determine the cause of error.

Standard Solution Results	Possible Causes	Remedy
low reading	faulty technique	repeat analysis carefully
	deteriorated reagent	purchase new reagents
high reading	faulty technique	repeat analysis carefully
	contaminated equipment	clean equipment
	contaminated reagent	purchase new reagents
correct reading	sample interference if AR% < 95	use equation 2 for correction
	faulty technique if AR% > 105	repeat analysis carefully

(1) $$AR\% = \frac{\text{Reading No.2 (mg/l)} - \text{Reading No.1 (mg/l)}}{\text{Standard Addition (mg/l)}}$$

(2) $$\text{Actual Concentration (mg/l)} = \frac{100 \times \text{Reading No.1 (mg/l)}}{AR\%}$$

For technical assistance, contact the Hach office or authorized Hach distributor serving you.

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Loveland, Colorado 80539
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Telephone: (303) 669-3050
Telex: 160840
FAX: (303) 6692932

Cat. No. 25566-88

CHEMetrics

Titrets®

hand-held titration cells

Cat. No. K-1920

CARBON DIOXIDE

100 – 1,000 PPM

SAFETY INFORMATION

Read MSDS before performing this test procedure.

If this product is used as directed, the user will not come in contact with the chemical reagents. If contact does occur, flush skin or eyes with water. Call a physician, if swallowed.

Titrets® is a registered trademark of CHEMetrics, Inc.

U.S. Patent No. 4,332,769

TEST PROCEDURE

1. Fill the sample cup to the **20 mL mark** with your sample.

   NOTE: If sulfide is present, add the necessary number of mL of A-1910 Neutralizer Solution before proceeding (see interferences).

2. Add **2 drops** of A-1900 Activator Solution to the sample.

3. Push the valve assembly (in ampoule tray) onto the Titret ampoule tip until it fits snugly (fig. 1).

   NOTE: The valve assembly should reach the reference line on the neck of the ampoule.

4. Gently snap the tip of the ampoule at the score mark (fig 2).

5. Lift the control bar and insert the Titret assembly into the body of the Titrettor (fig. 3).

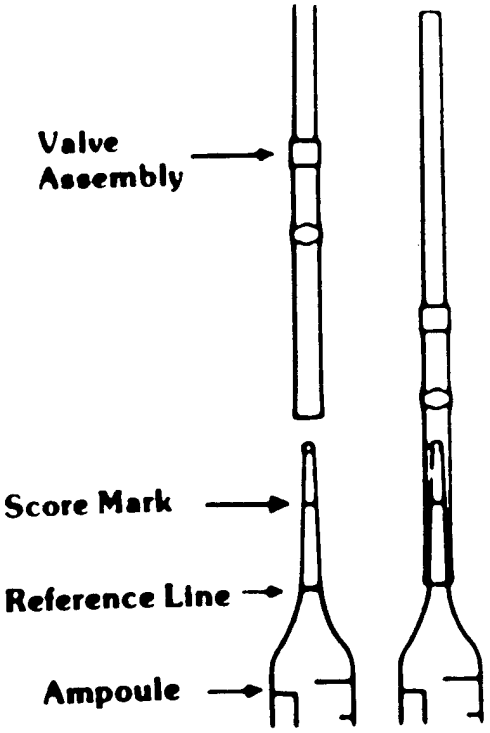


Fig. 1

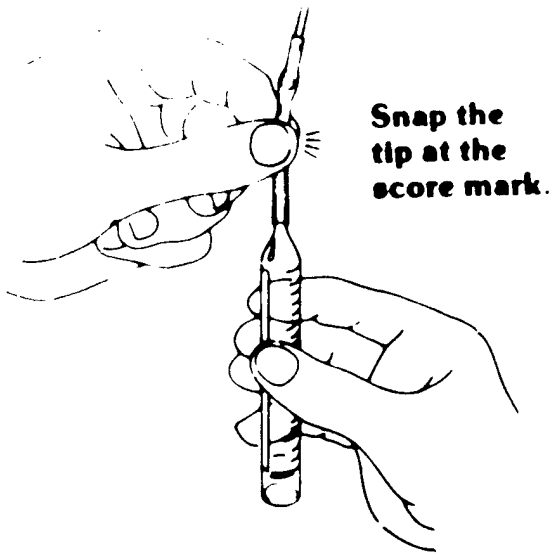


Fig. 2

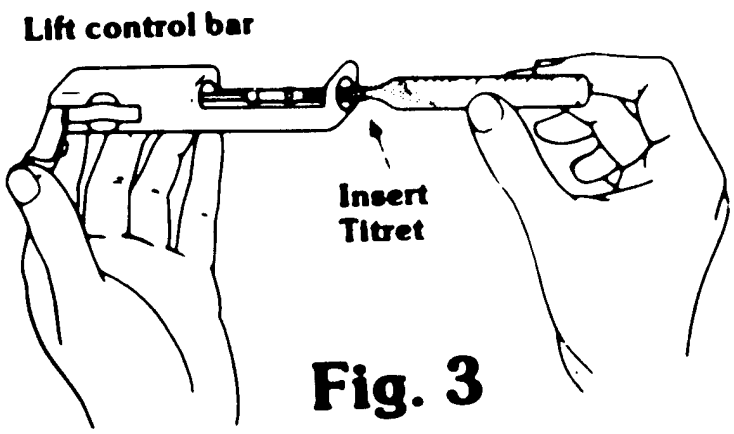


Fig. 3

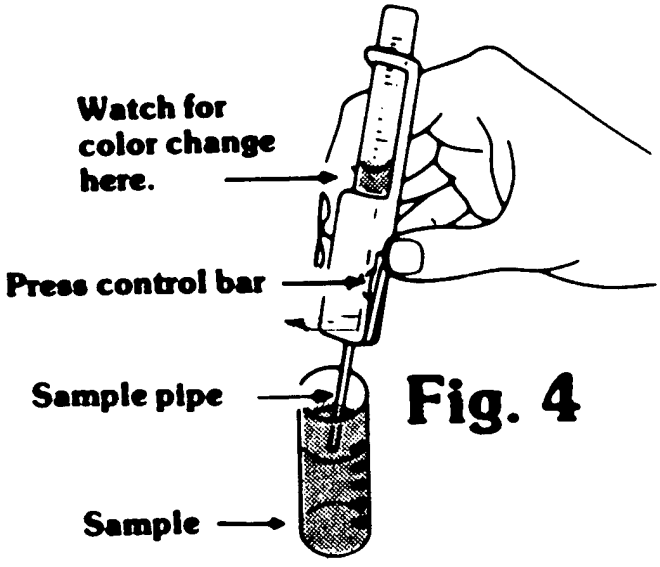


Fig. 4



Fig. 5

TABLE FOR SULFIDE CORRECTION

ppm Sulfide	mL of A-1910 Sol. per 20 mL of sample
0	no correction
1	no correction
2	no correction
3	no correction
4	.05
5	.05
6	.05
7	.05
8	.1
9	.1
10	.1
20	.2
30	.3
40	.4
50	.5
60	.6
70	.7
80	.8
90	.9
100	1.0

mL of A-1910 Neutralizer Solution per 20 mL of sample = ppm sulfide/100

6. Hold the Titrettor with the sample pipe in the sample and press the control bar firmly, but briefly, to pull in a small amount of sample (fig. 4).

   The contents will turn a pink color.

7. Press the control bar again briefly to allow another small amount of sample to be drawn into the ampoule.

   CAUTION: Do not press the control bar unless the sample pipe is immersed in the liquid.

8. After each addition, rock the entire assembly to mix the contents of the ampoule. Watch for a color change **FROM PINK TO COLORLESS.**

9. Repeat steps 7 and 8 until a permanent color change occurs.

10. When the color of the liquid in the ampoule changes to **COLORLESS**, remove the ampoule from the Titrettor. Hold the ampoule in a vertical position and carefully read the scale opposite the liquid level

to obtain test results in ppm (mg/Liter) carbon dioxide as CO_2 (fig. 5).

CAUTION

1. Be careful to squeeze the control bar only briefly during a test and mix the contents of the Titret ampoule well.

2. If the control bar is pressed while the sample pipe is not immersed, air will enter the Titret ampoule and the vacuum may not be sufficient to complete the test.

3. If the Titret ampoule fills completely without a color change (remains pink), the test result is **less** than the lowest scale reading.

   If the contents of the Titret ampoule turn colorless right away (see step #6), the test result is **greater** than the highest scale reading.

4. Dispose of used Titrets safely.

Chlorine does not interfere up to 200 ppm (mg/L).

Sulfide **will not interfere up to 4 ppm (mg/L)**. However, if the sulfide concentration of your sample is 4 ppm (mg/L) or higher, the following pretreatment procedure must be performed before the carbon dioxide concentration can be determined:

A. Determine the sulfide content of your sample in ppm (mg/L).

NOTE: Our K-9510D Sulfide Test Kit determines sulfide from 0 to 250 ppm (mg/L).

B. Use the formula or the table on the following page to determine the number of mL of A-1910 Neutralizer Solution necessary to inhibit the sulfide present in your sample.

C. Add the necessary number of mL of neutralizer solution to **20 mL of your sample.**

EXAMPLE: Sulfide concentration of sample is 50 ppm; mL of A-1910 neutralizer solution needed is 0.5 mL.

D. Proceed with the instructions for the carbon dioxide determination.

Model DR/700
PORTABLE COLORIMETER
Instrument Manual

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2.2 Operating the DR/700 Colorimeter

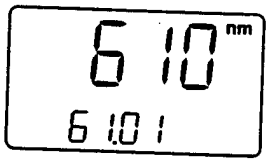
Illustrated parameter-specific procedures for performing measurements with the DR/700 Colorimeter are provided as part of the filter module unit. In the following paragraphs of this section, the various operational functions are discussed to further clarify its use.

NOTE

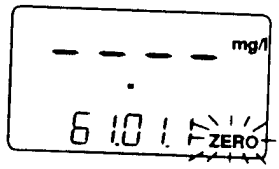
Typical indoor lighting permits the DR/700 to operate with the cell compartment cover open. In bright sunlight, it may be necessary to close the cell compartment cover. Transfer 10 mL of the blank solution to a 10-mL cell. If the 10-mL cell is used for the blank, another 10-mL cell must be used for the sample.

2.2.1 Initial Turn-On Sequence

When the colorimeter is turned on with the **I/O** key, the meter display gives the filter wavelength and filter module number with software version number (610) for approximately 2 seconds. For example:

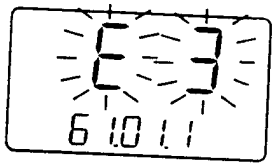


The colorimeter will display a concentration format (decimal point position and unit of measure) of a preprogrammed test. The lower display shows the program number with its current version number.



NOTE

If no filter module is installed, the error message E3 will flash.



NOTE

The colorimeter will turn itself off to conserve battery life if no keys are pressed for 28 minutes.

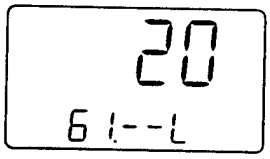
2.2.2 Lamp Intensity Adjustment

Before performing any colorimetric tests with a new filter module installed, a lamp intensity adjustment should be performed. With the proper sequence of keystrokes, the lamp voltage can be adjusted to give the optimum meter response. This adjustment

should be performed with the instrument on a firm surface and with a sample cell containing clear water in the cell compartment.

The lamp voltage setting for each filter module is stored in that module so that the colorimeter lamp intensity will always be correct for any given filter module. If a filter module is used with another colorimeter the adjustment must be repeated in that colorimeter. Perform the lamp intensity adjustment as follows:

1. With the colorimeter off, press and hold the **READ** key down while turning on the colorimeter. Continue holding the **READ** key down until "– –L" appears in the lower display as shown:



At this point, release the **READ** key. The display will count down from 20 to 0, the lamp will light and then the lamp voltage will automatically adjust to the optimum setting. The upper display field will show the lamp voltage (within the range of 2.000 to 3.300 V) as the instrument adjusts for optimum intensity. When the lamp annunciator goes out, the adjustment is complete.

2. Press the **PROGRAM** key or turn the colorimeter off momentarily to return to normal operation. The lamp voltage is now established and stored in this module.

2.2.3 Using Preprogrammed Calibrations

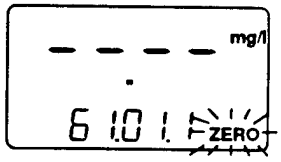
Each filter module is preprogrammed with factory-entered calibrations. *Refer to Table 1* for a list of test methods available.

NOTE

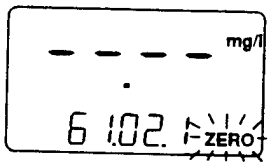
A lamp intensity adjustment should be performed after installing the filter module. *See Section 2.2.2.*

2.2.3.1 Selecting a Method

At power up or after pressing the **PROGRAM** key, the colorimeter display shows one of the preprogrammed methods contained in the installed filter module. The upper display field will show the decimal point position and the units of measure used in that calibration, with hyphens in all digit positions. The lower display field shows the program number. For example:



The operator can select a different method by pressing the **UP ARROW** key.

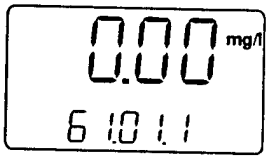


With each press of the **UP ARROW** key, the colorimeter steps to the next preprogrammed method with the appropriate method number, decimal point position and unit of measure displayed. At the end of the cycle, the colorimeter will return to the first method in the menu.

2.2.3.2 Zeroing a Preprogrammed Method

The colorimeter must be zeroed with a reference solution before unknown solutions can be measured. At the appropriate time the colorimeter will prompt for the zeroing procedure with a flashing ZERO indicator. Zero the meter as follows:

1. Select the desired preprogrammed method.
2. Place a sample cell containing the blank solution into the sample compartment.
3. Press the **ZERO** key. After approximately 8 seconds in which time the display will count down from 20 to 0 and the lamp indicator will be displayed, the colorimeter will display zero concentration and the Zero indicator will be turned off as follows:

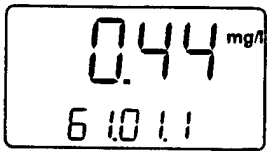


NOTE

A flashing display after the zeroing procedure warns the operator that an operational parameter has not been met. *Refer to Error Indications and Codes in Section 4.*

2.2.3.3 Reading the Concentration

After zeroing has been accomplished, each press of the **READ** key will cause the colorimeter to cycle through the lamp stabilization period and then read the concentration of the solution in the cell compartment, such as:



A period of approximately eight seconds (with 20 to 0 countdown) will elapse between pressing the **READ** key and the appearance of the reading. For continuous readings, holding the **READ** key

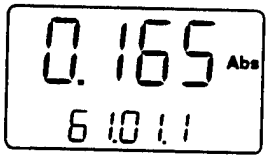
will update the display approximately every two seconds as long as the key is held.

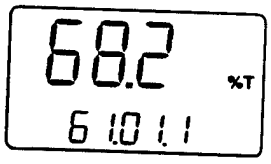
NOTE

A flashing display after the read sequence warns the operator of an operational parameter that has not been met. *Refer to Error Indications and Codes in Section 4.*

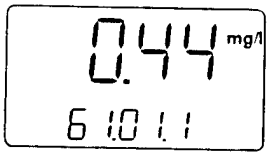
2.2.3.4 Reading Absorbance and Percent Transmittance

Absorbance (Abs) and percent transmittance (%T) equivalent values for the measured concentration of the solution in the sample cell compartment can be determined by pressing the **ABS/%T** key. The first press of the key provides the absorbance reading and the next press results in the percent transmittance reading.





Concentration can be recalled by pressing the **PROGRAM** key.

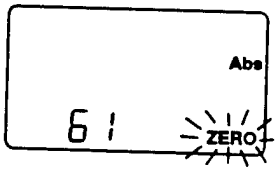


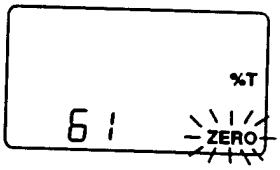
These values are relative to the zero setting in the particular calibration being used; they must be considered relative absorbance and relative percent transmittance.

2.2.3.5 Absorbance and Transmittance Measurement

Values (based on clear water) in Abs and %T can be determined if the colorimeter is zeroed in the absorbance or percent transmittance mode with a zero reference solution in the sample cell compartment. Proceed as follows:

1. Press the **ABS/%T** key once for absorbance or twice for percent transmittance. Verify that the desired mode is displayed and that the ZERO indicator is flashing as follows:





2. Place the zero solution blank into the sample compartment.

3.1 Preparation For Use

3.1.1 Unpacking

Remove the colorimeter and accessories from the shipping containers and inspect each item for any damage that may have occurred during shipment. Verify that the following items, plus any optional accessory items ordered, are present:

- Carrying Case
- DR/700 Colorimeter, with one filter module of choice
- Sample Cells, w/caps, 10-mL size (2)
- Sample Cells, w/caps, 25-mL size (2)
- Batteries, AA alkaline (4)
- DR/700 AccuVac Vial Adapter
- COD Vial Adapter (provided with 420-nm, 610-nm modules only)
- Clippers, for opening reagent pillows
- Instrument Manual, Procedure Manual w/3-Ring Binder
- Filter Module(s), (ordered separately)

If any items are missing or damaged, please contact the Customer Service Department, Hach Company, Loveland, Colorado for instructions. The toll-free number is **800-227-4224**. For customers outside the USA, contact the Hach office or authorized distributor serving you. In Canada, the Caribbean, Latin America, Australia, the Far East and the Pacific Basin, contact Hach Company, P.O. Box 389, Loveland, Colorado, U.S.A., 80539, Telephone (970)669-3050, Telex 160840, FAX (970)669-2932. In Europe, Africa, the Middle East and the Indian Subcontinent, contact Hach Europe, S.A./N.V., Chaussée de Namur 1, B-5150 Floriffoux (Namur), Belgium, Telephone (32)(81)44.71.71, Telex 846-59027, FAX (32)(81)44.13.00

3.1.2 Battery Installation

The colorimeter operates on battery power. Four AA alkaline cells are supplied with the instrument and must be installed by the operator *as shown in Figure 6.* Correct battery polarity is indicated on the battery holder. If optional rechargeable batteries are to be used, they are installed in the same manner after initally being charged for 14 to 16 hours in an external battery charger.

3.1.3 Filter Module Installation

Filter modules are inserted in the bottom of the colorimeter as *shown in Figure 7.* The module

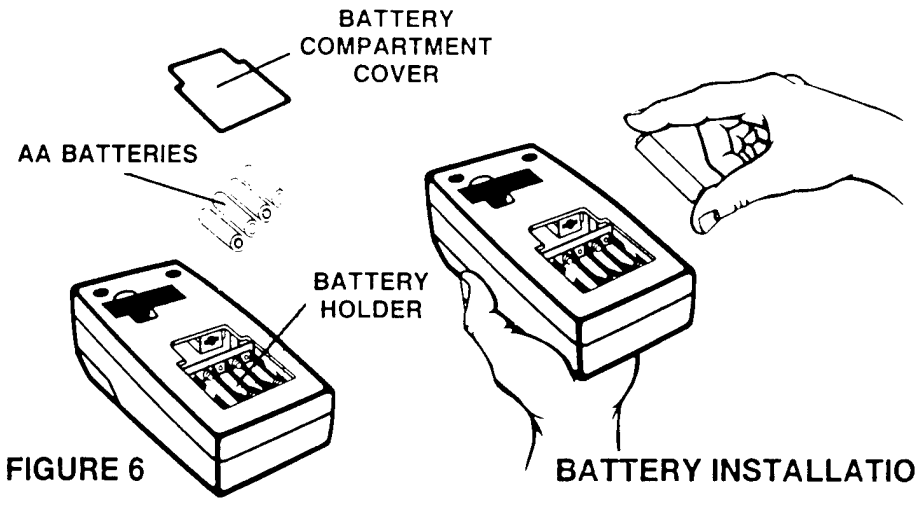


FIGURE 6 BATTERY INSTALLATION

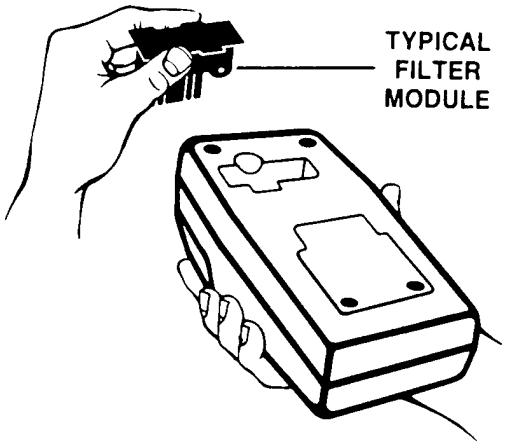


FIGURE 7 FILTER MODULE INSTALLATION

opening is keyed such that the filter module cannot be inserted improperly. Press the module in until its base is flush with the bottom of the instrument case. Before using the colorimeter, perform a lamp intensity adjustment with each filter module installed in the colorimeter. This will permanently store the optimum lamp intensity setting for each particular filter module, and further adjustment should not be necessary unless the lamp is replaced. *Refer to paragraph 2.2.2.*

The filter modules latch in position when fully installed. When removing a module, the

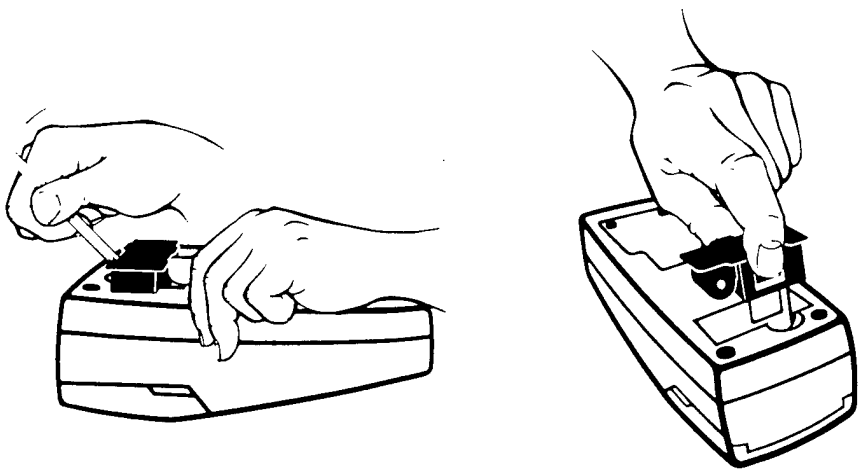


FIGURE 8 FILTER MODULE REMOVAL

latch must be disengaged by pressing on the finger grip while pulling the module out. *See Figure 8.*

3.1.4 DR/700 AccuVac Vial Adapter Installation

The DR/700 AccuVac Vial Adapter is needed only when using the Hach AccuVac Reagent Vials. Illustrated test procedures are provided in the procedure manual for each AccuVac method.

3.2 Cleaning

Maintain the colorimeter, filter modules and sample cells as clean as possible, and store in the carrying case when not in use. Filter modules not in use should be stored in the antistatic bags in which they were received. Wipe up spills promptly. The color filter surfaces in the filter module can be wiped clean with a water-dampened cotton swab. Sample cells should be washed with detergent and rinsed thoroughly with demineralized water. Avoid scratching the glass surfaces of the cell and wipe off any fingerprints before inserting it into the cell compartment for measurement.

3.2.1 Cleaning the Filter Module Circuit Board

If necessary, the filter module circuit boards may be cleaned to remove salts or other ionic substances from the instrument circuit board. **This procedure will not remove oils or other organic contamination.**

1) Fill a beaker with a solution of 25% deionized water and 75% isopropyl alcohol. The solution level should cover the circuit board

portion of the module, not the color filter portion. Use of other types of alcohol besides isopropyl may damage the circuit board.

2) Soak the module for 30 minutes. Periodically swirl the module during the 30-minute period.

3) Blow the module out with instrument grade or ionized air to remove any trapped liquid.

4) If the color filter accidentally comes in contact with the solution, use a cotton swab to gently clean the filter glass.

3.3 Battery Replacement

AA alkaline batteries are typically suitable for up to 500 tests. A low battery indicator will flash when battery replacement is needed. *Refer to Battery Installation paragraph 3.1.2.*

WARNING

Batteries may explode if recharged or disposed of in a fire.

ADVERTENCIA

Las pilas pueden explotar si se recargan o se tiran al fuego.

AVISO

Bateris pode explodir se for recarregada ou descartada em fogo.

ATTENTION

La pile peut exploser si elle est rechargee ou mise au feu pour evacuation.

WARNHINWEIS

Bei Aufladen oderBeseitigung in Feuer kann die Batterie explodieren.

If after changing batteries the colorimeter keys do not function at all and the **I/O** key will not turn the colorimeter on or off when the batteries are known to be good, a cold start should be performed. A cold start is performed by removing one of the batteries for one to two minutes (to allow circuits to discharge), installing the battery again and then turning the instrument on with the **I/O** key. If the lockup still exists, contact a Hach service center or your authorized distributor.

SECTION 4 TROUBLESHOOTING

4.1 Introduction

Troubleshooting by the operator is generally limited to performing two diagnostic tests and responding to error codes displayed when certain predetermined limits are exceeded. If the colorimeter does not perform properly in the diagnostic tests or an error condition cannot be corrected, contact a Hach service center for assistance. *Refer to Section 6.*

4.2 Display Test

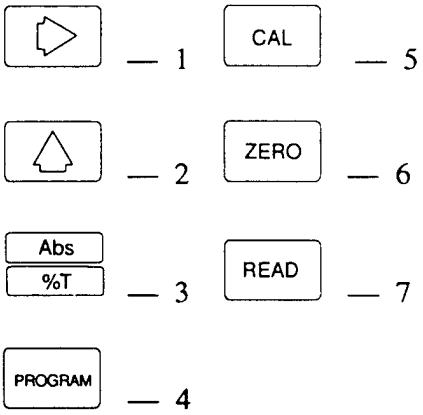
Operation of the display elements can be checked by holding the **I/O** key down at instrument turn-on while observing the display test sequence. Hold the key down until all the annunciators and digital readout elements are verified. The display test sequence will continue to cycle as long as the key is held down.

4.3 Keyboard Test

Each key of the keyboard can be checked easily as follows:

1. With the instrument off, press and hold the **UP ARROW** key while pressing and releasing the **I/O** key. Keep holding the **UP ARROW** key down until a "-2-" appears in the upper display. Disregard the lower display for this test. It is the raw millivolt reading of the photocell output.

2. Now press each key **except** the **I/O** key and verify that a number appears momentarily in the upper display. The following key number scheme will appear:



3. Press the **I/O** key to exit the keyboard check mode.

4.4 Error Indications and Codes

4.4.1 Flashing Maximum Concentration Display

A flashing display of the concentration range maximum value is an indication that the reading taken was beyond the upper end of the factory-entered calibrated range. A sample dilution (prior to treatment) may be necessary to bring the concentration within the range of

the colorimeter. If a diluted sample is measured, multiply the test result by the dilution factor. *Refer to Sample Dilution Techniques in Section 1 of your DR/700 Colorimeter Procedures Manual.*

4.4.2 Flashing Minimum Concentration Display

A flashing minimum concentration value indicates that the sample measured had a concentration value less than zero. It may be caused by a bad choice of blank solution or by sample cells poorly matched.

4.4.3 Flashing S1 and S2 Annunciators

When both standard annunciators are flashing simultaneously, it is an indication that the sample measured was out of range of a user-entered calibration, either underrange or overrange.

4.4.4 Flashing 4.00 Abs Indication

This indication is caused by a relative absorbance reading greater than 4.00. This will occur when a very dark sample is measured.

4.4.5 Flashing 9999 %T Indication

This indication is caused by a relative percent transmittance measurement greater than the instrument's maximum displayable limit.

4.4.6 Flashing 0.0 %T Indication

This indication probably is caused by an electronics failure. It also may be due to a large change in ambient light while measuring a dark sample. If another filter module is available, install it to determine if the problem is with the meter or filter module. Contact a Hach service center. *Refer to the Repair Service Section.*

4.4.7 Flashing Lamp Annunciator

This indication is a precautionary warning and occurs during the zeroing function when there may not be enough light for a valid measurement. Perform a lamp intensity adjustment and try zeroing again. The lamp annunciator will continue to flash until the instrument is zeroed properly.

4.4.8 Error Code E1 (Overrange)

E1 indicates an electronic overrange condition. Perform the lamp intensity adjustment procedure *described in paragraph 2.2.2.* To verify that the problem is not in the filter module, try another module if one is available. The error code display can be cleared by pressing the **PROGRAM** or **I/O** key. If the problem can not be corrected, contact a Hach service

center. *Refer to the Repair Service Section.*

4.4.9 Error Code E2 (Underrange)

E2 indicates an electronic underrange condition caused by a hardware failure. Because it could be caused by the filter module, try another module first if one is available. Contact a Hach service center. *Refer to the Repair Service Section.*

4.4.10 Error Code E3 (No Filter Module Installed)

Error code E3 occurs when the instrument is turned on and a filter module has not yet been installed or is not installed properly. Installing a filter module will correct this condition. Power need not be turned off to install a filter module.

4.4.11 Error Code E4 (User Method Concentration Error)

E4 occurs after the **CAL** key is pressed at the end of a calibration procedure and the same concentration value is entered for both the S1 and S2 standards. Repeat the calibration.

4.4.12 Error Code E5 (User Method Absorbance Error)

This error code occurs after the **CAL** key is pressed at the end of a calibration procedure and the absorbance of S2 minus the absorbance of S1 is equal to or less than 0.005 Abs. Check the standards and repeat the calibration.

4.4.13 Error Code E6 (Low Light)

Low light while zeroing the colorimeter causes an E6 indication. It occurs when the difference between the photodetector amplifier voltage with the lamp off and with the lamp on is less than 1 mV. Either the sample is too dark or the lamp intensity needs adjusting. *Refer to paragraph 2.2.2.* A bad lamp or circuit failure could be the cause of the problem.

4.4.14 Error Code E7 (Lamp Out)

If the lamp is burned out or disconnected, an E7 error code will be displayed. Check the lamp connection, and if that is not the problem, replace the lamp. *Refer to paragraph 3.4.*

4.5 Diagnostics Mode

Diagnostic checks are incorporated in the colorimeter software to help determine the cause of colorimeter malfunctions. If problems occur, perform these checks and record the readings before contacting a service center. The diagnostic sequence is initiated by turning the colorimeter off and then holding the **ABS/%T** key down while

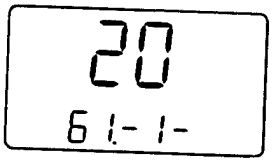
turning on the colorimeter again with the **I/O** key. The checks include:

-1- Power Supply Voltage with lamp on
-2- Power Supply Voltage with lamp off
-3- Lamp Voltage
-4- Lamp Intensity Set Point
-5- Sample Reading (in millivolts) before lamp turns on
-6- Sample Reading (in millivolts) at end of read sequence

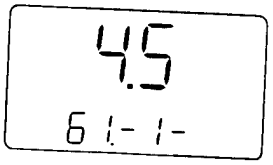
In the following procedure, the complete sequence is performed.

1. Place a sample cell containing clear water into the sample compartment. Close the sample compartment cover.

2. With the colorimeter off, press and hold down the **ABS/%T** key while pressing and releasing the **I/O** key. Hold the **ABS/%T** key until "-1-" appears in the lower display and the countdown begins.

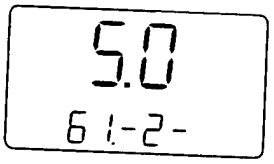


The readings for the complete diagnostics sequence take place at this time. At the end of the countdown, the power supply voltage with lamp on will appear in the upper display.

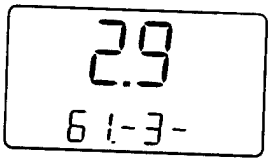


If the reading is less than 4.2 volts, batteries should be replaced (or recharged if NiCad).

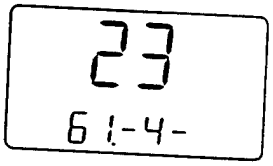
3. Press the **UP ARROW** key. Diagnostic -2- will be displayed showing the power supply voltage with lamp off. Voltage should not exceed 5.1 volts.

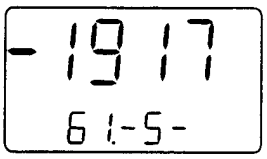


4. Press the **UP ARROW** key to go to the next diagnostic check. The lamp voltage, -3-, will be displayed as follows. The lamp voltage should fall within 2.0 to 3.3 volts.

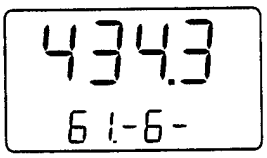


5. Press the **UP ARROW** key to go to the next diagnostic check. The lamp set point, diagnostic -4- is displayed as shown. It will fall between 1 and 31.





6. Press the **UP ARROW** key to check the sample reading before the lamp turns on. The millivolt reading should be within the -1800 to -2000 mV range. This will be diagnostic check -5-.



7. Press the **UP ARROW** key again to check the sample reading with the lamp on. The millivolt reading should fall within -1000 to +1000 mV range. An out of tolerance reading here may be the result of not doing a lamp intensity adjustment for the filter module installed. Record the reading and perform the lamp intensity adjustment procedure. *Refer to paragraph 2.2.2.* Rerun the diagnostic checks. This will be diagnostic check -6-.

One more press of the **UP ARROW** key will begin the diagnostic sequence again with check -1- and repeat the same readings. To perform another diagnostic sequence with new readings, press the **READ** key. There is no need to turn the colorimeter off at this point to perform a new diagnostic sequence.

8. To return to normal operation, press the **PROGRAM** key.

46014-88

DR/700
COLORIMETER
PROCEDURES MANUAL



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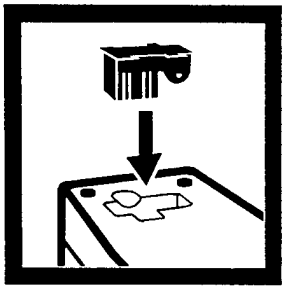
Method 8146

IRON, FERROUS (0 to 5.00 mg/L)

For water, wastewater and seawater

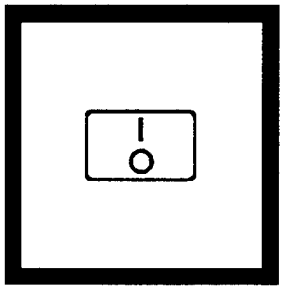
1,10 Phenanthroline Method*
(Powder Pillows or AccuVac Ampuls)

USING POWDER PILLOWS



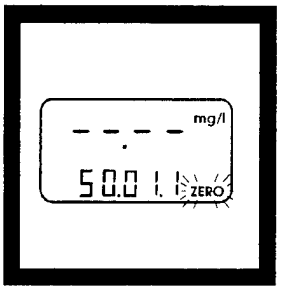
1. Install module
50.01
in a DR/700.

Note: Analyze samples as soon as possible to prevent air oxidation of ferrous iron to ferric iron, which is not measured.



2. Press: **I/O**

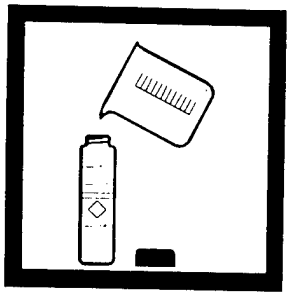
The display will show
500 nm
and module number
50.01



3. After 2 seconds, the display will show a program number, concentration units and the zero prompt. If necessary, press the **UP ARROW** key until the lower display shows program number
50.01.1

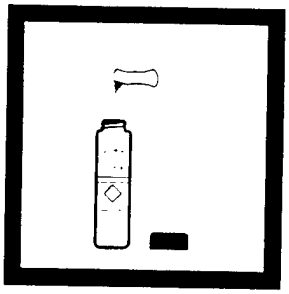
*Adapted from *Standard Methods for the Examination of Water and Wastewater*

IRON, FERROUS, continued



4. Fill a 25-mL cell to the 25-mL line with sample.

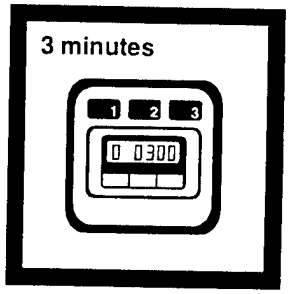
Note: For proof of accuracy, use a 1.00 mg/L ferrous standard solution (preparation given in Accuracy Check) in place of the sample.



5. Add the contents of one Ferrous Iron Reagent Powder Pillow to the sample cell (the prepared sample). Cap and invert to mix.

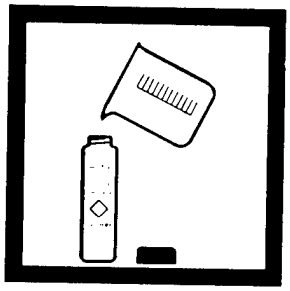
Note: An orange color will develop if ferrous iron is present.

Note: Undissolved powder does not affect accuracy.



6. Wait 3 minutes.

Note: Steps 7 and 8 can be completed during this reaction period.

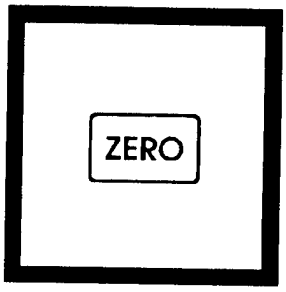


7. Fill a 25-mL cell to the 25-mL line with sample (the blank). Cap.



8. Place the blank in the cell holder.

Note: In bright light, put 10 mL in a 10-mL cell, insert it and close the cell compartment cover.



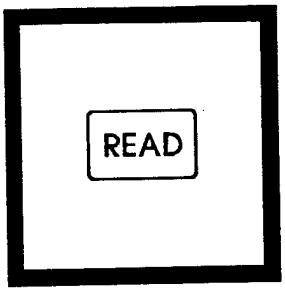
9. Press: **ZERO**

The display will count down to 0. Then the display will show 0.00 mg/L and the zero prompt will turn off.



10. Place the prepared sample in the cell holder.

Note: *In bright light, put 10 mL in a 10-mL cell, insert it and close the cell compartment cover.*

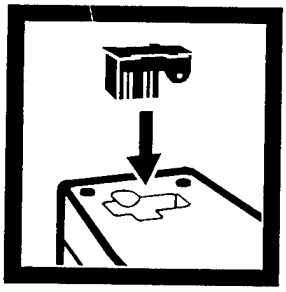


11. Press: **READ**

The display will count down to 0. Then the display will show the results in mg/L ferrous iron (Fe^{2+}).

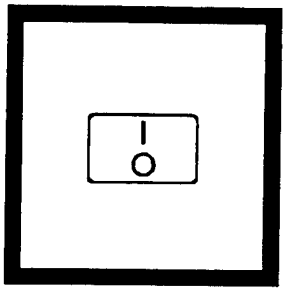
IRON, FERROUS, continued

USING ACCUVAC AMPULS



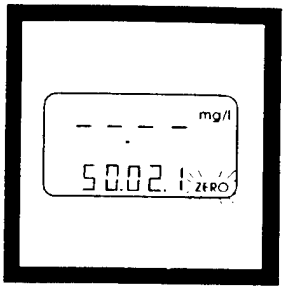
1. Install module
50.01
in a DR/700.

Note: Analyze samples as soon as possible to prevent air oxidation of ferrous iron to ferric iron, which is not measured.

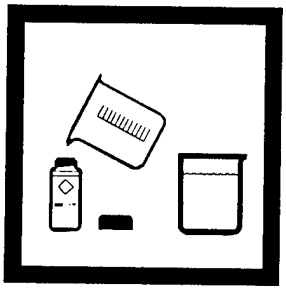


2. Press: **I/O**

The display will show
500 nm
and module number
50.01

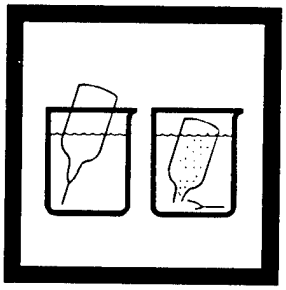


3. After 2 seconds, the display will show a program number, concentration units and the zero prompt. If necessary, press the **UP ARROW** key until the lower display shows program number
50.02.1



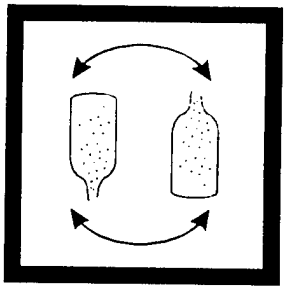
4. Fill a cell with 10 mL of sample (the blank). Cap. Collect at least 40 mL of sample in a 50-mL beaker.

***Note:** In bright light use a 10-mL cell.*



5. Fill a Ferrous Iron AccuVac Ampul with sample.

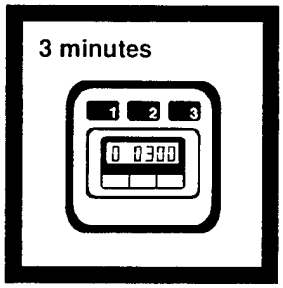
Note: Keep the tip immersed while the ampul fills completely.



6. Quickly invert the ampul several times to mix. Wipe off any liquid or fingerprints.

***Note:** An orange color will develop if ferrous iron is present.*

***Note:** Undissolved powder does not affect accuracy.*

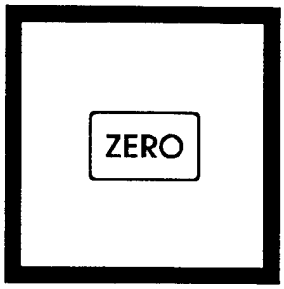


7. Wait 3 minutes.



8. Place the blank in the cell holder.

Note: In bright light close the cell compartment cover.



9. Press: **ZERO**

The display will count down to 0. then the display will show 0.00 mg/L and the zero prompt will turn off.

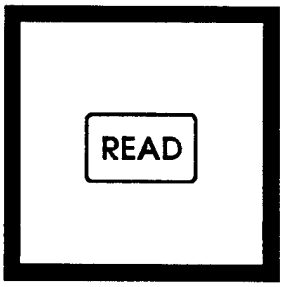


10. Insert the AccuVac Vial Adapter into the cell holder.



11. Place the prepared sample in the cell holder.

Note: In bright light close the cell compartment cover.



12. Press: **READ**

The display will count down to 0. Then the display will show the results in mg/L ferrous iron (Fe^{2+}).

ACCURACY CHECK

Standard Solution Method

Prepare a ferrous iron stock solution (100 mg/L Fe^{2+}) by dissolving 0.7022 grams of Ferrous Ammonium Sulfate, hexahydrate, in demineralized water. Dilute to 1 liter. Prepare immediately before use. Dilute 1.0 mL of this solution to 100 mL with demineralized water to make a 1.0 mg/L standard solution. Prepare this immediately before use.

STATISTICAL EVALUATION

A single operator repetitively tested samples of two laboratory prepared solutions, using one DR/700, matched sample cells and two representative lots of testing reagents. Testing 1.50 mg/L Fe^{2+} concentration samples, the standard deviation was ±0.008 mg/L Fe^{2+}.

Testing zero concentration samples, the limit of detection was 0.007 mg/L Fe^{2+}. The limit of detection was calculated as three times the standard deviation whin testing zero concentration samples (Adapted from *Analytical Chemistry*, **1980**, 52, 2242-2249).

Using two representative lots of Ferrous Iron AccuVac Ampuls, the standard deviation was 0.014 mg/L Fe^{2+}.

SUMMARY OF METHOD

The 1,10 phenanthroline indicator in Ferrous Iron Reagent reacts with ferrous iron in the sample to form an orange color in proportion to the iron concentration. Ferric iron does not interfere. The ferric iron (Fe^{3+}) concentration can be determined by subtracting the ferrous iron concentration from the results of a total iron test.

REQUIRED REAGENTS (Using Powder Pillows)

Description	Quantity per test	Unit	Cat. No.
Ferrous Iron Reagent			
Powder Pillows, 25-mL	1 pillow	100/pkg	1037-69

REQUIRED APPARATUS (Using Powder Pillows)

Clippers, large,			
for opening pillows	1	each	968-00
DR/700 Filter Module			
Number 50.01	1	each	46250-00

IRON, FERROUS, continued

REQUIRED REAGENTS (Using AccuVac Ampuls)

Description	Quantity per test	Unit	Cat. No.
Ferrous Iron Reagent			
AccuVac Ampuls	1 ampul	25/pkg	25140-25

REQUIRED APPARATUS (Using AccuVac Ampuls)

Beaker, 50 mL	1	each	500-41
DR/700 Filter Module			
Number 50.01	1	each	46250-00

OPTIONAL REAGENTS

Ferrous Ammonium Sulfate,			
Hexahydrate, ACS	113 g		11256-10
Water, demineralized	4 L		272-56

OPTIONAL APPARATUS

AccuVac Snapper Kit		each	24052-00
Adapter, AccuVac Vial, DR/700		each	46025-00
Cap for 10- and 25-mL sample cells		12/pkg	24018-12
Flask, volumetric, 100 mL		each	547-42
Flask, volumetric, 1000 mL		each	547-53
Pipet, volumetric, 1 mL		each	515-35
Pipet Filler, safety bulb		each	14651-00
Sample Cell, 10-mL with screw cap		6/pkg	24276-06
Sample Cell, 25-mL with screw cap		6/pkg	24019-06

For Technical Assistance, Prices and Ordering

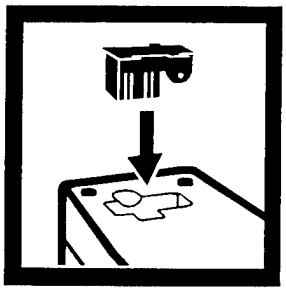
In the U.S.A. - Call 800-227-4224 toll-free for more information

Outside the U.S.A. - Contact the Hach Office or distributor serving you.

MANGANESE, HR (0 to 20.0 mg/L)

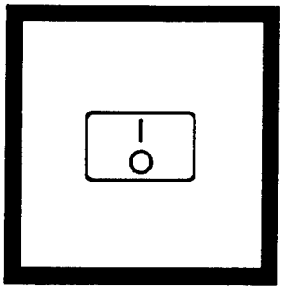
For water and wastewater

Periodate Oxidation Method*; USEPA approved for reporting†
Digestion is required; see Section 1.



1. Install module number
52.01
in a DR/700.

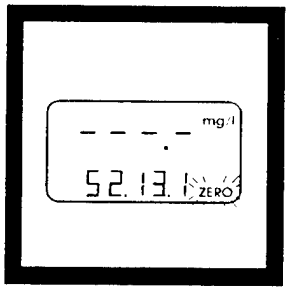
Note: If samples cannot be analyzed immediately, see Sampling and Storage following these steps. Adjust the pH of stored samples before analysis.



2. Press: **I/O**

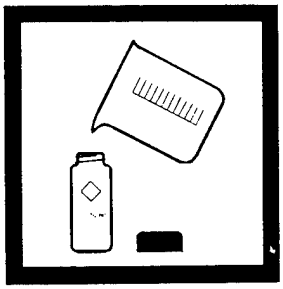
The display will show
525 nm
and module number
52.01

Note: Total manganese determination requires prior digestion; use either the Digesdahl or mild digestion (Section 1).



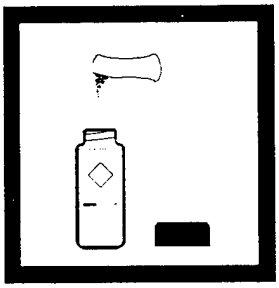
3. After 2 seconds, the display will show a program number, the concentration units, decimal position and the zero prompt. If necessary, press the **UP ARROW** key until the lower display shows program number
52.13.1

*Adapted from *Standard Methods for the Examination for Water and Wastewater*
†*Federal Register*, **June 14, 1979** *44*(116), 34193.



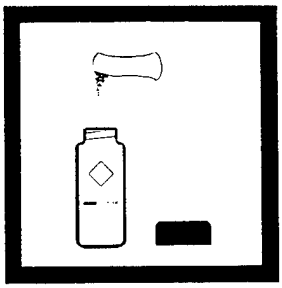
4. Fill a 10-mL cell to the 10 mL line with sample.

Note: A 25-mL sample can be tested by using 25-mL sample cells and optional reagents.



5. Add the contents of one Buffer Powder Pillow, citrate type. Swirl to mix.

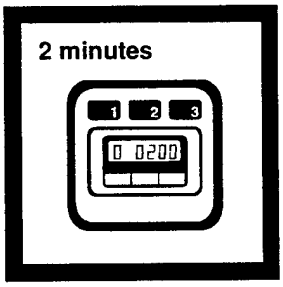
Note: For proof of accuracy, use a 5.0 mg/L manganese standard solution (preparation given in Accuracy Check) in place of the sample.



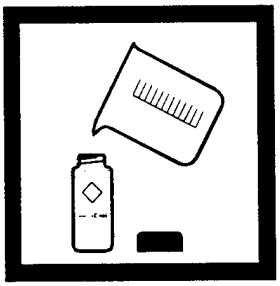
6. Add the contents of one Sodium Periodate Powder Pillow to the sample cell (the prepared sample). Cap and invert several times to mix.

Note: *A violet color will develop if manganese is present.*

Note: *Accuracy is not affected by undissolved powder.*



7. Wait 2 minutes.

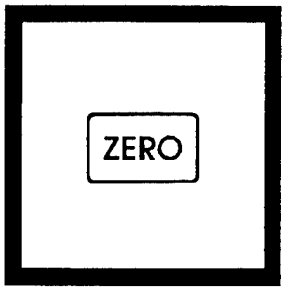


8. Fill a 10-mL cell to the 10-mL line with sample (the blank). Cap.



9. Place the blank in the cell holder.

Note: *In bright sunlight it may be necessary to close the cell compartment cover.*



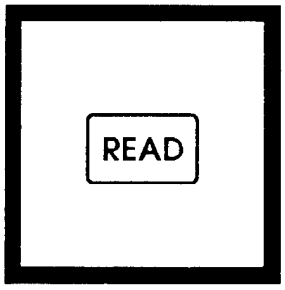
10. Press: **ZERO**

The display will count down to 0. Then the display will show 0.0 mg/L and the zero prompt will turn off.



11. Within eight minutes after the 2-minute period, place the prepared sample in the cell holder.

Note: In bright sunlight it may be necessary to close the cell compartment cover.



12. Press: **READ**

The display will count down to 0. Then the display will show the results in mg/L manganese (Mn).

Note: To convert results to other units, see Table 1.

Table 1. Conversion Factors

To convert results from	To	Multiply by
mg/L Mn	mg/L MnO_4-	2.16
mg/L Mn	mg/L $KMnO^4$	2.88

SAMPLING AND STORAGE

Collect samples in acid-washed plastic bottles. Manganese may be lost by adsorption to glass container walls. Adjust the pH to 2 or less with nitric acid (about 2 mL per liter). Preserved samples may be stored at room temperature for 6 months. Adjust the pH to 4 to 5 with 5.0 N sodium hydroxide before analysis. Do not exceed pH 5, as manganese may be lost as a precipitate. Correct the test result for volume additions; see Sampling and Storage, Volume Additions, (Section I) for more information.

If only dissolved manganese is to be determined, filter the sample before acid addition.

ACCURACY CHECK

Standard Additions Method

a) Snap the neck off a Manganese Voluette Ampule Standard Solution, High Range, 250 mg/L Mn.

b) Use the TenSette Pipet to add 0.1, 0.2 and 0.3 mL of standard to three 25-mL water samples. Mix thoroughly.

c) Analyze each sample as described above. The manganese concentration should increase 1.0 mg/L for each 0.1 mL of standard added.

d) If these increases do not occur, see Standard Additions (Section 1) for more information.

Standard Solution Method

Prepare a 5.0-mg/L manganese standard solution by pipetting 5.00 mL of Manganese Standard Solution, 1000 mg/L Mn, into a 1000-mL volumetric flask. Dilute to the mark with demineralized water. Or, prepare this standard by diluting 1.00 mL of the contents of a Voluette Ampule For High Range Manganese to 50 mL, using the TenSette Pipet. Prepare these solutions daily.

INTERFERENCES

The following may interfere when present in concentrations exceeding those listed below:

Calcium	700 mg/L
Chloride	70,000 mg/L

Iron	5 mg/L
Magnesium	100,000 mg/L

Highly buffered samples or extreme sample pH may exceed the buffering capacity of the reagents and require sample pretreatment; see Interferences, pH (Section I).

STATISTICAL EVALUATION

A single operator repetitively tested samples of two laboratory prepared solutions, using one DR/700, matched sample cells and two representative lots of testing reagents. Testing 10.0 mg/L Mn concentration samples, the standard deviation was ±0.11 mg/L Mn.

Testing zero concentration samples, the limit of detection was calculated as three times the standard deviation when testing zero concentration samples (Adapted from *Analytical Chemistry*, **1980,** 52, 2242-2249).

SUMMARY OF METHOD

Manganese in the sample is oxidized to the purple permanganate state by sodium periodate, after buffering the sample with citrate. The purple color is directly proportional to the manganese concentration. If only dissolved manganese is to be determined, filter the sample before acid addition.

REQUIRED REAGENTS

Description	Quantity Per Test	Unit	Cat. No.
Buffer Powder Pillows, citrate type for manganese, 10 mL	1 pillow	50/pkg	21076-69
Sodium Periodate Powder Pillows for manganese, 10 mL	1 pillow	100/pkg	21077-69

REQUIRED APPARATUS

Clippers, for opening powder pillows	1	each	968-00
DR/700 Filter Module Number 52.01	1	each	46252-00

OPTIONAL REAGENTS

Buffer Powder Pillows, Citrate, 25 mL (for manganese)	100/pkg	983-99
Hydrochloric Acid, 6N	500 mL	884-49

OPTIONAL REAGENTS (continued)

Description	Unit	Cat. No.
Manganese Standard Solution, 1000 mg/L Mn	100 mL*	12791-42
Manganese Standard Solution, Voluette ampule, High Range, 250 mg/L Mn, 10 mL	16/pkg	14258-10
Nitric Acid, ACS	500 mL	152-49
Nitric Acid Solution 1:1	500 mL	2540-49
Sodium Hydroxide Standard Solution, 1.0 N	100 mL MDB	1045-32
Sodium Hydroxide Standard Solution, 5.0 N	100 mL MDB	2450-32
Sodium Periodate Powder Pillows, 25 mL	100/pkg	984-99
Water, demineralized	4 L	272-56

OPTIONAL APPARATUS

Ampule Breaker Kit	each	21968-00
Cap for 10- and 25-mL sample cells	12/pkg	24018-12
Dropper, plastic, 0.5 and 1.0 mL marks	10/pkg	21247-10
Flask, volumetric, Class A, 50 mL	each	14574-41
Flask, volumetric, Class A, 100 mL	each	14574-42
Flask, volumetric, Class A, 1000 mL	each	14574-53
pH Indicator Paper, 1 to 11 pH	5 rolls/pkg	391-33
pH Meter, EC10, portable	each	50050-00
Pipet, serological, 1 mL	each	532-35
Pipet, serological, 5 mL	each	532-37
Pipet, TenSette, 0.1 to 1.0 mL	each	19700-01
Pipet Tips, for 19700-01 TenSette Pipet	50/pkg	21856-96
Pipet, volumetric, 5.0 mL	each	14515-37
Pipet Filler, safety bulb	each	14651-00
Sample Cell, 10-mL with screw cap	6/pkg	24276-06
Sample Cell, 25-mL with screw cap	6/pkg	24019-06

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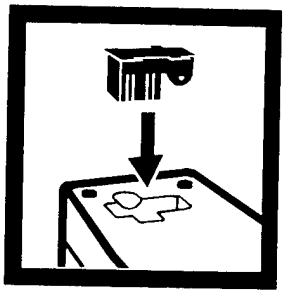
In the U.S.A. - Call 800-227-4224 toll-free for more information.
Outside the U.S.A. - Contact the Hach office or distributor serving you.

*Contact Hach for larger sizes.

SULFIDE (0 to 0.600 mg/L S^{2-})

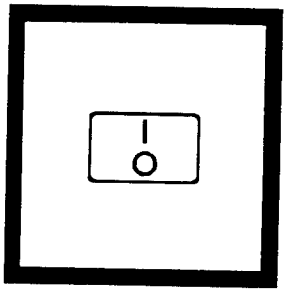
For water, wastewater and seawater

Methylene Blue Method*; USEPA accepted for reporting**



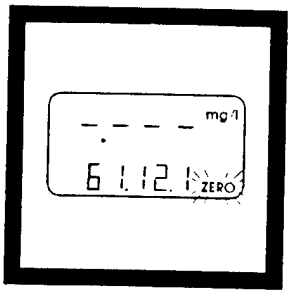
1. Install module **61.01** in a DR/700.

Note: Samples must be analyzed immediately and cannot be preserved for later analysis. Avoid excessive agitation.

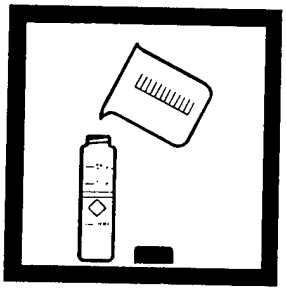


2. Press: **I/O**

The display will show **610 nm** and module number **61.01**

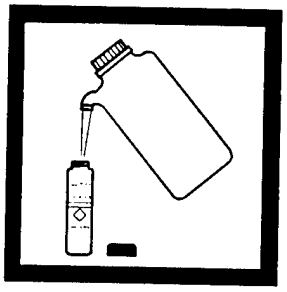


3. After 2 seconds, the display will show a program number, concentration units, decimal position and the zero prompt. If necessary, press the **UP ARROW** key until the lower display shows program number **61.12.1**

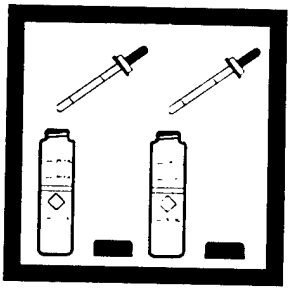


4. Fill a 25-mL sample cell to the 25 mL line with sample (the prepared sample).

Note: For turbid samples, see Interferences following these steps for pretreatment instructions.

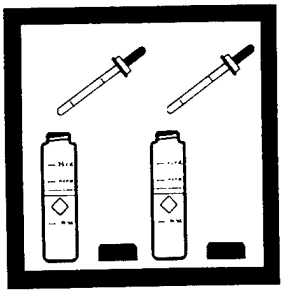


5. Fill another 25-mL cell to the 25 mL line with demineralized water (the blank).



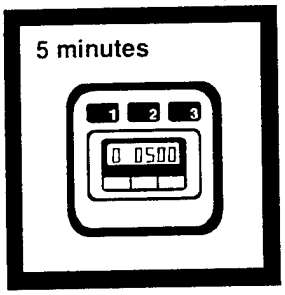
6. Add 1.0 mL of Sulfide 1 Reagent to each cell. Swirl to mix.

*Adapted from *Standard Methods for the Examination of Water and Wastewater.*
**Procedure is equivalent to USEPA method 376.2 and Standard Method 4500-S^{2-}D for wastewater.



7. Add 1.0 mL of Sulfide 2 Reagent to each cell and cap. Immediately swirl to mix.

Note: *A pink color will develop. Then the solution will turn blue if sulfide is present.*

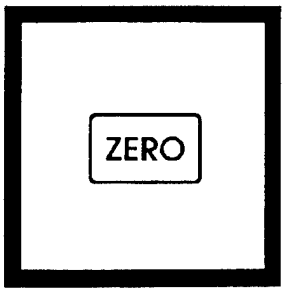


8. Wait 5 minutes.



9. Place the blank in the cell holder.

Note: *Typical indoor lighting permits the DR/700 to operate with the cell compartment cover open. In bright sunlight, it may be necessary to close the cell compartment cover. Transfer 10 mL of the blank solution to a 10-mL cell. If the 10-mL cell is used for the blank, another 10-mL cell must be used for the sample.*



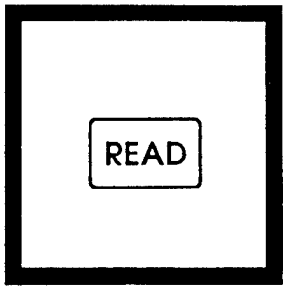
10. Press: **ZERO**

The display will count down to 0. Then the display will show 0.000 mg/L and the zero prompt will turn off.



11. Immediately place the prepared sample into the cell holder.

Note: Typical indoor lighting permits the DR/700 to operate with the cell compartment cover open. In bright sunlight, it may be necessary to close the cell compartment cover. Transfer 10 mL of the blank solution to a 10-mL cell. If the 10-mL cell is used for the blank, another 10-mL cell must be used for the sample.



12. Press: **READ**

The display will count down to 0. Then the display will show the results in mg/L sulfide (S^{2-}).

ACCURACY CHECK

Standard Solution Method

Sulfide standard solutions are very unstable and should be prepared from sodium sulfate and standardized as described in *Standard Methods for the Examination of Water and Wastewater,* 17th ed., page 4-195.

STATISTICAL EVALUATION

A single operator repetitively tested samples of two laboratory prepared solutions using one DR/700, matched sample cells and two representative lots of testing reagents, Testing 0.595 mg/L S^{2-} concentration samples, the standard deviation was ±0.008 mg/L S^{2-}.

Testing zero concentration samples, the limit of detection was 0.010 mg/L S^{2-}. The limit of detection was calculated as three times the standard deviation when testing zero concentration samples (Adapted from *Analytical Chemistry,* **1980,** *52,* 2242-2249).

INTERFERENCES

For turbid samples, prepare a sulfide-free blank as follows. Use it in place of the demineralized water blank in the procedure.

a) Measure 25 mL of sample into a 50-mL erlenmeyer flask.

b) Add Bromine Water dropwise with constant swirling until a yellow color remains.

c) Add Phenol Solution dropwise until the yellow color just disappears. Use of this blank solution will compensate for turbidity in the sample.

Strong reducing substances such as sulfite, thiosulfate and hydrosulfite interfere by reducing the blue color or preventing its development. High concentrations of sulfide may inhibit full color development and require sample dilution. Some sulfide loss may occur when the sample is diluted.

SUMMARY OF METHOD

Hydrogen sulfide and acid-soluble metal sulfides react with N,N-dimethyl-p-phenylenediamine oxalate to form methylene blue. The intensity of the blue color is proportional to the sulfide concentration.

High sulfide levels in oil field waters may be determined after proper dilution.

Determine soluble sulfides by centrifuging the sample in completely filled, capped tubes and analyzing the supernatant. Insoluble sulfides are then estimated by subtracting the soluble sulfide concentration from the total sulfide result.

REQUIRED REAGENTS

	Cat. No.
Sulfide Reagent Set (100 tests)	22445-00
Includes: (2) 1816-14, (2) 1817-14	

Description	Quantity Per Test	Unit	Cat. No
Sulfide 1 Reagent	2 mL	100 mL MDB	1816-32
Sulfide 2 Reagent	2 mL	100 mL MDB	1817-32

REQUIRED APPARATUS

Description	Quantity Per Test	Unit	Cat. No
DR/700 Filter Module Number 61.01	1	each	46261-00

OPTIONAL REAGENTS

Bromine Water, 30 g/L	29 mL	2211-20
Phenol Solution, 30 g/L	29 mL	2112-20
Sodium Sulfide, ACS	114 g	785-14

OPTIONAL APPARATUS

Cap for 10- and 25- mL sample cells	12/pkg	24018-12
Cylinder, graduated, 25 mL	each	508-40
Dropper, for 1 oz bottle	each	2258-00
Flask, erlenmeyer, 50 mL	each	505-41
Sample Cell, 10-mL with screw cap	6/pkg	24276-06
Sample Cell, 25-mL with screw cap	6/pkg	24019-06
Standard Methods for the Examination of Water and Wastewater, 18th ed.	each	22708-00

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ACCURACY AND PRECISION

Accuracy is the nearness of a test result to the true value. Precision refers to the agreement of a set of replicate results or repeatability. Although good precision suggests good accuracy, precise results can be inaccurate. The following paragraphs describe techniques to improve accuracy and precision of analysis.

Standard Additions

Standard additions is a widely accepted technique for checking the validity of test results. Also known as "spiking" and "known additions," the technique also can be used to check the performance of the reagents, the instrument and apparatus, and the procedure.

Standard additions is performed by adding a small amount of a standard solution containing a known amount of the component being measured to an analyzed sample and repeating the analysis—using the same reagent, instrument and technique. The amount of increase in the test result should equal exactly the amount of component added.

For example, if testing shows a 25-mL water sample analyzed for iron contains 1.0 mg/L, the result can be checked by adding 0.10 mL of a 50.0-mg/L iron standard solution to another 25-mL portion of the water sample and repeating the analysis. The result of the analysis on the second sample should be 1.2 mg/L iron because the standard added an equivalent of 0.2 mg/L. For example:

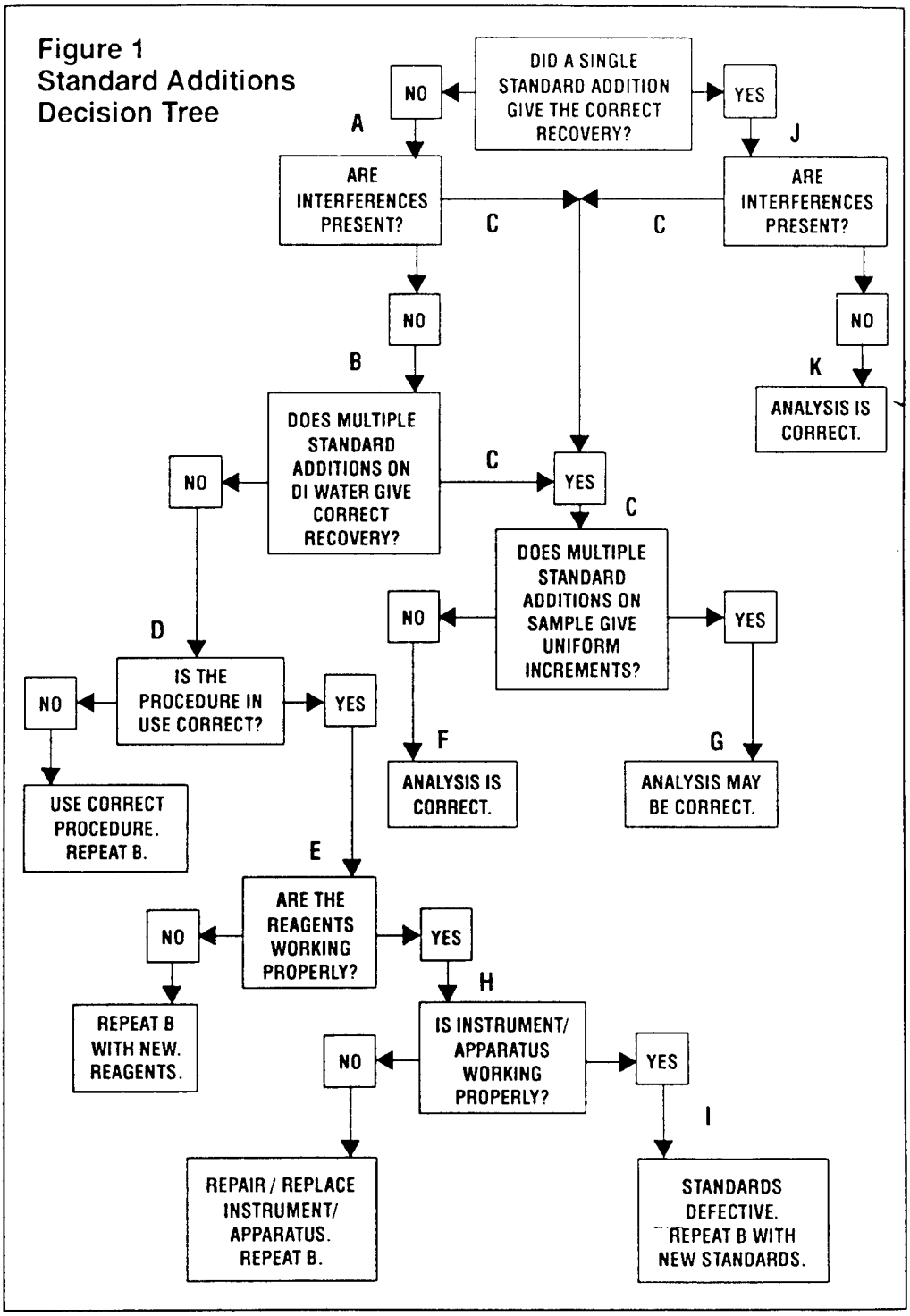
$$\frac{0.10\ \text{mL} \times 50.0\ \text{mg/L}}{25\ \text{mL}} = 0.2\ \text{mg/L}$$

If 0.2 mg/L is recovered from the 0.2 mg/L addition, the analyst can conclude the first answer was correct and the reagents, instrument and method used are all working properly. Because the effect of incremental volume additions is small, the sample volume used in the above equation was 25 mL (not 25 + 0.1). Using 25 mL, instead of 25.1 mL, represents less than 0.4% error. For 0.3 mL standard addition, the error would be less than 1.2% error.

If the second analysis does not give the correct amount of increase in the iron content, it must be concluded the first answer also may be incorrect. The analyst must determine why the technique did not work. The source of the problem can be determined by using a logical troubleshooting

approach whether the fault lies in the reagent, the instrument and apparatus, the test procedure or an interfering substance present in the test sample. A decision tree, such as the one in *Figure 1*, establishes a systematic method for identifying the problem. Request Hach Publication 7004 for additional information on standard additions. Explanations of the various steps follow.

Figure 1
Standard Additions Decision Tree



Branch A

Suppose a single standard addition to the sample did not give the correct concentration increase. A possible cause could be interferences. Other causes could be defective reagents, an incorrect procedure, a defective instrument and apparatus or a defective standard used for standard additions. If interferences are known or assumed to be absent, proceed to Branch B. If interferences are known to be present, proceed to Branch C.

Branch B

Perform multiple standard additions on a sample of deionized water as in the following example:

1. Conduct an iron analysis on a 25.0-mL sample of deionized water.

2. Add 0.1 mL of a 50-mg/L iron standard solution to a second 25.0-mL sample of deionized water. Analyze this sample for iron.

3. Add 0.2 mL of a 50-mg/L iron standard solution to a third 25.0-mL sample of deionized water. Analyze this sample for iron.

4. Add 0.3 of a 50-mg/L iron standard solution to a fourth 25.0-mL sample of deionized water. Analyze this sample for iron.

5. Tabulate the data as shown below.

mL Std. Added	mg/L Std. Added	mg/L Iron Found
0	0	0
0.1	0.2	0.2
0.2	0.4	0.4
0.3	0.6	0.6

The data shown above indicates several points upon which the following conclusions may be made: First, the chemicals, instrument, procedures and standards are working correctly because iron added to the deionized water sample was recovered entirely in the same uniform steps of addition. Second, because iron added to deionized water was recovered, but was not recovered when an addition was made to an actual water sample (Branch A), the sample contains interferences which prevent the test reagents from operating properly. Third, the first sample analysis gave an incorrect result.

If the results of multiple standard additions gave the correct increments between additions, proceed to Branch C. If the results of multiple standard additions gave other than the correct increments between additions, proceed to Branch D.

Branch C

If interfering ions are present, the analysis may be incorrect. However, it may be possible, with multiple standard additions, to arrive at a close approximation of the correct result. Suppose the result of a sample analyzed for iron was 1.0 mg/L. The analyst, knowing interfering ions could be present, made one standard addition of 0.1 mL of 50-mg/L iron standard to 25.0 mL of sample. Rather than finding an increase of 0.2 mg/L as expected, the analyst found an increase of 0.1 mg/L. The analyst took a third and fourth water sample and added a standard addition of 0.2 and 0.3 mL, respectively. Samples were analyzed and results tabulated. If steps between each addition are roughly uniform (i.e., 0.1 mg/L difference between each addition), proceed to Branch G. If the results are not uniform (i.e., 0.1, 0.08, and 0.05 mg/L), proceed to Branch F.

Branch D

Carefully check the instructions or directions for use of the test, making sure the proper reagents are used in the proper order and time, the colorimeter is adjusted for the correct wavelength and calibration and the glassware in use is that specified. Be sure time for color development and the sample temperature are exactly as specified. If the procedure in use is found to be in error, repeat Branch B using the correct procedure. If the procedure is found to be correct, proceed to Branch E.

Branch E

Check the performance of the reagents. This may be done easily by obtaining a new fresh lot of reagent or by using a known standard solution to run the test. Make sure the color development time given in the procedure is equal to or greater than the time required for the reagent in question. If it is determined reagents are defective, repeat Branch B with new reagents. If the reagents are proven in good condition, proceed with Branch H.

Branch H

Check operation of the instrument and/or apparatus used in the performance of the test. Perform the wavelength and linearity checks

given in your instrument manual. Check glassware used in the procedure, making sure that it is scrupulously clean. Dirty pipets and graduated cylinders are sources of contamination and will not deliver the correct volumes. Hach's TenSette Pipet for dispensing Standards and standards sealed in Voluette Ampules are ideal for standard additions.

If a defect is found in the instrument and/or apparatus, repeat Branch B after repair or replacement of the instrument and/or apparatus. If the instrument and apparatus are found to be in good working order, proceed with Branch I.

Branch I

After determining the procedure, reagents, instrument and/or apparatus are correct and operating properly, an analyst may conclude the only possible cause for standard additions not functioning properly in deionized water is the set of standards used in performing the standard additions. Obtain a new set of standards and repeat Branch B.

Branch F

Examples of non uniform increments between standard additions are shown below.

Example A:

mL Std. Added	mg/L Std. Added	mg/L Found
0	0	1.0
0.1	0.2	1.10
0.2	0.4	1.18
0.3	0.6	1.23

Example B:

mL Std. Added	mg/L Std. Added	mg/L Found
0	0	0
0.1	0.2	0
0.2	0.4	0.2
0.3	0.6	0.4

The two examples illustrate the effect of interferences on the standard addition and on substances in the sample. Data plotted on the *Figure 2*

graph as A and B show that the four data points do not lie on a straight line. Plot A illustrates an interference becoming progressively worse as the concentration of the standard increases. This type of interference is not common and may be caused by an error or malfunction of the procedure, reagents or instrument. It is recommended Branch B be performed to verify the supposed interference.

Plot B illustrates a common chemical interference which becomes less or even zero as the concentration of the standard increases. The graph of the example shows the first standard addition was consumed by the interference and the remaining additions gave the correct incremental increase of 0.2 mg/L.

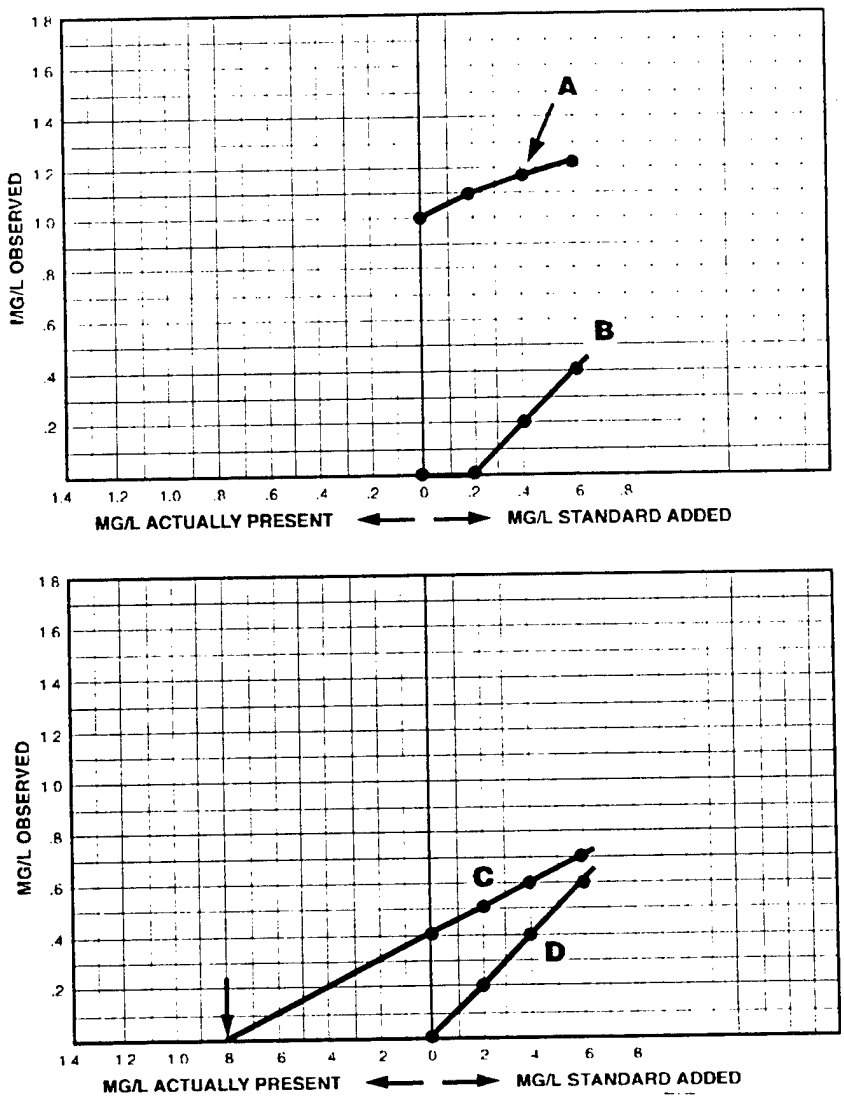


Figure 2 **Multiple Standard Additions Graph**

The apparent interference in Example B could be the result of an error made in the standard addition. The analysis should be repeated.

The two examples illustrate chemical interferences which most certainly mean the result of the first analysis of the water sample was incorrect. When this type of interference occurs, the analyst should attempt to analyze the sample with an alternate method which uses a different type of chemistry.

Branch G

Examples of uniform increments between standard additions are given below.

Example C:

mL Std. Added	mg/L Std. Added	mg/L Found
0	0	0.4
0.1	0.2	0.5
0.2	0.4	0.6
0.3	0.6	0.7

Plot C illustrates a common interference with a uniform effect upon the standard and the substances in the sample. The four data points form a straight line which may be extrapolated back through the horizontal axis. The point intersection with the horizontal axis can be used to determine the concentration of the substance in question. In the example, the first analysis showed 0.4 mg/L. The result located graphically should be much closer to the correct result: 0.8 mg/L.

Apparent interferences also may be caused by a defect in the instrument or the standards. Before assuming the interference is chemical in nature, check Branch B.

Example D:

mL Std. Added	mg/L Std. Added	mg/L Found
0	0	0
0.1	0.2	0.2
0.2	0.4	0.4
0.3	0.6	0.6

Plot D illustrates a problem for the analyst. Increments found are uniform and the recovery of the standard was complete. The result of the first analysis was 0 mg/L and the graph plots back through 0 mg/L. If interferences are known to be present, the interference may be present in an amount equal to the substance in question, thereby preventing the analyst from finding the substance. This would be an uncommon situation.

Branch J

If the standard addition gives the correct result, the analyst must then determine if interfering substances are present. If interfering substances are not present, the result of the analysis prior to the standard addition is correct. If interfering substances are present, proceed to Branch C.

One of the greatest aids to the analyst is knowledge of the sample's composition. An analyst need not know the exact composition of each sample but should be aware of potential interferences in the method of analysis to be used. When performing a particular method, the analyst should know if those interferences are present or not in order to have confidence in the accuracy of the results.

INTERFERENCES

Many analytical determinations are subject to interference from substances that may be present in the sample. Most common interferences are mentioned either in the test procedures or in the accompanying notes. Our reagent formulations eliminate many interferences and others are removed by special sample pretreatments described in the procedure.

Interference also may be caused by a high concentration of the constituent under analysis. For example, the presence of a larger excess of chlorine will cause the test to read less than full scale. Dilution of the sample to 5 mg/L will result in a reading higher than full scale. This indicates the need for more dilution until the instrument reading is "on scale."

When an unusual answer is obtained, a color other than that expected is formed, or an unusual odor or turbidity is noticed, the result is suspect. Repeat the test on a sample diluted with deionized water; see *Sample Dilution Techniques*. Compare the result (corrected for the dilution) with the result of the original test. If these two are not identical, the original result probably is in error and an additional dilution should be made to check the second test (first dilution). This process is repeated until the same corrected result is obtained on two successive dilutions.

More complete information about interferences and methods to overcome them is contained in the General Introduction Section of APHA *Standard Methods*. The analyst is urged to obtain this book and refer to it when problems are encountered.

pH Interference

Many of the procedures in this manual are pH dependent. Hach reagents contain built-in buffers to adjust the pH of the typical sample to the correct pH range. However, the reagent buffer capacity may not be sufficient for some unusual samples. This occurs most often with highly buffered samples or samples with extreme sample pH. Check for pH interference in the following manner:

1. From the Sampling and Storage section of your procedure determine the optimum pH range of the test. This is the pH the preserved sample is adjusted to just before running the test. For some procedures this information may not be given. If the pH of your sample is within the optimum pH range, buffering is not needed.

2. Measure the pH of your analyzed sample with a pH meter.

3. Prepare a reagent blank using deionized water as the sample, add all reagents called for in the procedure. Timer sequences, etc., may be ignored. Mix well.

4. Measure the pH of the reagent blank with a pH meter.

5. Compare the pH values of your analyzed sample with the reagent blank.

6. If there is no difference in the pH values of your analyzed sample and the reagent blank, then pH interference is not the problem. Follow the Accuracy Check given in the procedure to more clearly identify the problem.

7. If there is a significant difference between the values of your analyzed sample and the reagent blank, adjust the sample pH to within the optimum pH test range, or if none is given, to the value of the reagent blank before analysis on all future determinations. Use the appropriate acid, usually nitric acid, to lower the pH, and use the appropriate base, usually sodium hydroxide, to raise the pH.

8. Analyze the sample as before.

Interference From Stray Light

Typical indoor lighting permits the DR/700 to operate with the cell compartment cover open. In bright sunlight, it may be necessary to close the cell compartment cover. If a 25-mL cell is used in the procedure, transfer 10 mL of the solution to a 10-mL cell. If the 10-mL cell is used for the blank, another 10-mL cell must be used for the sample.

Sample Dilution Techniques

Ten and Twenty-five milliliter (mL) are the specified volumes for most colorimetric tests. However, in some tests, the color developed in the sample may be too intense to be measured. Unexpected colors may develop in other tests. In both cases, it is necessary to dilute the sample or determine if interfering substances are present.

For example, when performing the chromium tests, the colorimeter may detect a concentration above the maximum range limit. This results in a flashing maximum concentration value in the display. A sample solution is necessary. The test can be repeated, for example, with a 25-mL graduated cylinder filled to the 5-mL mark with the sample and then to the 10-mL mark with deionized water. Because the sample was diluted to twice its original volume (5 mL to 10 mL), the test result should be multiplied by 2 to give the correct concentration of chromium.

To accomplish the sample dilution conveniently, pipet the chosen sample portion into a clean graduated cylinder (or clean volumetric flask for more accurate work) and fill the cylinder (or flask) to the desired volume with deionized water. Mix well. Use the diluted sample when running the test.

As an aid, Table 5 shows the amount of sample taken, the amount of deionized water used to bring the volume up to 25 mL and the multiplication factor.

Table 5. Sample Dilutions

Sample Volume (mL)	Deionized Water Used to Bring the Volume to 25 mL (mL)	Multiplication Factor
25.0	0.0	1
12.5	12.5	2
10.0*	15.0	2.5
5.0*	20.0	5
2.5*	22.5	10
1.0*	24.0	25
0.250*	24.75	100

*For sample sizes of 10 mL or less, a pipet should be used to measure the sample into the graduated cylinder or volumetric flask.

The concentration of the sample is equal to the diluted sample reading times the multiplication factor.

An example: A 2.5 mL sample was diluted with 22.5 mL of deionized water. The result was 0.35 mg/L. What is the concentration of the sample?

$$0.35 \times 10 = 3.5 \text{ mg/L}$$

More accurate dilutions can be done with a pipet and a 100-mL volumetric flask. Pipet the sample and dilute to volume with deionized water. Invert several times to mix.

Table 6. Multiplication factors to be used when sample is diluted to 100 mL

Sample Volume (mL)	Multiplication Factor
1	100
2	50
5	20
10	10
25	4
50	2

Sample dilution also influences the level at which a substance may interfere. The effect of the interferences decreases as the sample size decreases. Therefore, the effect of the interference described in the procedure notes will decrease as the sample size decreases. In other words, higher levels of an interfering substance can be present if the sample is diluted.

An example: Copper does not interfere at or below 100 mg/L for a 25.00 mL sample in a procedure. If the sample volume is diluted with an equal volume of water, what is the level at which copper will not interfere?

$$\frac{\text{Total Volume}}{\text{Sample Volume}} = \text{Dilution Factor}$$

$$\frac{25}{12.5} = 2$$

$$\text{Interference level} \times \text{Dilution factor} = \text{Interference level in sample}$$

$$100 \times 2 = 200 \text{ mg/L}$$

The level at which copper will not interfere in the sample is at or below 200 mg/L.

Temperature Considerations

For best results, most tests described in this manual should be performed with sample temperatures between 20 °C (68 °F) and 25 °C (77 °F). If certain tests require closer temperature control, that requirement will be indicated in notes following those procedures.

Use of Pipets and Graduated Cylinders

When small sample quantities are used, the accuracy of measurements is important. *Figure 6* illustrates the proper way of reading the sample level or the meniscus formed when the liquid wets the cylinder or pipet walls.

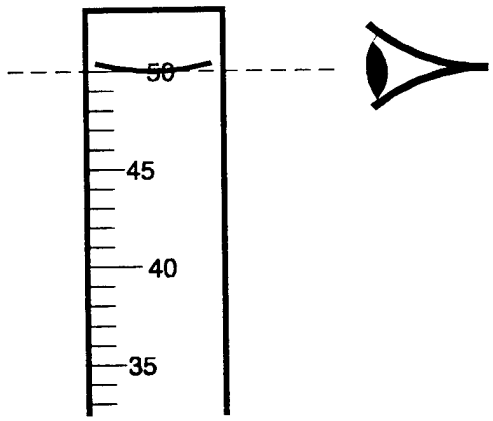


Figure 6 **Reading the Meniscus**

Rinse the pipet or cylinder two or three times with the sample to be tested before filling. Use a pipet filler or pipet bulb to draw the sample into the pipet. Never pipet chemical reagent solutions or samples by mouth. When filling a pipet, keep the tip of the pipet below the surface of the sample as the sample is drawn into the pipet.

Serological pipets are long tubes with a series of calibrated marks to indicate the volume of liquid delivered by the pipet. The calibrated marks may extend to the tip of the pipet or may be only on the straight portion of the tube. Fill serological pipets to the zero mark and discharge the sample by allowing the sample to drain until the meniscus is level with the desired mark. If the serological pipet has calibrated marks extended to the tip of the pipet, the sample must be blown out of the tip for accurate sample measurements.

Volumetric (transfer) pipets are long tubes with a bulb in the middle and a single ring above the bulb to indicate the volume of liquid to be delivered when it is filled to the mark. To discharge the sample from a volumetric pipet, hold the tip of the pipet at a slight angle against the container wall and drain. Do not attempt to discharge sample or reagent remaining in the tip of the pipet after draining. Volumetric pipets are designed to always retain a small reproducible amount of sample in the tip of the pipet.

Use of AccuVac Ampuls

AccuVac ampuls contain pre-measured reagent in optical-quality glass ampuls. The sample is collected in a beaker or other open container. The ampul tip is immersed stem first well below the sample surface and the tip is broken off *(see Figure 7)*. The break must be far enough below the surface to prevent air from being drawn in as the level of the sample lowers. The ampul is inverted several times to dissolve the reagent powder (capping is unnecessary). Test results are not affected by undissolved powder. Wipe the ampul with a towel to remove fingerprints, etc. Insert the ampul into the AccuVac adapter into the colorimeter sample compartment and read the results directly.

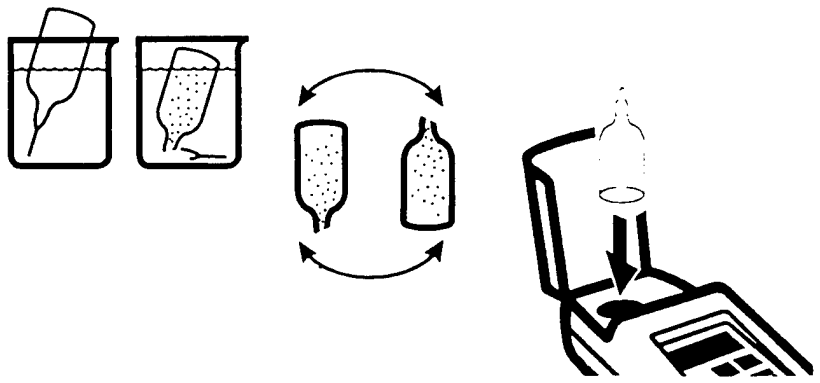


Figure 7 **Using AccuVac Ampuls**

Use of the DR/700 AccuVac Vial Adapter

For safety and ease of use, the DR/700 AccuVac Vial Adapter is provided with the instrument for use with Hach Company's AccuVac Ampul Reagents. Insert the adapter in the cell compartment by aligning

it about 1/4 inch out from the slot in the front side of the cell holder as in *Figure 8*. Push the adapter against the slot sides to seat it. to be sure the adapter is seated, gently slide it upward. The adapter should stop about half way up and stay there.

For measurements, leave the adapter in the up position and insert an AccuVac Ampul in the cell holder (see *Figure 9*). Taking care to avoid sharp edges, gently push the ampule down until it stops. This centers the ampul in the light path. Pushing down on the ampul will not fully seat it. To remove the ampul, pull the adapter up with the side tabs, then pull the ampul out.

The adapter should be removed before testing with round sample cells to allow alignment with the mark on the cells with the tab on the cell holder. To remove the adapter, tilt the top toward the front of the instrument and then pull upwards.

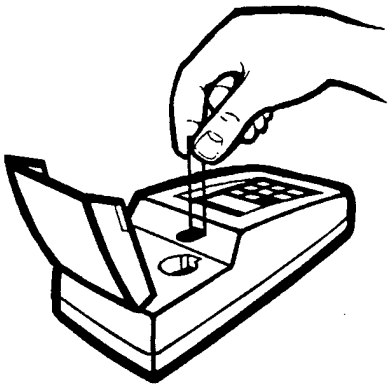


Figure 8 **Inserting AccuVac Vial Adapter**

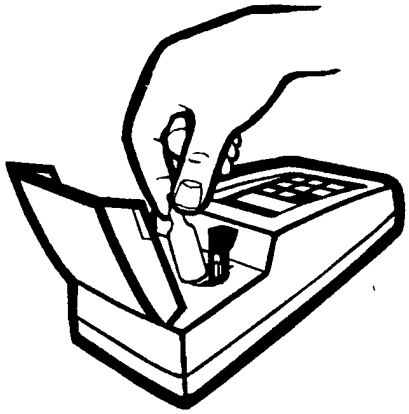


Figure 9 **Inserting AccuVac Ampul**

Use of Reagent Powder Pillows

Dry powdered reagents are used when possible to minimize problems of leakage and deterioration. Powders are packaged in individual, pre-measured, polyethylene "powder pillows." Each pillow contains enough reagent for one test and is opened easily with nail clippers or scissors; *see Figure 10.*

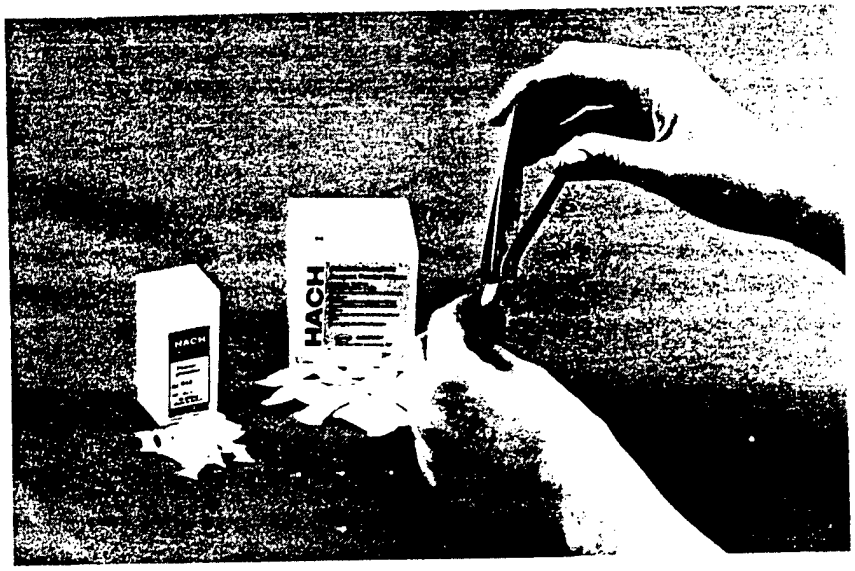


Figure 10 **Opening Powder Pillows**

Using PermaChem Pillows

For best results, slightly tap the pillow on a hard surface to collect the powdered reagent in the bottom. Then:

1. Tear across, from A to B, holding the pillow away from your face.
2. Using two hands, push both sides toward each other to form a spout.
3. Pour the pillow contents into the sample cell and continue the procedure according to the instructions.

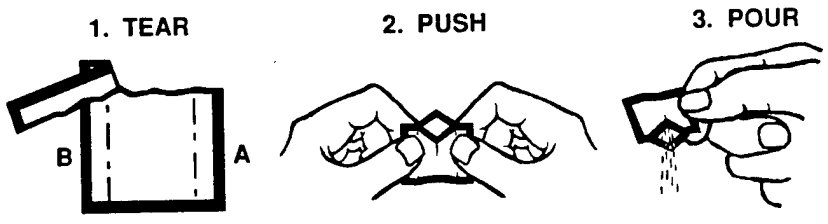
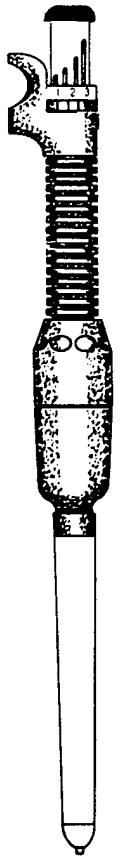


Figure 11 **Using PermaChem Pillows**

TenSette Pipet
Model 19700-10

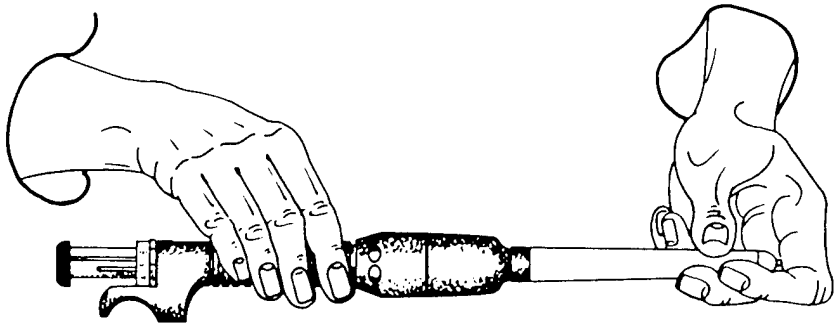


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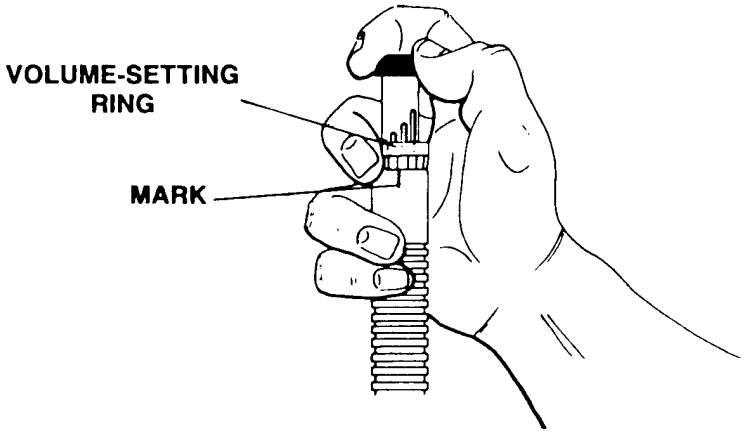
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Operating Instructions

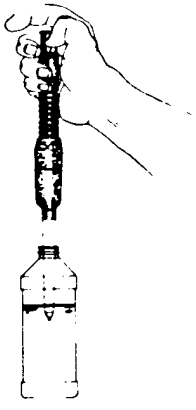
1. Attach a clean tip. Holding the TenSette Pipet in one hand, gently press the tip onto the tapered nose of the pipet until the tip is held firmly and a good seal is obtained.



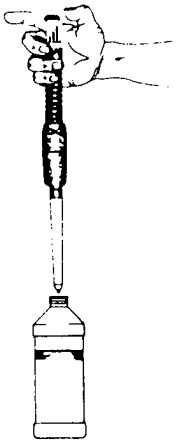
2. Turn the turret cap to align the desired volume on the volume-setting ring with the mark on the housing assembly.



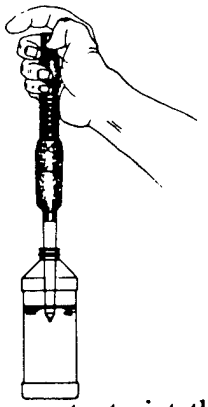
3. Press down on the turret cap with the thumb, using a smooth motion, until the turret reaches the stop. Immerse the tip about 5 mm (¼") below the surface of the solution to avoid drawing air into the tip. Do not insert the tip any deeper, or the delivery volume may be affected.



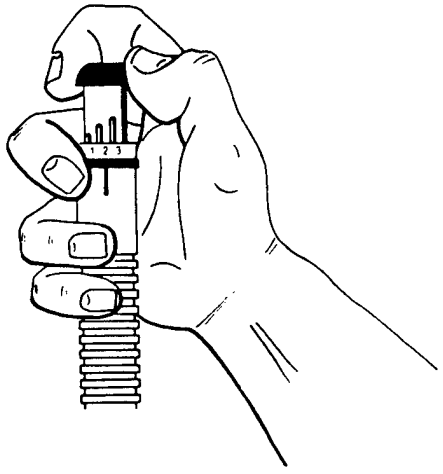
4. While maintaining a light constant pressure, allow the turret to return to the extended position very slowly. Do not let the turret snap into place, or the delivery volume will be affected.



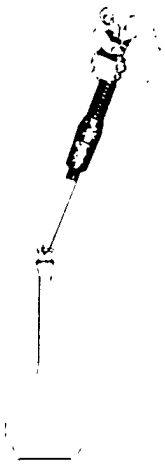
5. With the turret up, withdraw the tip from the liquid and move it to the receiving vessel. Avoid placing pressure on the cap while moving the pipet.



6. Use the thumb and forefinger to twist the turret cap to the next higher position on the volume-setting ring to assure full blowout and quantitive transfer of the solution. The "F" position provides full blowout for the 10.0-mL setting.



7. With the tip in contact with the side of the receiving vessel, slowly and smoothly press down on the cap until the turret reaches the stop and the solution is completely discharged.



Maintenance

Periodically disassemble the lower body. Clean and lubricate the piston and glass cylinder to ensure smooth operation. *See Figure 1.* Use a high quality stopcock grease.

If the TenSette Pipet is to be used at an altitude significantly different than 1000 feet (305 meters) above sea level, the delivery volume will be affected. *See Figure 2.* The instrument can be reset for greater accuracy as follows:

1. Remove the turret cap screw, turret cap and volume-setting ring. Loosen the turret set screw by one or two turns.
2. Place a narrow-necked vessel (for example, a volumetric flask) on an analytical balance and zero the balance (or record the weight if the balance is nonzeroing).
3. Weigh the quantity of water dispensed at the 1.0-mL setting. Use only high-quality demineralized water at 20-25°C.
4. If the weight of the water was other than 1.0 g, use a small screwdriver to give the turret adjustment screw (inside the metering turret) a slight turn. Turn clockwise to increase delivery volume.
5. Zero the balance (or record the weight) just prior to adding another 1.0 mL of demineralized water. If the added weight is other than 1.0 g, repeat Steps 3 through 5.

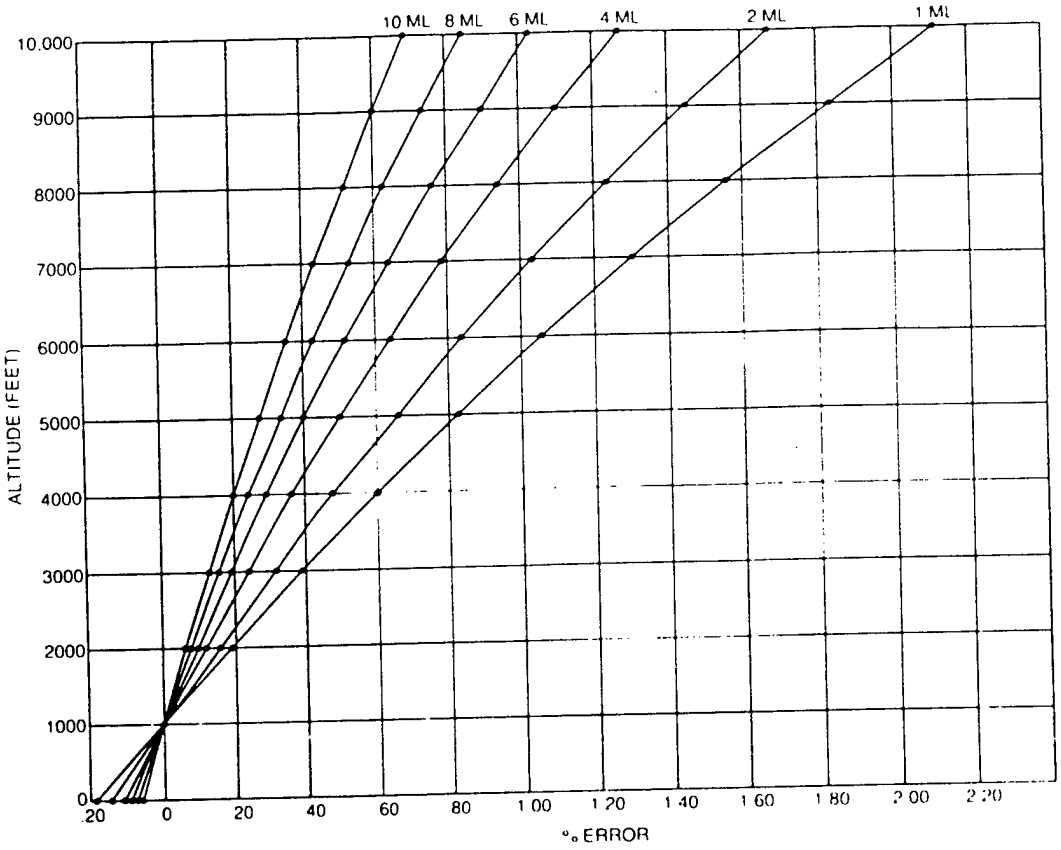


Figure 2 **Effect of Altitude on Delivery**

6. When the weight of the water delivered at the 1.0-mL setting is 1.0 g, set the turret for a delivery of 10.0 mL.

7. Zero the balance (or record the weight) just prior to adding 10.0 mL of water. If the weight is other than 10.0 g, adjust the delivery volume as described in Step 4. When the pipet delivers 10.0 g at the 10.0-mL setting, check the 1.0-mL setting again.

8. When the delivery volume is accurate for both the 1.0-mL and 10.0-mL settings, tighten the set screw until flush with the surface of the housing assembly. Replace the volume-setting ring, turret cap and turret cap screw.

ORION RESEARCH

INSTRUCTION MANUAL
platinum redox electrodes
model 96-78-00
model 97-78-00



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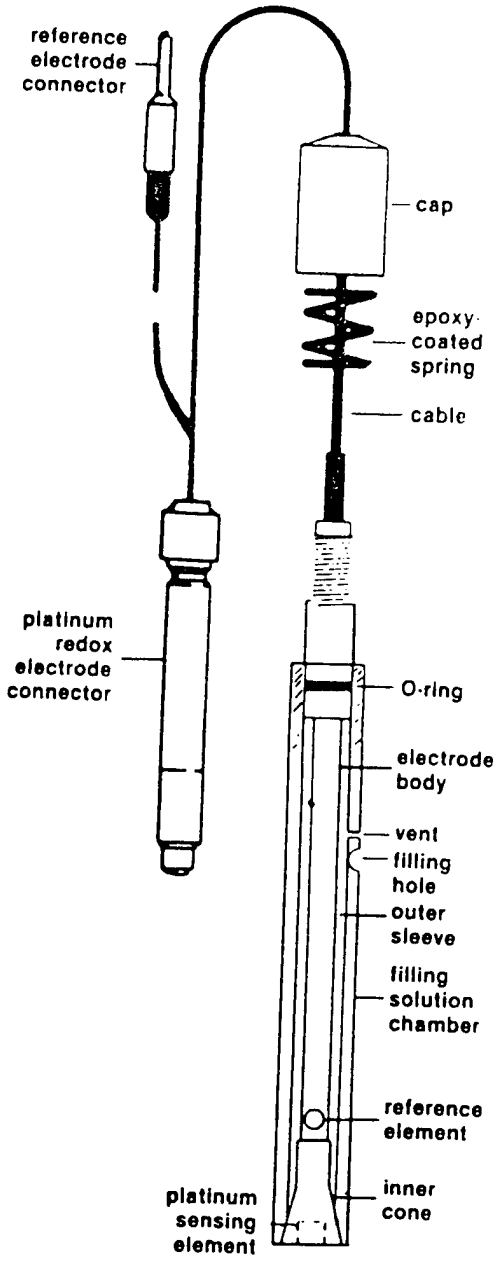
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529 MAIN STREET, BOSTON, MA 02129 USA
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figure 1

model 96-78 platinum redox electrode



introduction

The Models 96-78 and 97-78 combine a platinum redox and a silver/silver chloride reference electrode in one body. The Model 96-78 is an epoxy body electrode with a sleeve junction and the Model 97-78 has a glass body with a ceramic junction.

Both can be used to make direct measurements of redox potentials or to perform potentiometric titrations. They are not designed for amperometric or constant current titrations, such as the Karl Fischer.

choice of filling solution

The electrode filling solution should be selected to best match the ionic strength of the sample solution to minimize junction potentials.

- **dilute solutions** (total ionic strength less than 0.2 M) - Use ORION Cat. No. 900001 filling solution which will match the potential of a conventional calomel electrode.
- **concentrated solutions** (total ionic strength greater than 0.2 M) - Use ORION Cat. No. 900011 filling solution which is 4 M KCl saturated with Ag/AgCl.

filling the reference electrode

The filling solution level should always be at least one inch above the level of the solution being measured. Uncover filling hole of 97-78 by sliding rubber sleeve away from hole. To fill, replace the flat cap on the filling solution bottle with the flip-spout cap, lift the spout to the vertical position, insert into the filling hole, and squeeze the bottle. After filling a dry chamber of model 96-78, push cap and body together to leak some filling solution past conical reference junction.

connecting the electrode to the meter

Insert the platinum redox connector (large diameter) into the pH or sensing electrode input jack on the meter and the reference electrode connector (small diameter) into the reference electrode input jack.

electrode measurements

direct measurement

Direct redox potential (ORP) measurements can be used to determine the oxidizing or reducing capability of a solution and are commonly made in polluted streams, chlorinated waters, industrial waste waters, and other water samples.

procedure

1. Connect the electrode to the meter, set the function switch to the millivolt mode, and place the electrode in the sample solution. When the reading stabilizes, record the potential.
2. For some applications it is customary to report redox potential readings relative to the normal hydrogen electrode (NHE). To do this, select the value in **table 1** that corresponds to the filling solution used and the temperature of the solution measured. Substitute it in the equation and solve for E_{NHE}:

$$E_{NHE} = E_O + C$$

where:

E_{NHE} = oxidation reduction potential of the sample relative to the NHE, following the international sign convention.

E_O = potential developed by the platinum redox electrode.

C = potential developed by the reference electrode portion relative to the NHE (see **table 1**).

table 1: potentials, C, developed by the reference electrode portion relative to the normal hydrogen electrode at various temperatures.

temp °C	electrode potential in mV (C)	
	900001 solution*	900011 solution*
10	251	214
20	244	204
25	241	199
30	238	194

*Taken from Chateau, *J. Chim. Phys.*, 51, 590 (1954).

*Taken from Bates, *Determination of pH.*, 2nd Ed., Wiley-Interscience, p. 335

NOTE: Like all platinum redox electrodes, the 96-78 or 97-78 may give unstable readings in solutions containing chromous, vanadous, titanous, and other ions that are stronger reducing agents than hydrogen or platinum.

table II: typical redox titration methods

unknown	interferences	suitable titrants	titration reaction	ref.
antimony (Sb^{+3})	As; Fe; SO_2; V; organic substances and others interfere	potassium permanganate ($KMnO_4$)	$5Sb^{+3} + 2MnO_4^- + 16H^+ - 5Sb^{+5} + 2Mn^{+2} + 8H_2O$	2
arsenic (As^{+3})	other reducing agents	sodium bromate ($NaBrO_3$)	$BrO_3^- + 3As^{+3} + 6H^+ - Br^- + 3As^{+5} + 3H_2O$	3
hydrogen peroxide (H_2O_2)	preservatives present in commercial H_2O_2 may interfere	potassium permanganate ($KMnO_4$)	$5H_2O_2 + 2MnO_4^- + 6H - 5O_2 + 2Mn^{+2} + 8H_2O$	5
hypochlorite ion (ClO^-) or chlorine (Cl_2)	Br_2 and other oxidizing agents interfere by liberating I_2	sodium iodide (NaI)	In acid solution: $Cl_2 + 2I^- - I_2 + 2Cl^-$. In basic solution: $2ClO^- + 2I^- - I_2 + 2Cl^- + 2OH^-$	1
iodine (I_2)	other reducing agents	sodium iodate ($NaIO_3$)	$2I_2 + IO_3^- + 5HCN + H^+ - 5ICN + 3H_2O$	4
iodine (I_2)	direct sunlight, high acidity, copper salts and other catalysts promote air oxidation and cause false high results.	sodium thiosulfate ($Na_2S_2O_3$)	$I_2 + 2S_2O_3^= - 2I^- + S_4O_6^=$	3
iron (as Fe^{+2}, Fe^{+3}, or in steel)	high levels of organic acids, such as acetic, oxalic, tartaric, and alcohols; F^- if present in more than trace amounts; Cl^-; PO_4^{-3} (remove by adding acid)	ceric sulfate [$Ce(SO_4)_2$] (not recommended for samples containing Cl^-)	$Fe^{+2} + Ce^{+4} - Ce^{+3} + Fe^{+3}$	2
iron (as Fe^{+2}, Fe^{+3}, or in steel)	other reducing agents	potassium dichromate ($K_2Cr_2O_7$), recommended for samples containing Cl^-	$Cr_2O_7^= + 6Fe^{++} + 14H^+ - 2Cr^{+3} + 6Fe^{+3} + 7H_2O$	3
manganese (as permanganate MnO_4^-)	other oxidizing agents	ferrous sulfate ($FeSO_4$)	$MnO_4^- + 5Fe^{+2} + 8H^+ - Mn^{+2} + 5Fe^{+3} + 4H_2O$	2
manganese (as Mn^{+2})	other reducing agents	potassium permanganate ($KMnO_4$)	$3Mn^{+2} + 2MnO_4^- + 7H_2O - 5MnO_2 + H_2O + 4H^+$	1
stannous tin (Sn^{+2})	other reducing agents	ceric sulfate [$Ce(SO_4)_2$]	$Sn^{+2} + 2Ce^{+4} - Sn^{+4} + 2Ce^{+3}$	4
sulfur (as sulfur dioxide SO_2)	$S^=$ and $SO_3^=$, remove by shaking with $CdCo_3$ and filtering	iodine (I_2)	$SO_2 + I_2 + 2H_2O - SO_4^= + 2I^- + 4H^+$	1
thallium (Tl^+)	other reducing agents	sodium bromate ($NaBrO_3$)	$BrO_3^- + 3Tl^+ + 6H^+ - Br^- + 3Tl^{+3} + 3H_2O$	3
thiosulfate ion ($S_2O_3^=$)	$S^=$ and $SO_3^=$, remove by shaking with $CdCO_3$ and filtering	iodine (I_2)	$I_2 + 2S_2O_3^= - 2I^- + S_4O_6$	3
uranium (as uranyl ion UO^{+2})	other reducing agents	potassium dichromate ($K_2Cr_2O_7$)	$3UO^{+2} + Cr_2O_7^= + 8H^+ - 3UO_2^{+2} + 2Cr^{+3} + 4H_2O$	3
zinc (Zn^{+2})	other reducing agents	sodium iodate ($NaIO_3$)	$ZnHg(SCN)_4 + 6IO_3^- + 6Cl^- + 8H^+ - Zn^{+2} + Hg^{+2} + 6ICl + 4HCN + 4SO_4^=$	2

references:

1. Furman (ed.), **Scott's Standard Methods of Chemical Analysis,** 5th Ed., Van Nostrand, Princeton, N.J. 1938.
2. Hillebrand, Lundell, Bright, and Hoffman, **Applied Inorganic Analysis,** 2nd Ed., Wiley, New York, 1953.
3. Kolthoff and Sandell, **Testbook of Quantitative Ionorganic Analysis,** 3rd Ed., MacMillan, New York, 1952.
4. Oesper, **Newer Methods of Volumetric Chemical Analysis,** Van Nostrand, Princeton, N.J., 1938.
5. Treadwell and Hall, "Analytical Chemistry," vol. 2, **Quantitative Analysis,** 8th Ed., Wiley, New York, 1935.

oxidation reduction titrations

Oxidation-reduction, or redox titrations provide a simple, reliable method for determining many substances in solution. A redox titration consists of adding to an unknown sample small increments of a titrant that converts the unknown to a different oxidation state. After each addition of titrant, the platinum redox electrode develops a potential proportional to the logarithm of the ratio of the activities of the two oxidation states. At the inflection, or end point, the titrant has completely oxidized or reduced the unknown, causing a sharp change in the logarithm of the ratio of the activities of the two oxidation states. A corresponding sharp change in the potential is developed by the platinum electrode. Often several oxidizing or reducing species can be precisely determined in the same solution by a single titration with several inflection points.

Table II on the preceding pages lists suitable titrants for different unknowns, the equation for the titration reaction, interferences, and a reference where information about preparing the sample and running the titration can be found. For similar information about unknowns not listed in the table, consult the standard texts listed as references.

The following directions represent a general procedure for performing a redox titration once the sample is prepared for measurement.

procedure

1. Fill a 10 ml buret with a standard titrant solution whose normality is 5-10 times that of the sample.
2. Connect electrode to the meter and turn the function switch to the millivolt mode.
3. Pipet 50 ml sample into a 150 ml beaker. Stir with a magnetic stirrer throughout the titration.
4. At first add titrant in 0.5-1 ml increments, recording the potential after each addition. Near the end point, when large potential changes appear, add increments of 0.1-0.2 ml. Continue the titration 3-4 ml past the end point.
5. Plot the electrode potential versus volume of added titrant on linear graph paper and draw a smooth curve through the points. The end point is the point of inflection (the point of greatest slope).
6. Calculate the normality of the sample, N_x, in equivalents per liter:

$$N_x = \frac{V_t N_t}{V_x}$$

where:

N_t = normality of titrant (Eq/1)

V_t = volume of titrant at end point (ml)

V_x = volume of sample (ml)

electrode maintenance

Model 96-78 cleaning

The electrode can be routinely cleaned without disassembling. To remove precipitate that forms on the outside wall or tip of the electrode, rinse with distilled water. If sample or precipitate clogs the space between the electrode sleeve and the inner cone, clean the chamber by flushing out the filling solution. To do this, invert the electrode to moisten the O-ring. Holding the electrode by the cap with one hand, push the outer sleeve up into the cap with the other hand, allowing filling solution to drain from the chamber. If the chamber is not completely clean, repeat. Fill with filling solution.

If the preceding directions fail to remove all the precipitate, the electrode can be disassembled and cleaned using the following procedure. **This procedure is not recommended for routine cleaning of the electrode and should be used only when absolutely necessary.**

1. Unscrew the cap and slide the cap and epoxy-coated spring up along the cable.
2. Holding the outer sleeve with one hand, firmly push down on the threaded portion of the inner body to separate the inner body from the sleeve.
3. Rinse the sleeve and the inner body thoroughly with distilled water, and allow to air dry.
4. Moisten the O-ring on the electrode inner body with a drop of filling solution. Reassemble and fill the electrode.

changing the filling solution

The electrode need not be disassembled to change the filling solution in the reference chamber. Simply clean the electrode and fill with the new solution, using the following procedure:

1. Tip the electrode to moisten the O-ring. Holding the electrode by the cap with one hand, push the sleeve up into the cap with the other hand allowing solution to drain from the chamber.
2. Fill the electrode with distilled water and then drain the reference chamber by retracting the sleeve, as explained above. Now perform this filling and draining procedure twice with the new filling solution.
3. Fill the electrode with the new solution. Although the electrode is ready for use, readings may drift slightly for about a half hour while the electrode equilibrates with the new solution.

Model 97-78 cleaning

To remove precipitate or salts that form on the exterior of the electrode, rinse with distilled water.

To remove salt deposits formed inside the electrode:

1. Fill a wash bottle to half with distilled water.
2. Invert electrode so that glass membrane points up.
3. Invert the wash bottle so that its bottom points up.
4. Insert nozzle of wash bottle into electrode filling hole and squeeze bottle. Filling solution will drain out of chamber.
5. Fill chamber with distilled water from wash bottle. Repeat steps 2-4.
6. Continue to repeat steps 2-5 until all salts have been removed

To change the filling solution, follow steps 1-6 in cleaning above. After draining out distilled water, fill with filling solution, drain, and refill with the solution.

storage

When not in use the electrode may be kept in water or air. If left in air, remove salt crystals on the outside of the electrode sleeve by rinsing with distilled water, drain filling solution from chamber, flush out with distilled water, store dry. See **cleaning** procedures.

specifications

	Model 96-78	Model 97-78
ORION Cat. No.	967800	977800
construction	epoxy-body with sleeve reference junction - resistant to acids, bases and inorganic solvents Should not be used in polar organic solvents	glass body with ceramic frit junction - resistant to organic solvents
length	135 mm	140 mm
body diameter	12 mm	12 mm
cable length	1 m	1 m
temperature range	0-80°C 80-100°C	0-70°C
connectors	U S Standard and pin-tip	
filling solution	Cat No 900011 - suitable for use in samples having a total ionic strength greater than 0.2 M Cat No 900001 - suitable for use in samples having a total ionic strength less than 0.2 M	
minimum sample size	0 3 ml with the 96-78 in ORION microsample dish (Cat No 920014)	

specifications subject to change without notice

BASIS, PREPARATION AND USE OF ZoBell SOLUTIONS

prepared by R.L. Schmiermund

1.0 BACKGROUND

Numerous sources of non-trivial errors are associated with the use of platinum indicator electrodes in natural waters. Unfortunately, most of these errors are particularly difficult to detect because 1) mv readings can be erratic and prone to drift under the best circumstances, 2) the magnitude and even sign of mv readings is difficult to anticipate, 3) poisoning and other phenomena associated with the polished platinum surface are not necessarily visible and 4) serious or fatal difficulties can develop over the course of measuring a single sample. For these reasons it is incumbent upon the field operator to perform frequent checks of the system's performance against standard solutions with known redox characteristics. Surprisingly, this procedure is rarely followed.

Several systems of "redox standards" have been proposed, but the most commonly used is that of ZoBell (1946). By measuring the redox potential of a ZoBell solution (as one would measure any sample), one obtains a reading which correspond to a known potential. This "control point" is not a calibration point in the sense that the operator does not adjust the output of the mv meter to agree with the ZoBell potential. Rather, the procedure provides a performance check of the instrument and electrodes. However, any significant measurement bias (relative to the ZoBell) should be taken into account when Eh is calculated from the field mv measurements.

The ZoBell solution is analogous to a pH buffer in that it represents an equilibrium solution which fixes the variable of concern, in this case Eh. Furthermore, it tends to resist change. Specifically, ZoBell solutions contain Fe(II) cyanide and Fe(III) cyanide in known ratios and by thermodynamic-based theory can be shown to have an associated equilibrium Eh or pe. Unfortunately, while pH buffers have an effectively infinite shelf life and the same aliquot may be used many times even under poor field conditions, ZoBell solutions may last no more than a week. Whereas true (pH) buffer systems actively compensate for additions of H^+ or OH^-, ZoBell solutions apparently rely only on the inherent stability of the $[Fe(CN)_6]^{4-}$ ion and its kinetic resistance to oxidation. Accordingly, ZoBell solution should be shielded from light in an opaque bottle, exposed to air as little as possible and refrigerated when not in use.

Several excellent references exist and should be read and understood by the operator. These include discussions of procedures associated with redox determinations (Langmuir, 1971),

the latest accepted standard method for redox determinations (Greenberg et al., 1992, section 2580) and details of the thermochemical theory of Eh (Nordstrom, 1977).

2.0 SUMMARY OF OPERATIONAL CALCULATIONS

The theory and notations associated with electrochemical phenomena are tedious and often confusing - especially when comparing multiple authors. Fortunately, what is required for Eh determinations can be reduced to a very few convenient statements and operational equations.

1) The potential (mv reading of the instrument) of the ZoBell solution or of a water sample is the algebraic sum of potentials of the sensing electrode (the Pt electrode) and the reference electrode:

$$E_{Total} = E_{ref} + E_{sensing}$$

In the case of a Pt sensing electrode in conjunction with a Ag/AgCl-sat. KCl reference electrode:

$$E_{Total} = E_{Ag/AgCl\text{-}sat.KCl} + E_{Pt/solution}$$

where Pt/solution simply represents the Pt sensing electrode in some solution or sample.

Note that the reference electrode type (Ag/AgCl) and concentration of the filling solution (saturated KCl) are specified in the above equation and thus the resultant E_{Total} is a function of the type of reference electrode and the concentration of the filling solution.

2) In the case of equipment checks with ZoBell solutions, the mv reading required for comparison with the known value is functionally equivalent to E_{Total} above:

$$E_{ZoBell} = E_{Ag/AgCl\text{-}sat.KCl} + E_{Pt/ZoBell}$$

3) The $E_{Ag/AgCl\text{-}sat.\,KCl}$ value is a function of temperature (Fig. 1) as is the $E_{Pt/ZoBell}$ (not illustrated) and because E_{ZoBell} is the algebraic sum of the former two, E_{ZoBell} is a function of temperature (Fig. 2).

4) E_{ZoBell} (Fig. 2) is the theoretical value to which the mv reading in the ZoBell solution (the check value) should be compared. Obviously, the temperature is important.

5) In the case of an actual sample:

$$E_{sample} = E_{Ag/AgCl\text{-}sat.KCl} + E_{Pt/sample}$$

This is the value to be recorder in the field. *This is not the E_h of the sample and can only be compared to Eh in a relative sense*.

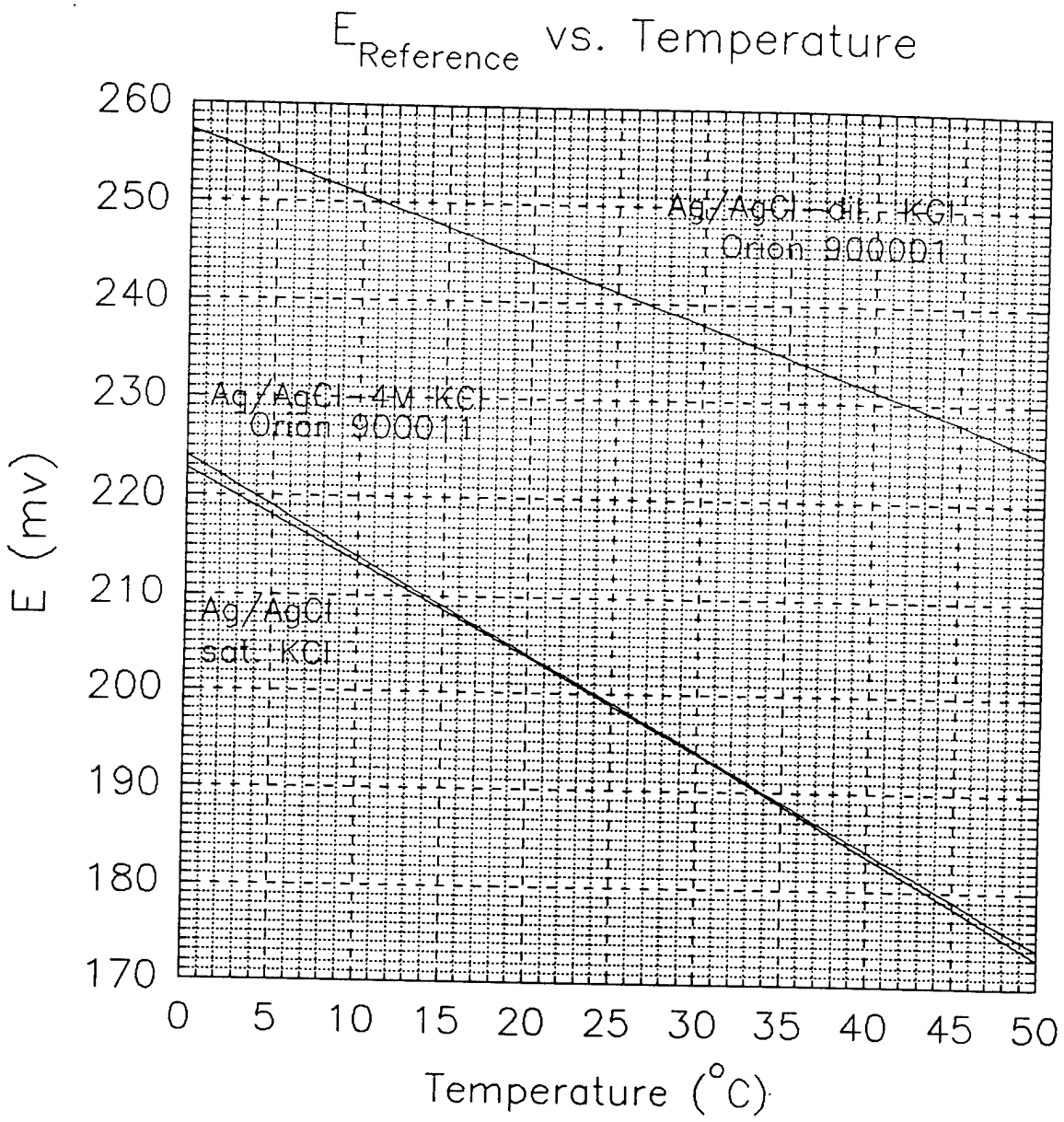


Figure 1. Potential of Ag/AgCl reference electrode with filling solutions of various KCl concentrations as a function of temperature. Saturated KCl data was taken from Nordstrom (1971), others from Orion manual accompanying electrode. Notice that saturated (4.58 M KCl) and 4 M KCl solutions (Orion filling solution 900011) are very similar but the dilute filling solution (Orion filling solution 900001) has very different potential. Orion reports that filling solution 900001 is 5 wt. % KCl (0.67 M KCl) but the potential data presented in their manual on redox electrodes (Table 1) may be erroneous (source cited is Chateau (1954) but the original data is for a calomel electrode with saturated KCl).

6) $E_{h\text{-}Total}$, $E_{h\text{-}sample}$ and $E_{h\text{-}ZoBell}$ is the E_{Total}, E_{sample} and E_{ZoBell} respectively, *computed relative to the standard hydrogen electrode.* Because E_h values are potentials stated relative to an absolute standard they may be compared to each another regardless of the measurement equipment, sensing electrode or reference electrode. Comparing or tabulating field measured E values is meaningless (unless of course enough information is provided to allow calculation of E_h values).

7) E_h of a sample (or the ZoBell solution) may be very simply calculated by the following equation and the measured E_{sample}:

$$E_{h\text{-}sample} = E_{Pt\text{-}sample} - (- E_{Ag\text{-}AgCl\text{-}sat.KCl})$$

Fig. 3 illustrates this for the ZoBell solution where A+B=C.

2.0 SAFETY

Care should be taken in the preparation, use and disposal of ZoBell solutions. The ferricyanide (Fe(III)-cyanide, or $[Fe(CN)_6]^{3-}$) ion, in particular, is unstable, reacts quickly and is quite poisonous (p. 760, Cotton and Wilkinson, 1980).

The following precautions should be taken:

1) Read and understand Material Safety Data Sheets (MSDSs) prior to working with reagent salts.

2) Label all appropriate containers as "POISON".

3) Place ZoBell solutions to be used in the field in heavy plastic bottles of minimum volume and stable design. Permanently attach cap to bottle in such a way to prevent interchange of caps with other bottles.

4) Do not mouth-pipette any of the ZoBell solutions.

5) Dispose of Kimwipes, rinse water etc. contaminated with ZoBell solutions properly.

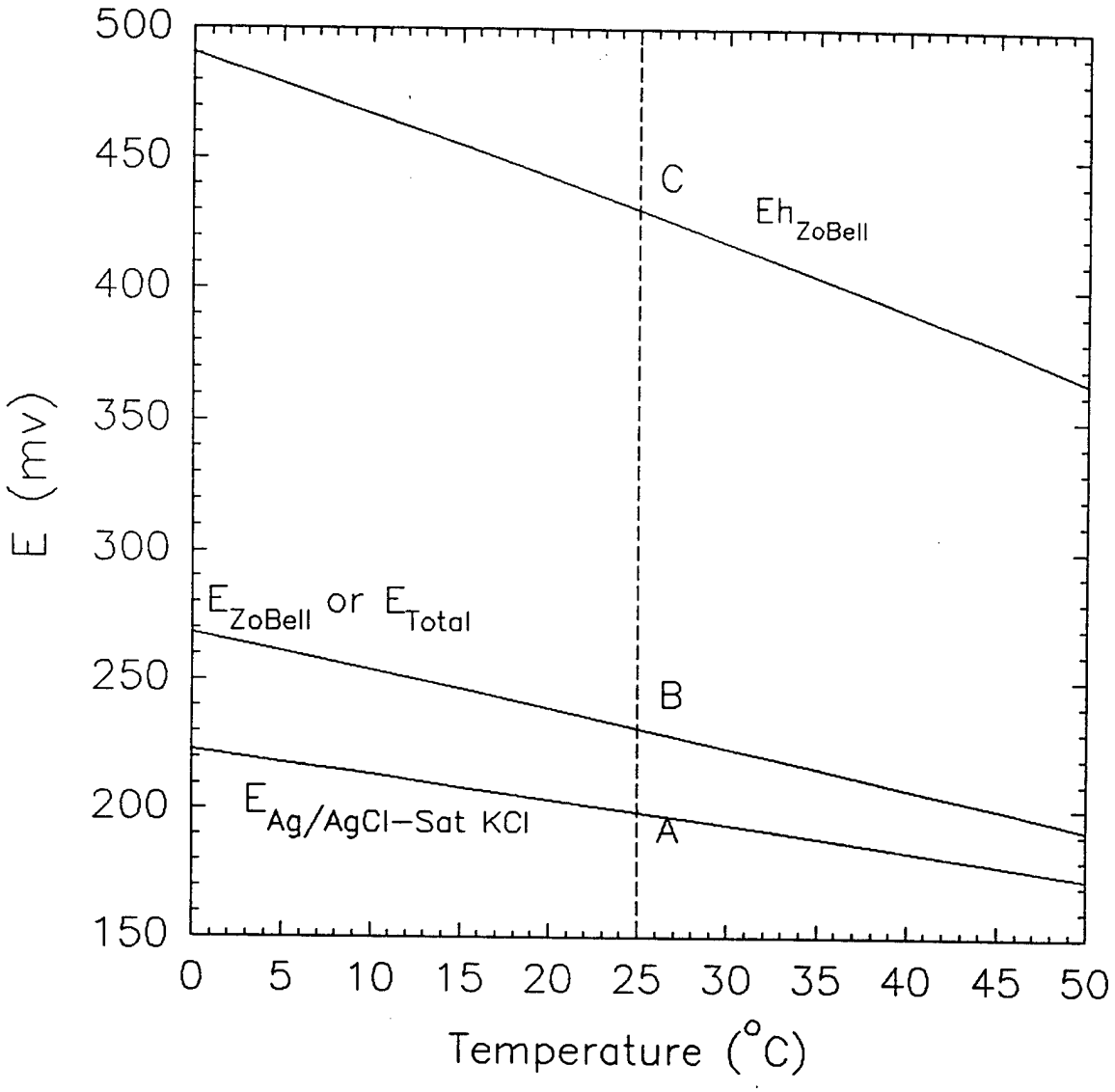


Figure 3. Potential vs temperature data for ZoBell solution. E_{ZoBell} is the potential read directly from the meter when a pt electrode and a Ag/AgCl-sat KCl reference electrode are placed in a ZoBell solution prepared as described in this report. The Eh_{ZoBell} is the sum of E_{ZoBell} and $E_{Ag/AgCl\text{-}sat.\ KCl}$ or A + B = C. To calculate the Eh of an other solution the measured E is added to the E of the reference electrode in an analogous manner.

4.0 CHECKING INSTRUMENT PERFORMANCE WITH ZOBELL SOLUTION

1) Prior to sampling and as part of daily routine checking of instruments and equipment, perform and record the results of a check of the mv meter/Pt electrode/reference electrode. Proceed as you would for a sample measurement of redox potential:

a) clean and polish Pt surface
b) be sure liquid junction is free flowing
c) fill reference electrode reservoir with (and only with) the filling solution provided by the manufacturer
d) place bottle containing ZoBell solution in a stable temperature environment and insert Pt/reference electrode in solution - allow few minutes for solution and electrode temperatures to equilibrate
e) determine equilibrated temperature of the ZoBell solution with electrode immersed
f) read mv output of meter

2) Record the following information:

a) time, date, operator, serial number of electrode and mv meter
b) date ZoBell solution was prepared and storage conditions
b) procedures used for performing check (std. procedure should already be recorded - note any deviations or particulars)
c) equilibrated temperature of the ZoBell solution with electrode immersed
d) mv reading of meter (be sure to correctly note polarity or polarity settings)
e) character of readings (eg., drift, stability etc.)

3) If mv readings are outside the range of acceptable reading for the temperature (say +/- 10 mv) according to Figure 2, or if character of readings is anomalous, repeat preparatory steps including the following as required:

a) re-polish and rinse electrode
b) reclean liquid junction
c) empty, flush and refill reference electrode filling solution cavity (if DI water is used for flushing, thoroughly flush with filling solution before refilling - this will prevent dilution of filling solution)
d) wipe off electrode leads with methanol to eliminate static
e) perform diagnostics on meter
f) prepare fresh ZoBell solution
g) be sure temperatures are stable
h) remove equipment from direct sunlight

4) Repeat all procedures until acceptable reading are obtained. Record all procedures - as always the field notebook is admissible as evidence and invaluable for unraveling difficulties after the fact.

5) Rinse and polish Pt electrode after each use of the ZoBell solution

6) Use the ZoBell solution to check the mv meter/Pt electrode/reference electrode performance <u>after</u> each sample. Record results. This prevents progressive problems from going undetected.

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APPENDIX D

SELECTED SECTIONS OF THE AFCEE TECHNICAL PROTOCOL DOCUMENT

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SELECTED SECTIONS OF THE AFCEE TECHNICAL PROTOCOL DOCUMENT

TECHNICAL PROTOCOL FOR EVALUATING NATURAL ATTENUATION OF CHLORINATED SOLVENTS IN GROUNDWATER

by

Todd H. Wiedemeier, Matthew A. Swanson, David E. Moutoux, and E. Kinzie Gordon
Parsons Engineering Science, Inc.
Denver, Colorado

Dr. John T. Wilson, Dr. Barbara H. Wilson, and Dr. Donald H. Kampbell
United States Environmental Protection Agency*
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
Ada, Oklahoma

Jerry E. Hansen and Patrick Haas
Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base, Texas

Dr. Francis H. Chapelle
United States Geological Survey
South Carolina

November 1996

for

Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas

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List of Acronyms and Abbreviations

AAR	American Association of Railroads
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
ASTM	American Society for Testing and Materials
bgs	below ground surface
BRA	baseline risk assessment
BRAC	Base Realignment and Closure
BTEX	benzene, toluene, ethylbenzene, xylenes
CAP	corrective action plan
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cfm	cubic feet per minute
CFR	Code of Federal Regulations
COPC	chemical of potential concern
CPT	cone penetrometer testing
CSM	conceptual site model
DAF	dilution/attenuation factor
DERP	Defense Environmental Restoration Program
DO	dissolved oxygen
DOD	Department of Defense
DQO	data quality objective
EE/CA	engineering evaluation/cost analysis
FS	feasibility study
gpd	gallons per day
$\Delta G_r°$	standard (Gibbs) free energy
HDPE	high-density polyethylene
HSSM	Hydrocarbon Screening Spill Model
HSWA	Hazardous and Solid Waste Amendments of 1984
ID	inside-diameter
IDW	investigation derived waste
IRP	Installation Restoration Program
L	liter
LEL	lower explosive limit
LNAPL	light nonaqueous-phase liquid

LTM	long-term monitoring
LTMP	long-term monitoring plan
LUFT	leaking underground fuel tank
MAP	management action plan
MCL	maximum contaminant level
MDL	method detection limit
µg	microgram
µg/kg	microgram per kilogram
µg/L	microgram per liter
mg	milligram
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mg/m^3	milligrams per cubic meter
mm Hg	millimeters of mercury
MOC	method of characteristics
MOGAS	motor gasoline
NAPL	nonaqueous-phase liquid
NCP	National Contingency Plan
NFRAP	no further response action plan
NOAA	National Oceanographic and Atmospheric Administration
NOEL	no-observed-effect level
NPL	National Priorities List
OD	outside-diameter
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PAH	polycyclic aromatic hydrocarbon
PEL	permissible exposure limit
POA	point-of-action
POC	point-of-compliance
POL	petroleum, oil, and lubricant
ppmv	parts per million per volume
psi	pounds per square foot
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
RAP	remedial action plan
RBCA	risk-based corrective action
RBSL	risk-based screening level
redox	reduction/oxidation
RFI	RCRA facility investigation

RI	remedial investigation
RME	reasonable maximum exposure
RPM	remedial project manager
SAP	sampling and analysis plan
SARA	Superfund Amendments and Reauthorization Act
scfm	standard cubic feet per minute
SPCC	spill prevention, control, and countermeasures
SSL	soil screening level
SSTL	site-specific target level
SVE	soil vapor extraction
SVOC	semivolatile organic compound
TC	toxicity characteristic
TCLP	toxicity-characteristic leaching procedure
TMB	trimethylbenzene
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TRPH	total recoverable petroleum hydrocarbons
TVH	total volatile hydrocarbons
TVPH	total volatile petroleum hydrocarbons
TWA	time-weighted-average
UCL	upper confidence limit
US	United States
USGS	US Geological Survey
UST	underground storage tank
VOCs	volatile organic compounds

Definitions

Aerobe: bacteria that use oxygen as an electron acceptor.

Anabolism: The process whereby energy is used to build organic compounds such as enzymes and nucleic acids that are necessary for life functions. In essence, energy is derived from catabolism, stored in high-energy intermediate compounds such as adenosine triphosphate (ATP), guanosine triphosphate (GTP) and acetyl-coenzyme A, and used in anabolic reactions that allow a cell to grow (Chapelle, 1993).

Anthropogenic: Man-made.

Catabolism: The process whereby energy is extracted from organic compounds by breaking them down into their component parts.

Cometabolism: The process in which a compound is fortuitously degraded by an enzyme or cofactor produced during microbial metabolism of another compound.

Daughter Product: A compound that results directly from the biodegradation of another. For example *cis*-1,2-dichloroethene (*cis*-1,2-DCE)is commonly a daughter product of trichloroethene (TCE).

Dehydrohalogenation: Elimination of HX resulting in formation of an alkene.

Diffusion: The process whereby molecules move from a region of higher concentration to a region of lower concentration as a result of Brownian motion.

Dihaloelimination: Reductive elimination of two halide substituents resulting in formation of an alkene.

Dispersivity: A property that quantifies mechanical dispersion in a medium.

Effective Porosity: The percentage of void volume that contributes to percolation; roughly equivalent to the specific yield.

Electron Acceptor: A compound capable of accepting electrons during oxidation-reduction reactions. Microorganisms obtain energy by transferring electrons from electron donors such as organic compounds (or sometimes reduced inorganic compounds such as sulfide) to an electron acceptor. Electron acceptors are compounds that are relatively oxidized and include oxygen, nitrate, iron (III), manganese (IV), sulfate, carbon dioxide, or in some cases the chlorinated aliphatic hydrocarbons such as perchloroethene (PCE), TCE, DCE, and vinyl chloride (VC).

Electron Donor: A compound capable of supplying (giving up) electrons during oxidation-reduction reactions. Microorganisms obtain energy by transferring electrons from electron donors such as organic compounds (or sometimes reduced inorganic compounds such as sulfide) to an electron acceptor. Electron donors are compounds that are relatively reduced and include fuel hydrocarbons and native organic carbon.

Electrophile: A reactive species that accepts an electron pair.

Elimination: Reaction where two groups such as chlorine and hydrogen are lost from adjacent carbon atoms and a double bond is formed in their place.

Epoxidation: A reaction wherein an oxygen molecule is inserted in a carbon-carbon double bond and an epoxide is formed.

Facultative Anaerobes: microorganisms that use (and prefer) oxygen when it is available, but can also use alternate electron acceptors such as nitrate under anaerobic conditions when necessary.

Fermentation: Microbial metabolism in which....

Heterotroph: Organism that uses organic carbon as an external energy source and as a carbon source.

Hydraulic Conductivity: The relative ability of a unit cube of soil, sediment, or rock to transmit water.

Hydraulic Head: The height above a datum plane of the surface of a column of water. In the groundwater environment, it is composed dominantly of elevation head and pressure head.

Hydraulic Gradient: The maximum change in head per unit distance.

Hydrogenolysis: A reductive reaction in which a carbon-halogen bond is broken, and hydrogen replaces the halogen substituent.

Hydroxylation: Addition of a hydroxyl group to a chlorinated aliphatic hydrocarbon.

Lithotroph: Organism that uses inorganic carbon such as carbon dioxide or bicarbonate as a carbon source and an external source of energy.

Mechanical Dispersion:

Metabolic Byproduct: A product of the reaction between an electron donor and an electron acceptor. Metabolic byproducts include volatile fatty acids, daughter products of chlorinated aliphatic hydrocarbons, methane, and chloride.

Monooxygenase: A microbial enzyme that catalyzes reactions in which one atom of the oxygen molecule is incorporated into a product and the other atom appears in water.

Nucleophile: A

Obligate Aerobe: Microorganisms that can use only oxygen as an electron acceptor. Thus, the presence of molecular oxygen is a requirement for these microbes.

Obligate Anaerobes: Microorganisms that grow only in the absence of oxygen; the presence of molecular oxygen either inhibits growth or kills the organism. For example, methanogens are very sensitive to oxygen and can live only under strictly anaerobic conditions. Sulfate reducers, on the other hand, can tolerate exposure to oxygen, but cannot grow in its presence (Chapelle, 1993).

Porosity: The ratio of void volume to total volume of a rock or sediment.

Respiration: The process of coupling oxidation of organic compounds with the reduction of inorganic compounds, such as oxygen, nitrate, iron (III), manganese (IV), and sulfate.

Solvolysis: A reaction in which the solvent serves as the nucleophile.

Substitution: A reaction in which one substituent on a molecule is replaced by another.

Volatile Fatty Acid: An acid produced as an intermediate during BTEX biodegradation.

SECTION 1

INTRODUCTION

Over the past several years remediation by natural attenuation has become increasingly accepted as a remedial alternative for organic compounds dissolved in groundwater. The United States Environmental Protection Agency (USEPA) Office of Research and Development (ORD) and the USEPA Office of Solid Waste and Emergency Response (OSWER) define natural attenuation as:

> *The biodegradation, dispersion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.*

In practice, natural attenuation also is referred to by several other names, such as intrinsic remediation, intrinsic bioremediation, or passive bioremediation. The goal of any site characterization effort is to understand the fate and transport of the contaminants of concern over time in order to assess any current or potential threat to human health or the environment. Natural attenuation processes, such as biodegradation, can often be dominant factors in the fate and transport of contaminants. Thus, consideration and quantification of natural attenuation is essential to a more thorough understanding of contaminant fate and transport.

The intent of this document is to present a technical protocol for data collection and analysis in support of natural attenuation with long-term monitoring (LTM) for restoration of groundwater contaminated with chlorinated solvents and groundwater contaminated with mixtures of fuels and chlorinated aliphatic hydrocarbons. Specifically, this protocol is designed to evaluate the fate in groundwater of chlorinated aliphatic hydrocarbons and/or fuel hydrocarbons that have regulatory standards. In some cases, the information collected using this protocol will show that natural degradation processes will reduce the concentrations of these contaminants below risk-based corrective action criteria or regulatory standards before potential receptor exposure pathways are completed. The evaluation should include consideration of existing exposure pathways, as well as exposure pathways arising from potential future use of the groundwater.

Natural attenuation in groundwater systems results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Biodegradation is the most important destructive attenuation mechanism, although abiotic destruction of some compounds does occur. Nondestructive attenuation mechanisms include sorption, dispersion, dilution from recharge, and volatilization. Figure 1.1 shows the significant fate and transport mechanisms that influence contaminant migration in the subsurface. The natural attenuation of fuel hydrocarbons is described in the *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater*, recently published by the Air Force Center for Environmental Excellence (AFCEE) (Wiedemeier *et al.*, 1995d). This document differs from the technical protocol for intrinsic remediation of fuel hydrocarbons because it focuses on the individual processes of chlorinated aliphatic hydrocarbon biodegradation which are fundamentally different from the processes involved in the biodegradation of fuel hydrocarbons.

For example, biodegradation of fuel hydrocarbons, especially benzene, toluene, ethylbenzene, and xylenes (BTEX), is mainly limited by electron acceptor availability, and generally will proceed until all of the contaminants biochemically accessible to the microbes are destroyed. In the experience of the authors, there appears to be an inexhaustible supply of electron acceptors in most, if not all, hydrogeologic environments. On the other hand, the more highly chlorinated solvents such as perchloroethene (PCE) and trichloroethene (TCE) typically are biodegraded under natural conditions via reductive dechlorination, a process that requires both electron acceptors (the chlorinated aliphatic hydrocarbons) and an adequate supply of electron donors. Electron donors include fuel hydrocarbons or other types of anthropogenic carbon (e.g., landfill leachate) or natural organic carbon. If the subsurface environment is depleted of electron donors before the chlorinated aliphatic hydrocarbons are removed, reductive dechlorination will cease, and natural attenuation may no longer be protective of human health and the environment. This is the most significant difference between the processes of fuel hydrocarbon and chlorinated aliphatic hydrocarbon biodegradation.

For this reason, it is more difficult to predict the long-term behavior of chlorinated aliphatic hydrocarbon plumes than fuel hydrocarbon plumes. Thus, it is important to have a good understanding of the important natural attenuation mechanisms. In addition to having a better understanding of the processes of advection, dispersion, dilution from recharge, and sorption, it is necessary to better quantify biodegradation. This requires an understanding of the interactions between chlorinated aliphatic hydrocarbons, anthropogenic or natural carbon, and inorganic electron acceptors at the site. Detailed site characterization is required to adequately document and understand these processes.

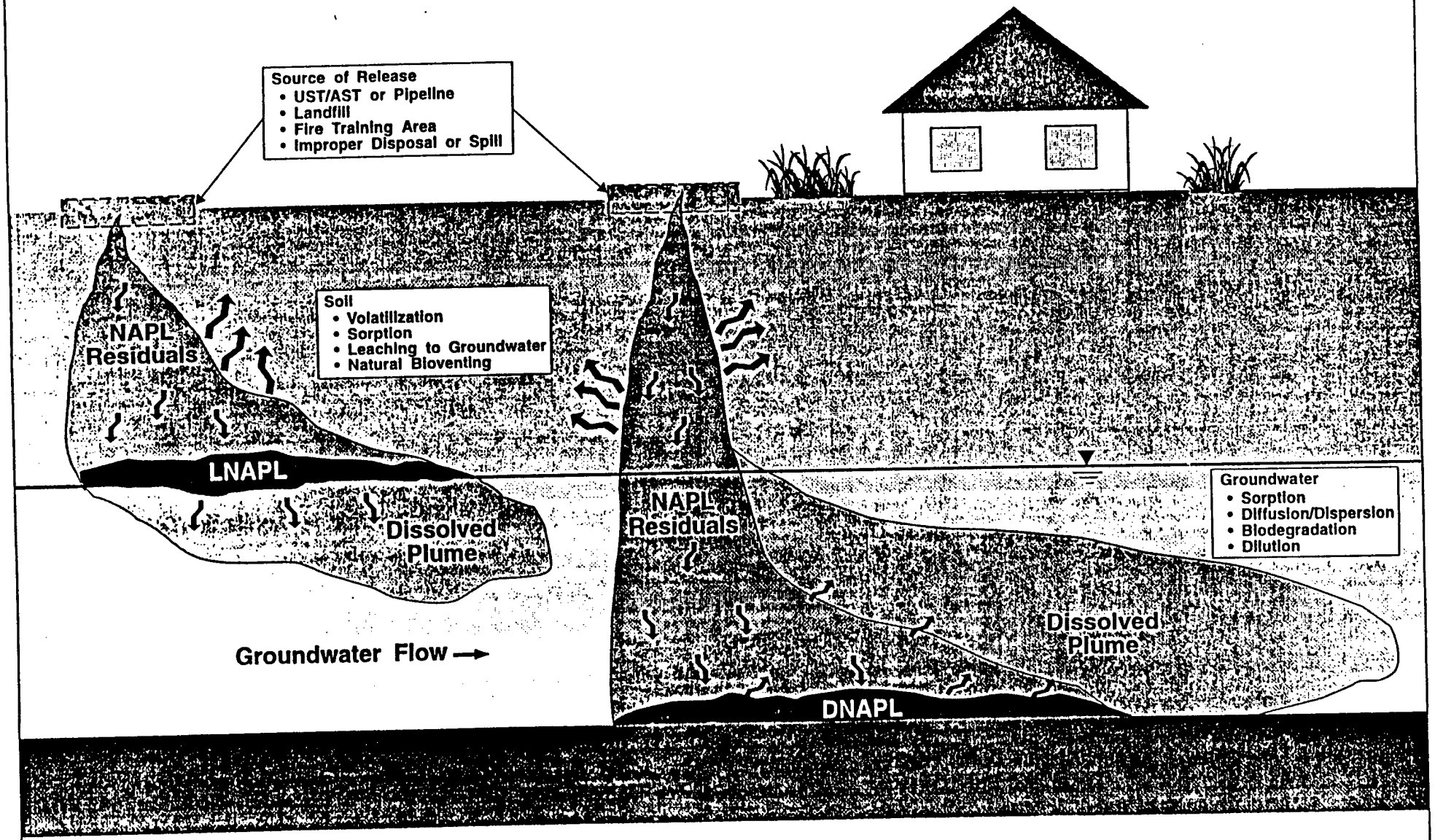


Figure 1.1
Significant Chemical Fate and Transport Mechanisms in the Subsurface

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Based on experience at over 40 Air Force sites, the cost to fully implement this protocol ranges from $100,000 to $175,000, depending on site conditions. These costs are relevant only for typical sites at Air Force bases; other sites may cost more or less. These costs include site characterization (with monitoring well installation), chemical analyses, numerical modeling, report preparation including comparative analysis of remedial options, and regulatory negotiations. The additional chemical analyses required to implement this protocol typically increase analytical costs by 10 to 15 percent over the analytical costs of a conventional remedial investigation.

The intended audience for this document is United States Air Force personnel and their contractors, scientists, consultants, regulatory personnel, and others charged with remediating groundwater contaminated with chlorinated aliphatic hydrocarbons or mixtures of fuel hydrocarbons and chlorinated aliphatic hydrocarbons. This protocol is intended to be used within the established regulatory framework. It is not the intent of this document to prescribe a course of action, including site characterization, in support of all possible remedial technologies. Instead, this protocol is another tool, similar to the AFCEE - Technology Transfer Division protocols for bioventing (Hinchee *et al.*, 1992) or bioslurping (Battelle, 1995) that allow practitioners to adequately evaluate these alternatives in subsequent feasibility studies. It is not the intent of this document to replace existing USEPA or state-specific guidance on conducting remedial investigations.

The AFCEE Remediation Matrix - Hierarchy of Preferred Alternatives identifies natural attenuation as the first option to be evaluated for remediation of contaminated groundwater at Air Force sites. This matrix implies only that natural attenuation should be evaluated prior to proceeding (if necessary) to more costly solutions (e.g., groundwater extraction and treatment or another engineered solution), not that natural attenuation be selected as a presumptive remedy. The USEPA has not identified natural attenuation as a presumptive remedy at the time of this writing.

Chlorinated solvents are released into the subsurface under two possible scenarios 1) As relatively pure solvents that are more dense than water; or 2) as mixtures of fuel hydrocarbons and chlorinated aliphatic hydrocarbons which, depending on the relative proportion of each, may be more or less dense that water. These products commonly are referred to as "nonaqueous-phase liquids," or NAPLs. If the NAPL is more dense than water the material is referred to as a "dense nonaqueous-phase liquid," or DNAPL. If the NAPL is less dense than water the material is referred to as a "light nonaqueous-phase liquid," or LNAPL. Contaminant sources generally consist of hydrocarbons present as mobile NAPL (NAPL occurring at sufficiently high saturations to drain under the influence of gravity into a well) and residual NAPL (NAPL occurring at immobile, residual saturations that are unable to drain into a well by gravity). In general, the

greatest mass of contaminant is associated with these NAPL source areas, not with the aqueous phase. As groundwater or recharge moves through the NAPL source areas, soluble constituents partition into the water to generate a plume of dissolved contamination. After further releases have been stopped, these NAPL source areas tend to slowly weather away as the soluble components, such as BTEX or TCE, are depleted. In cases where mobile NAPL removal is feasible, it is desirable to remove product and decrease the time required for complete remediation of the site. However, at many sites mobile NAPL removal is not feasible with available technology. In fact, the quantity of mobile NAPL recovered by commonly used recovery techniques is a trivial fraction of the total NAPL available to contaminate groundwater. Frequently less than 10 percent of the total NAPL mass in a spill can be recovered by mobile NAPL recovery.

In comparison to conventional engineered remediation technologies, natural attenuation is advantageous because:

- During natural attenuation, contaminants are ultimately transformed to innocuous byproducts (e.g., carbon dioxide, ethene, and water), not just transferred to another phase or location within the environment;
- Natural attenuation is nonintrusive and allows continuing use of infrastructure during remediation;
- Engineered remedial technologies can pose greater risk to potential receptors than natural attenuation when contaminants are transferred into the atmosphere during remediation activities;
- Natural attenuation is less costly than currently available remedial technologies such as groundwater extraction for *ex situ* treatment;
- Natural attenuation is not subject to limitations imposed by the use of mechanized remediation equipment (e.g., no equipment downtime); and
- Those compounds that are the most mobile and toxic generally are the most susceptible to biodegradation.

Natural attenuation has the following potential limitations:

- Natural attenuation is subject to natural and anthropogenic changes in local hydrogeologic conditions, including changes in groundwater velocity, pH, electron acceptor concentrations, electron donor concentrations, and potential future releases;
- Aquifer heterogeneity may complicate site characterization, as it will with any remedial technology;
- Time frames for complete remediation may be relatively long; and
- Intermediate products of biodegradation (e.g., vinyl chloride) can be more toxic than the original contaminant.

This document describes (1) those processes that bring about natural attenuation, (2) the site characterization activities that may be performed to conduct a full-scale evaluation of natural attenuation, (3) natural attenuation modeling using analytical or numerical solute fate and transport models, and (4) the post-modeling activities that should be completed to ensure successful support and verification of remediation by natural attenuation. The objective of the work described herein is to quantify and provide defensible data in support of natural attenuation at sites where naturally occurring subsurface attenuation processes are capable of reducing dissolved chlorinated aliphatic hydrocarbon and/or fuel hydrocarbon concentrations to acceptable levels. A comment made by a member of the regulatory community summarizes what is required to successfully implement natural attenuation:

> *A regulator looks for the data necessary to determine that a proposed treatment technology, if properly installed and operated, will reduce the contaminant concentrations in the soil and water to legally mandated limits. In this sense the use of biological treatment systems calls for the same level of investigation, demonstration of effectiveness, and monitoring as any conventional* [remediation] *system* (National Research Council, 1993).

To support remediation by natural attenuation, the proponent must scientifically demonstrate that attenuation of site contaminants is occurring at rates sufficient to be protective of human health and the environment. Three lines of evidence can be used to support natural attenuation of chlorinated aliphatic hydrocarbons, including:

1) Observed reductions in contaminant concentrations along the flow path downgradient from the source of contamination.

2) Documented loss of contaminant mass at the field scale using

   a) Chemical and geochemical analytical data including;
      - decreasing parent compound concentrations
      - increasing daughter compound concentrations
      - depletion of electron acceptors and donors
      - increasing metabolic byproduct concentrations

   b) A conservative tracer and a rigorous estimate of residence time along the flow path to document contaminant mass reduction and to calculate biological decay rates at the field scale.

3) Microbiological laboratory data that support the occurrence of biodegradation and give rates of biodegradation.

At a minimum, the investigator must obtain the first two lines of evidence or the first and third lines of evidence. The second and third lines of evidence are crucial to the natural attenuation demonstration because they provide biodegradation rate constants. These rate constants are used in conjunction with the other fate and transport parameters to predict contaminant concentrations and to assess risk at downgradient points of compliance.

The first line of evidence is simply an observed reduction in the concentration of released contaminants downgradient from the NAPL source area along the groundwater flow path. This line of evidence does not prove that contaminants are being destroyed because the reduction in contaminant concentration could be the result of advection, dispersion, dilution from recharge, sorption, and volatilization with no loss of contaminant mass (i.e., the majority of apparent contaminant loss could be due to dilution). Conversely, an increase in the concentrations of some contaminants, most notably degradation products such as VC, also could be indicative of natural attenuation.

In order to support remediation by natural attenuation at most sites, the investigator will have to show that contaminant mass is being destroyed via biodegradation. This is done using either, or both, of the second or third lines of evidence. The second line of evidence relies on chemical and physical data to show that contaminant mass is being destroyed via biodegradation, not just being diluted or sorbed to the aquifer matrix. The second line of evidence is divided into two components:

- Using chemical analytical data in mass balance calculations to show that decreases in contaminant and electron acceptor/donor concentrations can be directly correlated to increases in metabolic end products/daughter compounds. This evidence can be used to show that electron acceptor/donor concentrations in groundwater are sufficient to facilitate degradation of dissolved contaminants. Solute fate and transport models can be used to aid mass balance calculations and to collate and present information on degradation.
- Using measured concentrations of contaminants and/or biologically recalcitrant tracers in conjunction with aquifer hydrogeologic parameters such as seepage velocity and dilution to show that a reduction in contaminant mass is occurring at the site and to calculate biodegradation rate constants.

The third line of evidence, microbiological laboratory data, can be used to show that indigenous biota are capable of degrading site contaminants at a particular rate. Because it is

necessary to show that biodegradation is occurring and to obtain biodegradation rate constants, the best type of microbiological laboratory data is the microcosm study.

This document presents a technical course of action that allows converging lines of evidence to be used to scientifically document the occurrence and quantify rates of natural attenuation. Such a "weight-of-evidence" approach will greatly increase the likelihood of successfully implementing natural attenuation at sites where natural processes are restoring the environmental quality of groundwater. Ideally, the first two lines of evidence should be used in the natural attenuation demonstration. To further document natural attenuation, or at sites with complex hydrogeology, it may not be possible to obtain a field-scale biodegradation rate; in this case, microbiological laboratory data can be useful.

Development of an adequate database during the iterative site characterization process is an important step in the documentation of natural attenuation. Site characterization should provide data on the location, nature, and extent of contaminant sources. Site characterization also should provide information on the location, extent, and concentrations of dissolved contamination; groundwater geochemical data; geologic information on the type and distribution of subsurface materials; and hydrogeologic parameters such as hydraulic conductivity, hydraulic gradients, and potential contaminant migration pathways to human or ecological receptor exposure points. Methodologies for determining these parameters are discussed in Appendix A.

The data collected during site characterization can be used to simulate the fate and transport of contaminants in the subsurface. Such simulation allows prediction of the future extent and concentrations of the dissolved contaminant plume. Several types of model can be used to simulate dissolved contaminant transport and attenuation. The natural attenuation modeling effort has three primary objectives:

- To predict the future extent and concentration of a dissolved contaminant plume by simulating the combined effects of contaminant loading, advection, dispersion, sorption, and biodegradation;
- To assess the potential for downgradient receptors to be exposed to contaminant concentrations that exceed regulatory or risk-based levels intended to be protective of human health and the environment; and
- To provide technical support for the natural attenuation remedial option at post-modeling regulatory negotiations. Appendix C discusses data interpretation and pre-modeling calculations. The use of solute fate and transport models is discussed in Appendix D.

Upon completion of the fate and transport modeling effort, model predictions can be used in an analysis of receptor exposure pathways. If natural attenuation is sufficient to mitigate risks to potential receptors, the proponent of natural attenuation has a reasonable basis for negotiating this option with regulators.

Natural attenuation is achieved when naturally occurring attenuation mechanisms, such as biodegradation, bring about a reduction in the total mass of a contaminant dissolved in groundwater. In many cases, natural attenuation will reduce dissolved contaminant concentrations to below regulatory standards such as maximum contaminant levels (MCLs) before the contaminant plume reaches potential receptors. To date, this protocol has been fully or partially implemented at 10 Air Force sites including Plattsburgh Air Force Base (AFB), NY; Hill AFB, Utah; Offutt AFB, NE; Rickenbacker AFB, OH; Westover Air Force Reserve Base (AFRB), MA; and Cape Canaveral AFB, FL. At the sites where historical data are available, contaminant concentrations and mass have declined over time.

The material presented herein was prepared through the joint effort of the AFCEE Technology Transfer Division; the Bioremediation Research Team at USEPA's National Risk Management Research Laboratory (NRMRL) in Ada, Oklahoma, Subsurface Protection and Remediation Division; and Parsons Engineering Science, Inc. (Parsons ES). It is designed to facilitate implementation of natural attenuation at chlorinated aliphatic hydrocarbon-contaminated sites owned by the United States Air Force and other United States Department of Defense (DOD) agencies, the United States Department of Energy, and public interests. This document contains three sections, including this introduction, and six appendices. Section 2 presents the protocol to be used to obtain scientific data to support the natural attenuation option. Section 3 presents the references used in preparing this document. Appendix A describes the collection of site characterization data necessary to support natural attenuation, and provides soil and groundwater sampling procedures and analytical protocols. Appendix B provides an in-depth discussion of the destructive and nondestructive mechanisms of natural attenuation. Appendix C covers data interpretation and pre-modeling calculations. Appendix D describes solute fate and transport modeling in support of natural attenuation. Appendix D also describes the post-modeling monitoring and verification process. Appendices E and F present case studies of site investigations and modeling efforts conducted in support of natural attenuation of solvents, using the methods described in this document.

SECTION 2

PROTOCOL FOR IMPLEMENTING NATURAL ATTENUATION

The primary objective of the natural attenuation investigation is to determine whether natural processes of contaminant degradation will reduce contaminant concentrations in groundwater to below regulatory standards before potential receptor exposure pathways are completed. Further, natural attenuation should be evaluated to determine if it can meet all appropriate federal and state remediation objectives for a given site. This requires that projections of the potential extent and concentrations of the contaminant plume in time and space be made. These projections should be based on historic variations in, and the current extent and concentrations of, the contaminant plume, in conjunction with measured rates of contaminant attenuation. Because of the inherent uncertainty associated with such predictions, it is the responsibility of the proponent of natural attenuation to provide sufficient evidence to demonstrate that the mechanisms of natural attenuation will reduce contaminant concentrations to acceptable levels before potential receptors are reached. This requires the use of solute fate and transport models with conservative input parameters and numerous sensitivity analyses so that consideration is given to all plausible contaminant migration scenarios. When possible, both historical data and modeling should be used to provide information that collectively and consistently confirms the natural reduction and removal of the dissolved contaminant plume.

Figure 2.1 outlines the steps involved in a natural attenuation demonstration and shows the important regulatory decision points for implementing natural attenuation. The key steps outlined in this figure include:

1) Review available site data and develop preliminary conceptual model;
2) Screen the site and assess the potential for natural attenuation;
3) If natural attenuation is selected as potentially appropriate, perform site characterization to support natural attenuation;
4) Refine conceptual model based on site characterization data, complete pre-modeling calculations, and document indicators of natural attenuation;
5) Simulate natural attenuation using analytical or numerical solute fate and transport models that allow incorporation of a biodegradation term, as necessary;

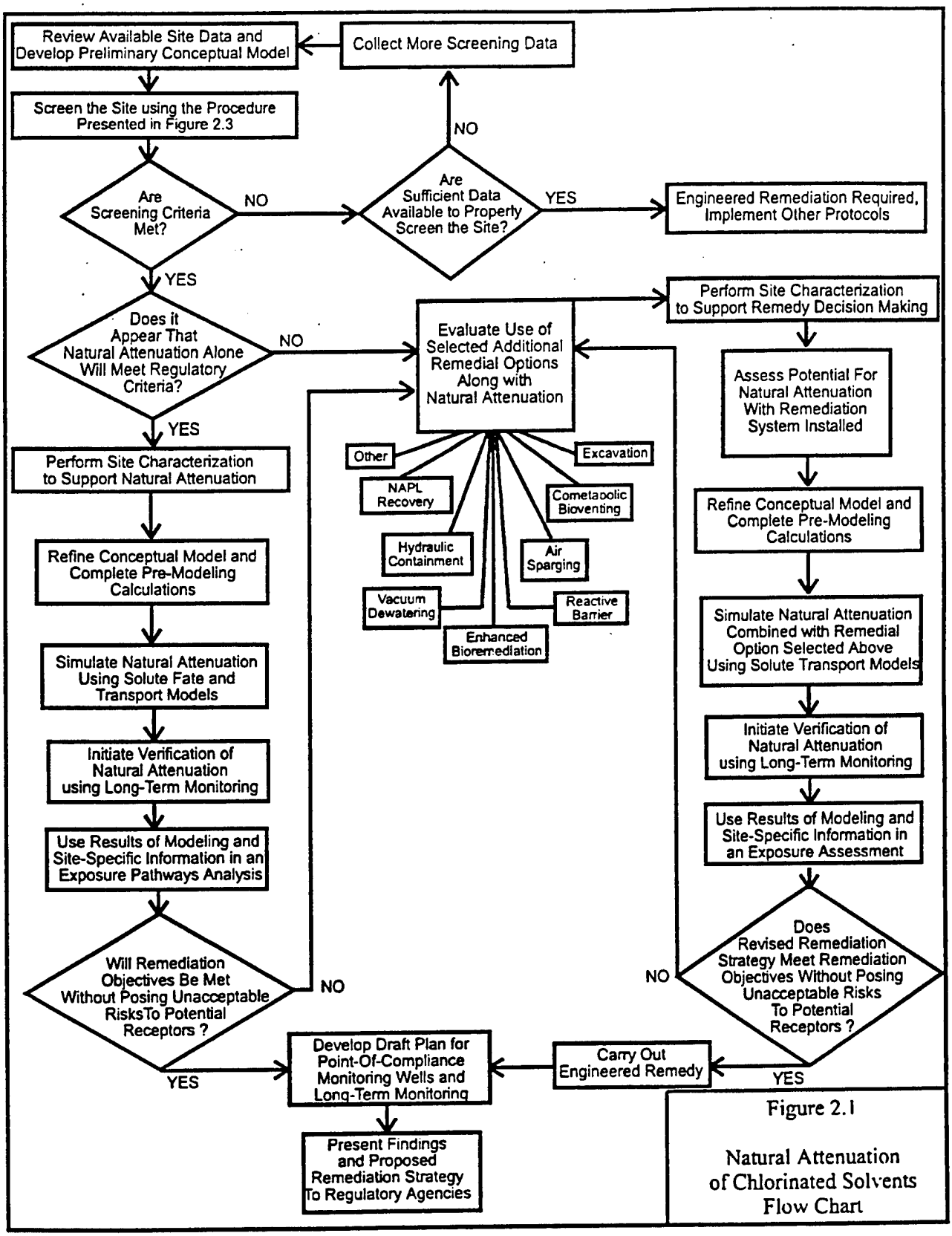


Figure 2.1

Natural Attenuation of Chlorinated Solvents Flow Chart

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6) Identify potential receptors and exposure points and conduct an exposure pathways analysis;

7) Evaluate practicability and potential efficiency of supplemental source removal;

8) If natural attenuation with or without source removal is acceptable, prepare LTM plan; and

9) Present findings to regulatory agencies and obtain approval for the natural attenuation with LTM option.

The following sections describe each of these steps in more detail.

2.1 REVIEW AVAILABLE SITE DATA AND DEVELOP PRELIMINARY CONCEPTUAL MODEL

The first step in the natural attenuation investigation is to review available site-specific data. Once this is done it is possible to use the initial site screening processes presented in Section 2.2 to determine if natural attenuation is a viable remedial option. A thorough review of these data also allows development of a preliminary conceptual model. The preliminary conceptual model will help identify any shortcomings in the data and will facilitate placement of additional data collection points in the most scientifically advantageous and cost-effective manner possible.

When available, information to be obtained during data review includes:

- Nature, extent, and magnitude of contamination:
  - Nature and history of the contaminant release:
    --Catastrophic or gradual release of NAPL ?
    --More than one source area possible or present ?
    --Divergent or coalescing plumes ?
  - Three-dimensional distribution of mobile and residual NAPL and dissolved contaminants. The distribution of mobile and residual NAPL will be used to define the dissolved plume source area.
  - Groundwater and soil chemical data.
  - Historical water quality data showing variations in contaminant concentrations.
  - Chemical and physical characteristics of the contaminants.
  - Potential for biodegradation of the contaminants.
- Geologic and hydrogeologic data (in three dimensions, if feasible):
  - Lithology and stratigraphic relationships.
  - Grain-size distribution (sand *vs.* silt *vs.* clay).
  - Aquifer hydraulic conductivity.

- Groundwater flow gradients and potentiometric or water table surface maps (over several seasons, if possible).
- Preferential flow paths.
- Interactions between groundwater and surface water and rates of infiltration/recharge.

- Locations of potential receptor exposure points:
  - Groundwater wells.
  - Downgradient and crossgradient groundwater discharge points.

In some cases, few or no site-specific data are available. If this is the case, all future site characterization activities should include collecting the data necessary to screen the site for potential natural attenuation. The additional costs incurred by such data collection are greatly outweighed by the cost savings that will be realized if natural attenuation is selected. Moreover, much of the data collected in support of natural attenuation can be used to design and support other remedial measures.

Available site characterization data should be used to develop a conceptual model for the site. The conceptual model is a three-dimensional representation of the NAPL source area, groundwater flow, and solute transport system based on available geological, biological, geochemical, hydrological, climatological, and analytical data for the site. This type of conceptual model differs from the conceptual site models commonly used by risk assessors that qualitatively consider the location of contaminant sources, release mechanisms, transport pathways, exposure points, and receptors. However, the groundwater system conceptual model facilitates identification of these risk-assessment elements for the exposure pathways analysis. After development, the conceptual model can be used to help determine optimal placement of additional data collection points, as necessary, to aid in the natural attenuation investigation and to develop the solute fate and transport model. Contracting and management controls must be flexible enough to allow for the potential for revisions to the conceptual model and thus the data collection effort.

Successful conceptual model development involves:

- Definition of the problem to be solved (generally the nature, magnitude, and extent of existing and future contamination).
- Integration and presentation of available data, including:
  - Local geologic and topographic maps,
  - Geologic data,
  - Hydraulic data,

- Biological data,
- Geochemical data, and
- Contaminant concentration and distribution data.

- Determination of additional data requirements, including:
  - Borehole locations and monitoring well spacing,
  - A sampling and analysis plan (SAP), and
  - Any data requirements listed in Section 2.1 that have not been adequately addressed.

Table 2.1 contains the recommended soil and groundwater analytical protocol for natural attenuation of chlorinated aliphatic hydrocarbons and/or fuel hydrocarbons. Any plan to collect additional groundwater and soil quality data should include the analytes listed in this table.

2.2 INITIAL SITE SCREENING

After reviewing available site data and developing a preliminary conceptual model, an assessment of the potential for natural attenuation must be made. As stated previously, existing data can be useful to determine if natural attenuation might be sufficient to prevent a dissolved contaminant plume from completing receptor exposure pathways, or from reaching a predetermined point of compliance (POC), in concentrations above applicable federal, state, or risk-based standards. Determining the likelihood of exposure pathway completion is an important component of the natural attenuation investigation. This is achieved by estimating the migration and future extent of the plume based on (1) contaminant properties, including volatility, sorptive properties, and biodegradability; (2) aquifer properties, including hydraulic gradient, hydraulic conductivity, porosity and total organic carbon (TOC) concentrations, and (3) the location of the plume and contaminant source relative to potential receptor exposure points (i.e., the distance between the leading edge of the plume and the potential receptor exposure points). These parameters (estimated or actual) are used in this section to make a preliminary assessment of the effectiveness of natural attenuation in reducing contaminant concentrations.

Table 2.1A. Soil, Soil Gas, and Groundwater Analytical Protocol/ Standard*

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Aromatic and chlorinated hydrocarbons (benzene, toluene, ethylbenzene, and xylene [BTEX]; chlorinated compounds)	SW8260A	Handbook method	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Sample volume approximately 100 ml; use teflon-lined cap on an undisturbed sample or completely filled glass container; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW9060 modified for soil samples	Procedure must be accurate over the range of 0.01–5 percent TOC	The rate of migration of petroleum contaminants in groundwater is dependent upon the amount of TOC in the aquifer matrix.	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil Gas	O_2, CO_2	Field Soil Gas Analyzer		Useful for determining bioactvity in vadose zone.	At initial sampling and respiration testing	Reusable 3-liter Tedlar bags.	Field
Soil Gas	Fuel and Chlorinated VOCs	EPA Method TO-14		Useful for determining chlorinated and BTEX compounds in soil	At initial sampling	1-liter Summa Canister	Fixed-base

Table 2.1.A. (Continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Aromatic and chlorinated hydrocarbons (BTEX, trimethylbenzene isomers, chlorinated compounds)	SW8260A	Handbook method; analysis may be extended to higher molecular weight alkyl benzenes	Method of analysis for BTEX and chlorinated solvents/byproducts, which are the primary target analytes for monitoring natural attenuation; method can be extended to higher molecular weight alkyl-benzenes; trimethylben-zenes are used to monitor plume dilution if degradation is primarily anaerobic.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional, intended for diesel and other heavy oils)	GC/mass spectroscopy method SW8270B; high-performance liquid chromatography method SW8310	Analysis needed only when required for regulatory compliance.	PAHs are components of fuel and are typically analyzed for regulatory compliance. These compounds also are a potential carbon source.	As required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base

Table 2.1.A. (Continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure.	Concentrations less than 1 mg/L generally indicate an anaerobic pathway	Each sampling round	Measure dissolved oxygen onsite using a flow-through cell	Field
Water	Nitrate	IC method E300	Method E300 is a Handbook method.	Substrate for microbial respiration if oxygen is depleted	Each sampling round	Collect at least 40 mL of water in a glass or plastic container; add H_2SO_4 to pH less than 2, cool to 4°C	Fixed-base
Water	Iron (II) (Fe^{2+})	Colorimetric Hach Method # 8146	Filter if turbid.	May indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese	Each sampling round	Collect 100 mL of water in a glass container and analyze as soon as possible	Field
Water	Sulfate (SO_4^{2-})	IC method E300	Method E300 is a Handbook method, if this method is used for sulfate analysis, do not use the field method.	Substrate for anaerobic microbial respiration	Each sampling round	Collect at least 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base
Water	Sulfate (SO_4^{2-})	Hach method # 8051	Colorimetric, if this method is used for sulfate analysis, do not use the fixed-base laboratory method.	Same as above	Each sampling round	Collect at least 40 mL of water in a glass or plastic container; cool to 4°C	Field
Water	Methane, ethane, and ethene	Kampbell *et al.*, 1989 or SW3810 Modified	Method published by researchers at the US Environmental Protection Agency. Limited to few commercial labs.	The presence of CH_4 suggests BTEX degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing biological transformation.	Each sampling round	Collect water samples in 50 mL glass serum bottles with butyl gray/Teflon-lined caps; add H_2SO_4 to pH less than 2, cool to 4°C	Fixed-base

Table 2.1.A. (Continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Alkalinity	Hach alkalinity test kit model AL AP MG-L	Phenolphthalein method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same groundwater system; (2) to measure the buffering capacity of groundwater; and (3) to estimate the amount of carbon dioxide produced.	Each sampling round	Collect 100 mL of water in glass container	Field
Water	Oxidation-reduction potential (ORP)	A2580B	Measurements made with electrodes; results are displayed on a meter; protect samples from exposure to oxygen. Report results against a silver/silver chloride reference electrode	The ORP of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the ORP of groundwater may range from more than 800 mV to less than -400 mV.	Each sampling round	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Water	pH	Field probe with direct reading meter.	Field	Aerobic and anaerobic processes are pH-sensitive	Each sampling round	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Water	Temperature	Field probe with direct reading meter.	Field only	Well development	Each sampling round	Not Applicable	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Each sampling round	Collect 100–250 mL of water in a glass or plastic container	Field

Table 2.1.A. (Concluded)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Chloride	Mercuric nitrate titration A4500-Cl^- C	Ion chromatography (IC) method E300 or method SW9050 may also be used	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system. Final product of chlorinated solvent reduction.	Each sampling round	Collect 250 mL of water in a glass container	Fixed-base
Water	Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Total Organic Carbon	SW9060	Laboratory	Used to classify plume and to determine if cometabolism is possible in the absence of anthropogenic carbon	Each sampling round	Collect 100 mL of water in a glass container, cool	Laboratory

Table 2.1.B. Soil and Groundwater Analytical Protocol/ Special Analyses*

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Container, and Preservation	Field or Fixed-Base Laboratory
Soil	Biologically Available Iron (III)	Under development	HCL extraction followed by quantification of released iron (III)	To predict the possible extent of iron reduction in an aquifer	One round of sampling in five borings, five cores from each boring	Minimum 1inch diameter core samples collected into plastic liner. Cap and prevent aeration	Laboratory
Water	Nutritional quality of native organic matter	Under Development	Spectrophotometric method	Used to determine the extent of reductive dechlorination allowed by the supply of electron donor	One round of sampling in two to five wells	1,000 mL in amber glass container	Laboratory
Water	Hydrogen (H_2)	Equilibration with gas in the field. Determined with a reducing gas detector.	Specialized analysis	Determine terminal electron accepting process. Predicts the possibility for reductive dechlorination.	One round of sampling	Sampled at well head requires the production of 100mL per minute of water for 30 minutes	Field
Water	Oxygenates (including MTBE, ethers, acetic acid, methanol, and acetone)	SW8260/8015	Laboratory	Contaminant or electron donors for dechlorination of solvents.	At least one sampling round or as determined by regulators	Collect 1 L of water in a glass container, preserve with HCL	Laboratory

NOTES:

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

1. "Hach" refers to the Hach Company catalog, 1990.
2. "A" refers to *Standard Methods for the Examination of Water and Wastewater*, 18th edition, 1992.
3. "E" refers to *Methods for Chemical Analysis of Water and Wastes*, USEPA, 1983.
4. "Protocols" refers to the AFCEE *Environmental Chemistry Function Installation Restoration Program Analytical Protocols*, 11 June 1992.
5. "Handbook" refers to the AFCEE *Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS)*, September 1993.
6. "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods*, SW-846, USEPA, 3rd edition, 1986.
7. "ASTM" refers to the *American Society for Testing and Materials.*
8. "LUFT" refers to the State of California *Leaking Underground Fuel Tank Field Manual*, 1988 edition.

If, after completing the steps outlined in this section, it appears that natural attenuation will be a significant factor in contaminant removal, detailed site characterization activities in support of this remedial option should be performed. If exposure pathways have already been completed and contaminant concentrations exceed regulatory levels, or if such completion is likely, other remedial measures should be considered, possibly in conjunction with natural attenuation. Even so, the collection of data in support of the natural attenuation option can be integrated into a comprehensive remedial strategy and may help reduce the cost and duration of engineered remedial measures such as intensive source removal operations or pump-and-treat technologies.

2.2.1 Overview of Chlorinated Aliphatic Hydrocarbon Biodegradation

Because biodegradation is the most important destructive process acting to reduce contaminant concentrations in groundwater, an accurate estimate of the potential for natural biodegradation is important to consider when determining whether groundwater contamination presents a substantial threat to human health and the environment. This information also will be useful when selecting the remedial alternative that will be most cost effective at eliminating or abating these threats should natural attenuation alone not prove to be sufficient.

Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons and chlorinated solvents (e.g., Bouwer *et al.*, 1981; Miller and Guengerich, 1982; Wilson and Wilson, 1985; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Lee, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). Whereas fuel hydrocarbons are biodegraded through use as a primary substrate (electron donor), chlorinated aliphatic hydrocarbons may undergo biodegradation through three different pathways: use as an electron acceptor; use as an electron donor; or through cometabolism, where degradation of the chlorinated organic is fortuitous, and there is no benefit to the microorganism. At a given site, one or all of these processes may be operating, although at many sites the use of chlorinated aliphatic hydrocarbons as electron acceptors appears to be most important under natural conditions. In this case biodegradation of chlorinated aliphatic hydrocarbons will be an electron-donor-limited process. Conversely, biodegradation of fuel hydrocarbons is an electron-acceptor-limited process.

In a pristine aquifer, native organic carbon is used as an electron donor, and dissolved oxygen (DO) is used first as the prime electron acceptor. Where anthropogenic carbon (e.g., as fuel hydrocarbons) is present, it also will be used as an electron donor. After the DO is consumed,

anaerobic microorganisms typically use additional electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how chlorinated aliphatic hydrocarbon biodegradation is occurring. In addition, because chlorinated aliphatic hydrocarbons may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of these compounds and their daughter products can provide evidence of the mechanisms of biodegradation working at a site. As with BTEX, the driving force behind oxidation-reduction reactions resulting in chlorinated aliphatic hydrocarbon degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in chlorinated aliphatic hydrocarbon reduction and oxidation do not proceed abiotically. Microorganisms are capable of carrying out the reactions, but they will facilitate only those oxidation-reduction reactions that have a net yield of energy.

2.2.1.1 Mechanisms of Chlorinated Aliphatic Hydrocarbon Biodegradation

2.2.1.1.1 Electron Acceptor Reactions (Reductive Dehalogenation)

The most important process for the natural biodegradation of the more highly chlorinated solvents is reductive dechlorination. During this process, the chlorinated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a chlorine atom is removed and replaced with a hydrogen atom. Figure 2.2 illustrates the transformation of chlorinated ethenes via reductive dechlorination. In general, reductive dechlorination occurs by sequential dechlorination from PCE to TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dechlorination, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent of the three DCE isomers when they are present as daughter products. Reductive dechlorination of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in the concentration of chloride ions.

Reductive dechlorination affects each of the chlorinated ethenes differently. Of these compounds, PCE is the most susceptible to reductive dechlorination because it is the most oxidized. Conversely, VC is the least susceptible to reductive dechlorination because

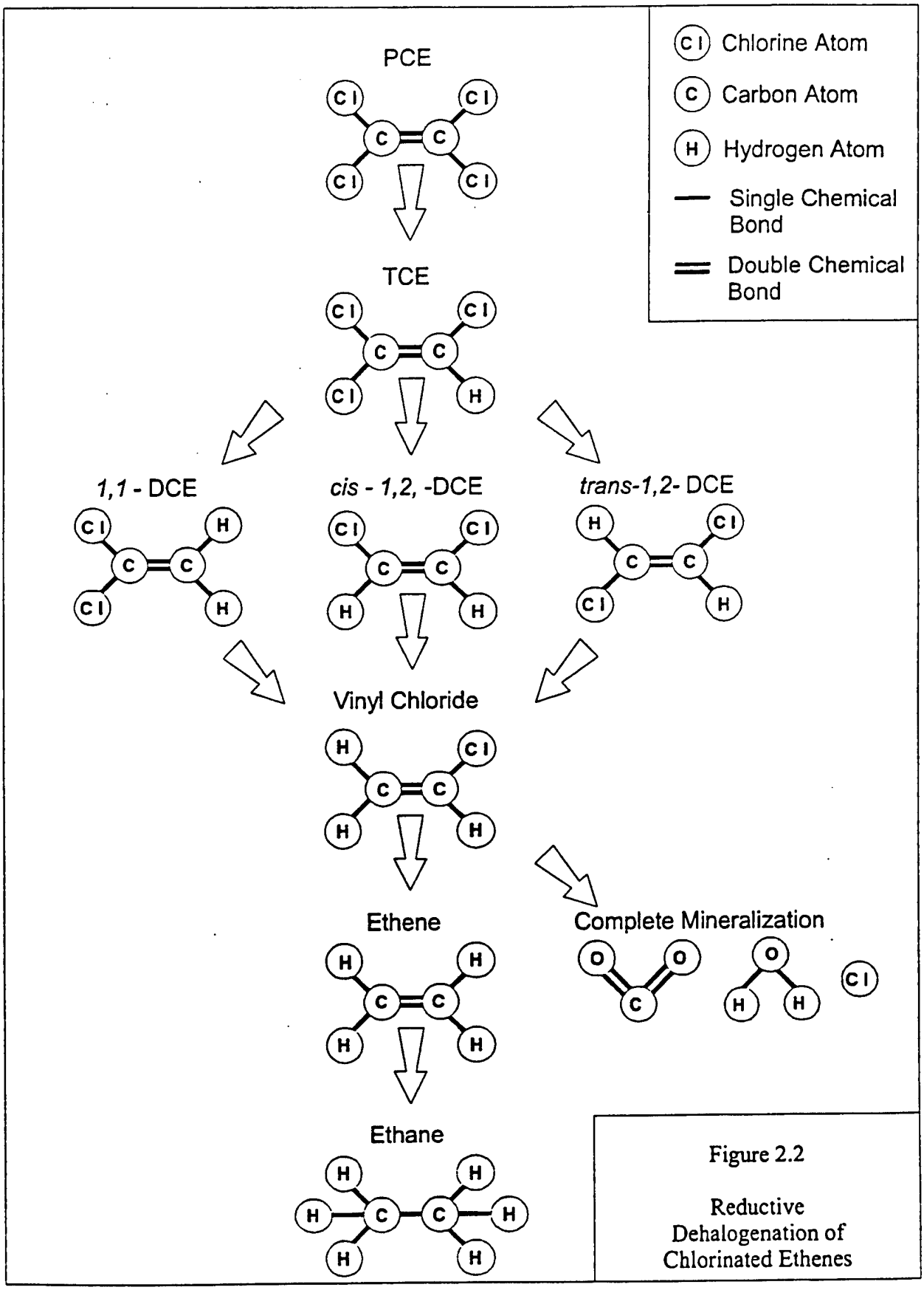


Figure 2.2

Reductive Dehalogenation of Chlorinated Ethenes

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it is the least oxidized of these compounds. As a result, the rate of reductive dechlorination decreases as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dechlorination. Reductive dechlorination has been demonstrated under nitrate- and iron-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of chlorinated aliphatic hydrocarbons, occur under sulfate-reducing and methanogenic conditions (Bouwer, 1994). Because chlorinated aliphatic hydrocarbon compounds are used as electron acceptors during reductive dechlorination, there must be an appropriate source of carbon for microbial growth in order for this process to occur (Bouwer, 1994). Potential carbon sources include natural organic matter, fuel hydrocarbons, or other anthropogenic organic compounds such as those found in landfill leachate.

2.2.1.1.2 Electron Donor Reactions

Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using PCE and TCE as a primary substrate (i.e., electron donor). However, under aerobic and some anaerobic conditions, the less oxidized chlorinated aliphatic hydrocarbons (e.g., VC) can be used as the primary substrate in biologically mediated oxidation-reduction reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded chlorinated aliphatic hydrocarbon. In contrast to reactions in which the chlorinated aliphatic hydrocarbon is used as an electron acceptor, only the least oxidized chlorinated aliphatic hydrocarbons can be used as electron donors in biologically mediated oxidation-reduction reactions. McCarty and Semprini (1994) describe investigations in which VC and 1,2-dichloroethane (DCA) were shown to serve as primary substrates under aerobic conditions. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Aerobic metabolism of VC may be characterized by a loss of VC mass and a decreasing molar ratio of VC to other chlorinated aliphatic hydrocarbon compounds.

2.2.1.1.3 Cometabolism

When a chlorinated aliphatic hydrocarbon is biodegraded via cometabolism, the degradation is catalyzed by an enzyme or cofactor that is fortuitously produced by the organisms for other purposes. The organism receives no known benefit from the degradation of the chlorinated

aliphatic hydrocarbon. Rather, the cometabolic degradation of the chlorinated aliphatic hydrocarbon may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994). Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the rate of cometabolism increases as the degree of dechlorination decreases. During cometabolism, the chlorinated alkene is indirectly transformed by bacteria as they use BTEX or another substrate to meet their energy requirements. Therefore, the chlorinated alkene does not enhance the degradation of BTEX or other carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources.

2.2.1.2 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of biologically available organic carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being used. Individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below.

2.2.1.2.1 Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate), and microbial degradation of this anthropogenic carbon drives reductive dechlorination. When evaluating natural attenuation of a plume exhibiting type 1 behavior the following questions must be answered:

1) Is the electron donor supply adequate to allow microbial reduction of the chlorinated organic compounds? In other words, will the microorganisms "strangle" before they "starve" [i.e., will they run out of chlorinated aliphatic hydrocarbons used as electron acceptors before they run out of anthropogenic carbon used as the primary substrate?
2) What is the role of competing electron acceptors (e.g., dissolved oxygen, nitrate, iron (III) and sulfate)?
3) Is VC oxidized, or is it reduced?

Appendices B and C discuss what these questions mean and how they are answered. Type 1 behavior results in the rapid and extensive degradation of the more highly-chlorinated solvents such as PCE, TCE, and DCE.

2.2.1.2.2 Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high concentrations of biologically available native organic carbon. Microbial utilization of this natural carbon source drives reductive dechlorination (i.e., it is the primary substrate for microorganism growth). When evaluating natural attenuation of a type 2 chlorinated solvent plume, the same questions as those posed in the description of type 1 behavior must be answered. Type 2 behavior generally results in slower biodegradation of the highly chlorinated solvents than Type 1 behavior, but under the right conditions (e.g., areas with high natural organic carbon contents), this type of behavior also can result in rapid degradation of these compounds.

2.2.1.2.3 Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low concentrations of native and/or anthropogenic carbon, and concentrations of dissolved oxygen that are greater than 1.0 mg/L. Under these aerobic conditions reductive dechlorination will not occur. The most significant natural attenuation mechanisms for PCE, TCE, and DCE will be advection, dispersion, and sorption. However, VC can be rapidly oxidized under these conditions, and cometabolism generally occurs under aerobic conditions.

2.2.1.2.4 Mixed Behavior

As mentioned above, a single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of chlorinated aliphatic hydrocarbon plumes. For example, Wiedemeier *et al.* (1996a) describe a plume at Plattsburgh AFB, New York that exhibits Type 1 behavior in the source area and Type 3 behavior downgradient from the source. The most fortuitous scenario involves a plume in which PCE, TCE, and DCE are reductively dechlorinated with accumulation of VC near the source area (Type 1 or Type 2 behavior), then VC is oxidized (Type 3 behavior), either aerobically or via iron reduction further downgradient. Vinyl chloride is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in a plume that exhibits this type of mixed behavior.

$$PCE \rightarrow TCE \rightarrow DCE \rightarrow VC \rightarrow \text{Carbon Dioxide}$$

In general, TCE, DCE, and VC may attenuate at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. Vinyl chloride is removed from the system much faster under these conditions than it is under VC-reducing conditions.

A less desirable scenario, but one in which all contaminants may be entirely biodegraded, involves a plume in which all chlorinated aliphatic hydrocarbons are reductively dechlorinated via Type 1 or Type 2 behavior. Vinyl chloride is reduced to ethene, which may be further reduced to ethane or methane. The following sequence of reactions occur in this type of plume.

$$\text{PCE} \rightarrow \text{TCE} \rightarrow \text{DCE} \rightarrow \text{VC} \rightarrow \text{Ethene} \rightarrow \text{Ethane}$$

This sequence has been investigated by Freedman and Gossett (1989). In this type of plume, VC degrades more slowly than TCE, and thus tends to accumulate.

2.2.2 Screening Process

Based on the experience of the authors, it is estimated that for 80 percent of fuel-hydrocarbon spills at federal facilities, natural attenuation will be protective of human health and the environment. For spills of chlorinated aliphatic hydrocarbons at federal facilities however, natural attenuation alone may be protective of human health and the environment for approximately 20 percent of spills. With this in mind, it is easy to understand why an accurate assessment of the potential for natural biodegradation of chlorinated compounds should be made before investing in a detailed study of natural attenuation. The screening process presented in this section is outlined in Figure 2.3. This approach should allow the investigator to determine if natural attenuation is likely to be a viable remedial alternative before additional time and money are expended. The data required to make the preliminary assessment of natural attenuation also can be used to aid the design of an engineered remedial solution should the screening process suggest that natural attenuation is not feasible.

The following information is required for the screening process:

- The chemical and geochemical data presented in Table 2.2 for a minimum of six (6) samples. Figure 2.4 shows the schematic locations of these data collection points

  Note: if other contaminants are suspected, then data on the concentrations and distribution of these compounds also should be obtained

- Locations of source(s) and receptor exposure points.

- An estimate of the transport velocity and direction of groundwater flow

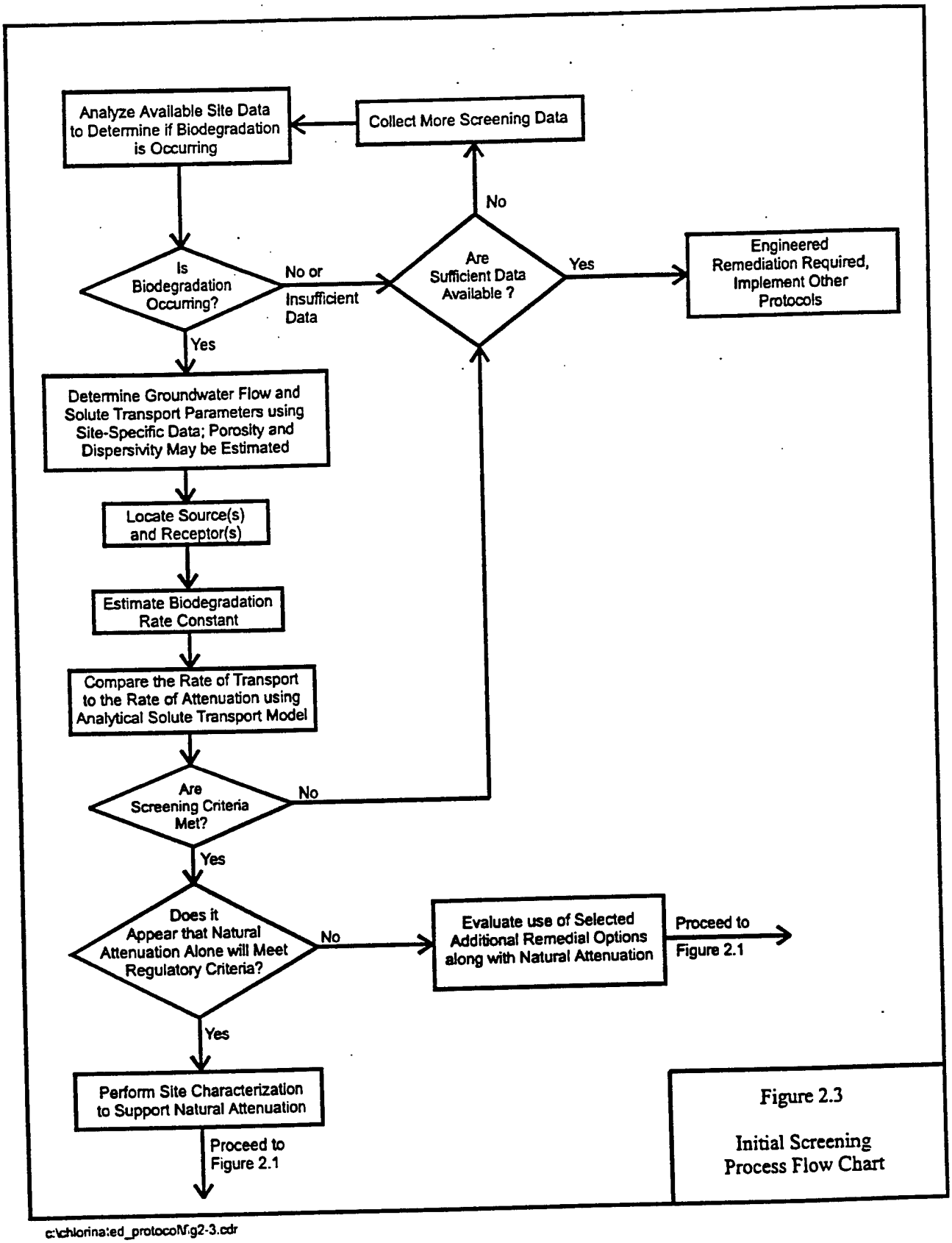


Figure 2.3

Initial Screening Process Flow Chart

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Table 2.2
Analytical Parameters and Weighting for Preliminary Screening

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	3
Oxygen*	>1 mg/L	VC may be oxidized aerobically	-3
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	2
Iron II*	>1 mg/L	Reductive pathway possible	3
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	2
Sulfide*	>1 mg/L	Reductive pathway possible	3
Methane*	<0.5 mg/L >0.5 mg/L	VC oxidizes Ultimate reductive daughter product, VC Accumulates	0 3
Oxidation Reduction Potential* (ORP)	<50 millivolts (mV) <-100mV	Reductive pathway possible Reductive pathway likely	1 2
pH*	5 < pH < 9 5 > pH >9	Optimal range for reductive pathway Outside optimal range for reductive pathway	0 -2
TOC	> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2
Temperature*	> 20°C	At T >20°C biochemical process is accelerated	1
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	1
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	1
Chloride*	>2x background	Daughter product of organic chlorine	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	3
Hydrogen	<1 nM	VC oxidized	0
Volatile Fatty Acids	> 0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	2
BTEX*	> 0.1 mg/L	Carbon and energy source; drives dechlorination	2
PCE*		Material released	0
TCE*		Material released Daughter product of PCE	0 2[a/]
DCE*		Material released Daughter product of TCE. If cis is greater than 80% of total DCE it is likely a daughter product of TCE	0 2[a/]
VC*		Material released Daughter product of DCE	0 2[a/]
Ethene/Ethane	>0.01mg/L >0.1 mg/L	Daughter product of VC/ethene	2 3
Chloroethane*		Daughter product of VC under reducing conditions	2
1,1,1-Trichloroethane*		Material released	0
1,2-dichlorobenzene*		Material released	0
1,3-dichlorobenzene*		material released	0
1,4-dichlorobenzene*		material released	0
chlorobenzene*		Material released or daughter product of dichlorobenzene	2[a/]
1,1-DCE*		Daughter product of TCE or chemical reaction of 1,1,1-TCA	2[a/]

* Required analysis.

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

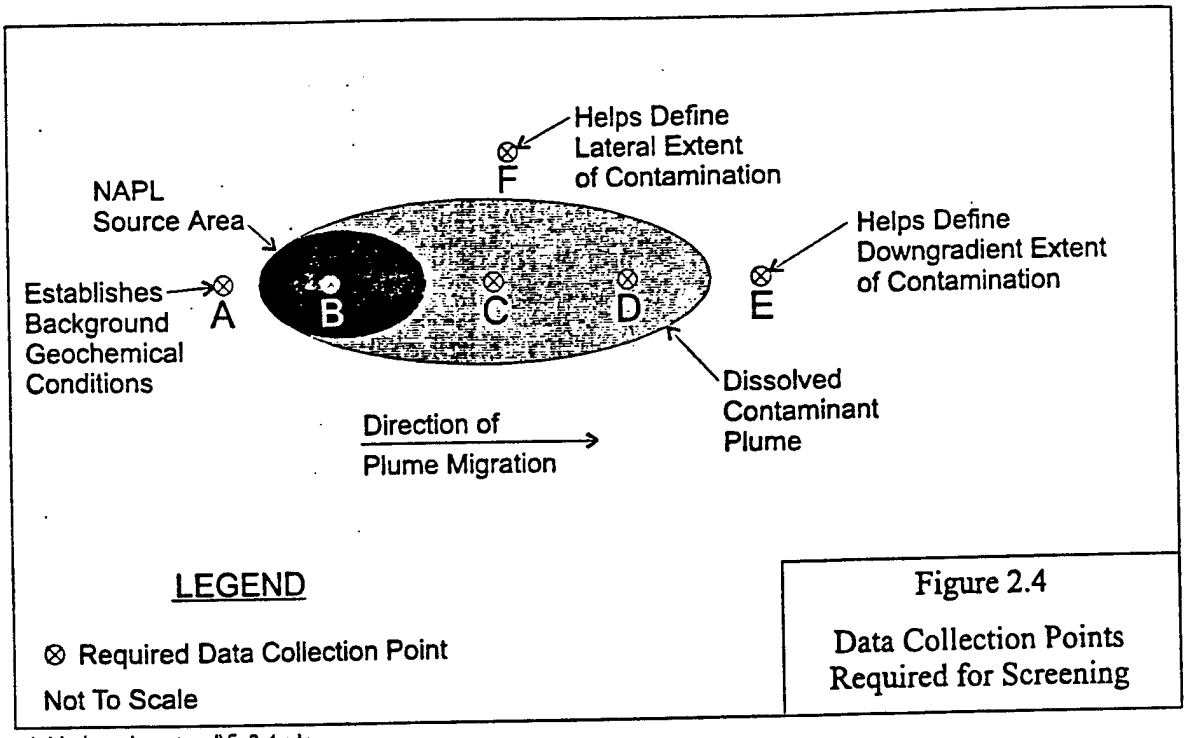


Figure 2.4

Data Collection Points Required for Screening

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Once these data have been collected, the screening process can be undertaken. The following steps summarize the screening processes:

1) Determine if biodegradation is occurring using geochemical data

   If biodegradation is occurring, proceed to step 2. If it is not, assess the amount and types of data available. If data are insufficient to determine if biodegradation is occurring, collect supplemental data.

2) Determine groundwater flow and solute transport parameters.

   Dispersivity and porosity may be estimated but the hydraulic conductivity and the groundwater gradient and flow direction may not. The investigator should use the highest hydraulic conductivity measured at the site during the preliminary screening because solute plumes tend to follow the path of least resistance (i.e., highest hydraulic conductivity). This will give the "worst-case" estimate of the solute migration distance over a given period of time.

3) Locate source(s) and receptor exposure points.

4) Estimate the biodegradation rate constant.

   Biodegradation rate constants can be estimated using a conservative tracer found commingled with the contaminant plume, as described in Appendix C and by Wiedemeier *et al.* (1996b). When dealing with a plume that contains only chlorinated solvents, this procedure can be modified to use chloride as a tracer. Rate constants derived from microcosm studies can also be used. If it is not possible to estimate the biodegradation rate using these procedures, then use a range of accepted literature

values for biodegradation of the contaminants of concern. Appendix C presents a range of biodegradation rate constants for various compounds.

5) Compare the rate of transport to the rate of attenuation.
   Use analytical solutions or a screening model such as BIOSCREEN.

6) Determine if screening criteria are met.

Step 1: Determine if Biodegradation is Occurring

The first step in the screening process is to sample at least six (6) wells that are representative of the contaminant flow system (Figure 2.4) and analyze them for the parameters listed in Table 2.2 (see also Section 2.3.2). These samples should include (1) a sample from the most contaminated portion of the aquifer (generally in the area where NAPL currently is present or was present in the past); (2) samples collected downgradient from the NAPL source area but still in the dissolved contaminant plume; (3) samples collected downgradient from the dissolved contaminant plume; and (4) samples collected from upgradient and lateral locations that are not impacted by the plume.

The sample collected in the NAPL source area allows determination of the dominant terminal electron-accepting processes operating at the site. In conjunction with the sample collected in the NAPL source zone, samples collected in the dissolved plume downgradient from the NAPL source zone allow the investigator to determine if the plume is degrading with distance along the flow path and to determine the distribution of electron acceptors and donors and metabolic byproducts along the flow path. The sample collected downgradient from the dissolved plume aids in plume delineation and allows the investigator to determine if metabolic byproducts are present in an area of groundwater that has been remediated. The upgradient and lateral samples allow delineation of the plume and determination of background concentrations of the electron acceptors and donors.

After these samples have been analyzed for the parameters listed in Table 2.2, the investigator should analyze the data to determine if biodegradation is occurring. The right-hand column of Table 2.2 contains scoring values that can be used as a test to assess the likelihood that biodegradation is occurring. This method relies on the fact that biodegradation will cause predictable changes in groundwater chemistry. For example, if the dissolved oxygen concentration in the area of the plume with the highest contaminant concentration is less than 0.5 milligrams per liter (mg/L), 3 points are awarded. Table 2.3 summarizes the range of possible scores and gives an interpretation for each score. If the score totals 15 or more points, it is likely that biodegradation is occurring, and the investigator can proceed to Step 2.

Table 2.3
Interpretation of Points Awarded During Screening Step 1

Score	Interpretation
0 to 5	Inadequate evidence for biodegradation of chlorinated organics
6 to 14	Limited evidence for biodegradation of chlorinated organics
15 to 20	Adequate evidence for biodegradation of chlorinated organics
> 20	Strong evidence for biodegradation of chlorinated organics

The following two examples illustrate how step 1 of the screening process is implemented. The site used in the first example is a former fire training area contaminated with chlorinated solvents mixed with fuel hydrocarbons. The presence of the fuel hydrocarbons appears to reduce the ORP of the groundwater to the extent that reductive dechlorination is favorable. The second example contains data from a dry cleaning site contaminated only with chlorinated solvents. This site was contaminated with spent cleaning solvents that were dumped into a shallow dry well situated just above a well-oxygenated, unconfined aquifer with low organic carbon concentrations.

Example 1: Strong Evidence for Biodegradation of Chlorinated Organics

Analyte	Concentration in Most Contaminated Zone	Points Awarded
Dissolved Oxygen	0.1 mg/L	3
Nitrate	0.3 mg/L	2
Iron (II)	10 mg/L	3
Sulfate	2 mg/L	2
Methane	5 mg/L	3
ORP	-190 mV	2
Chloride	3 times background	2
PCE (released)	1,000 µg/L	0
TCE (none released)	1,200 µg/L	2
cis-DCE (none released)	500 µg/L	2
VC (none released)	50 µg/L	2
	Total Points Awarded	23 Points

In this example the investigator can infer that biodegradation is likely occurring and may proceed to Step 2.

Example 2: Biodegradation Unlikely

Analyte	Concentration in Most Contaminated Zone	Points Awarded
Dissolved Oxygen	3 mg/L	-3
Nitrate	0.3 mg/L	2
Iron (II)	Not Detected (ND)	0
Sulfate	10 mg/L	2
Methane	ND	0
ORP	100 mV	0
Chloride	background	0
TCE (released)	1,200 µg/L	0
cis-DCE (none released)	ND	0
VC (none released)	ND	0
	Total Points Awarded	1 Point

In this example the investigator can infer that biodegradation is probably not occurring or is occurring too slowly to be a viable remedial option. In this case, the investigator should not proceed to Step 2 and will likely have to implement an engineered remediation system.

Step 2: Determine Groundwater Flow and Solute Transport Parameters

After it has been shown that biodegradation is occurring, it is important to quantify groundwater flow and solute transport parameters. This will make it possible to use a solute transport model to quantitatively estimate the concentration of the plume and its direction and rate of travel. To use an analytical model it is necessary to know the hydraulic gradient and hydraulic conductivity for the site and to have estimates of porosity and dispersivity. It also is helpful to know the coefficient of retardation. Quantification of these parameters is discussed in detail in Appendix B.

In order to make the modeling as accurate as possible, the investigator must have site-specific hydraulic gradient and hydraulic conductivity data. To determine the groundwater flow and solute transport direction, it is necessary to have at least three accurately surveyed wells at the site. The porosity and dispersivity are generally estimated using accepted literature values for the types of sediments found at the site. If the investigator has total organic carbon data for soil, it is possible to estimate the coefficient of retardation; otherwise it is best to assume that the solute transport and groundwater velocities are the same.

Step 3: Locate Sources and Receptor Exposure Points

To determine the length of flow for the predictive modeling to be conducted in Step 5, it is important to know the distance between the source of contamination, the toe of the dissolved plume, and any potential downgradient or cross-gradient receptor exposure points.

Step 4: Estimate the Biodegradation Rate

Biodegradation is the most important process that degrades contaminants in the subsurface; therefore, the biodegradation rate is one of the most important model input parameters. Biodegradation of chlorinated aliphatic hydrocarbons can commonly be represented as a first-order rate constant. It is generally best to use site-specific biodegradation rates. Calculation of site-specific biodegradation rates is discussed in Appendix C. If it is not possible to determine site-specific biodegradation rates, then it will be necessary to use literature values for the biodegradation rate of the contaminant of interest. A useful approach is to start with average values, and then to vary the model input to predict "best-case" and "worst-case" scenarios. Estimated biodegradation rates can be used only after it has been shown that biodegradation is occurring (see Step 1).

Step 5: Compare the Rate of Transport to the Rate of Attenuation

At this early stage in the natural attenuation demonstration, comparison of the rate of solute transport to the rate of attenuation is best accomplished using an analytical model. Several analytical models are available, but the BIOSCREEN model is probably the simplest to use. This model is non-proprietary and is available from the Robert S. Kerr Research Center's home page on the Internet (www.epa.gov/ada/kerrlab.html). The BIOSCREEN model is based on Domenico's (1987) solution to the advection-dispersion equation, and allows use of either a first-order biodegradation rate or an instantaneous reaction between contaminants and electron acceptors to simulate the effects of biodegradation. To model transport of chlorinated aliphatic hydrocarbons using BIOSCREEN, only the first-order decay rate option should be used. BIOCHLOR, a similar model, is under development by the Technology Transfer Division of AFCEE. This model will likely use the same analytical solution as BIOSCREEN, but will be geared toward evaluating transport of chlorinated compounds under the influence of biodegradation.

The primary purpose of comparing the rate of transport to the rate of attenuation is to determine if the residence time along the flow path is adequate to be protective of human health and the environment (i.e., to qualitatively estimate if the contaminant is attenuating at a rate fast enough to allow degradation of the contaminant to acceptable concentrations before receptors are exposed). It is important to perform a sensitivity analysis to help evaluate the confidence in the

preliminary screening modeling effort. If modeling shows that receptors will not be exposed to contaminants at concentrations above risk-based corrective action criteria, then the screening criteria are met, and the investigator can proceed with the natural attenuation evaluation.

Step 6: Determine if Screening Criteria are Met

Before proceeding with the full-scale natural attenuation evaluation, the investigator should ensure that the answers to all of the following questions are yes:

- Has the plume moved a shorter distance than expected based on the known (or estimated) time since the contaminant release and the contaminant velocity, as calculated from site-specific measurements of hydraulic conductivity and hydraulic gradient, and estimates of effective porosity and contaminant retardation?
- Is it likely that the contaminant mass is attenuating at rates sufficient to be protective of human health and the environment at potential exposure points (e.g., at a point of discharge to a sensitive environmental resource)?
- Does it appear that the plume is going to attenuate to concentrations less than federal, state, or risk-based guidelines before reaching potential receptors?

If the answer to each of these questions is yes, then the investigator can proceed with the full-scale natural attenuation demonstration.

2.3 COLLECT ADDITIONAL SITE CHARACTERIZATION DATA IN SUPPORT OF NATURAL ATTENUATION AS REQUIRED

Detailed site characterization is necessary to document the potential for natural attenuation to meet cleanup objectives. As discussed in Section 2.1, review of existing site characterization data is particularly useful before initiating site characterization activities. Such review should allow identification of data gaps and guide the most effective placement of additional data collection points.

There are two goals during the site characterization phase of a natural attenuation investigation. The first is to collect the data needed to determine if natural mechanisms of contaminant attenuation are occurring at rates sufficient to protect human health and the environment. The second is to provide sufficient site-specific data to allow prediction of the future extent and concentrations of a contaminant plume through solute fate and transport modeling. It is the responsibility of the proponent to "make the case" for natural attenuation. Thus, detailed site characterization is required to achieve these goals and to support this remedial

option. Adequate site characterization in support of natural attenuation requires that the following site-specific parameters be determined:

- Extent and types of soil and groundwater contamination.
- Location and extent of contaminant source area(s) (i.e., areas containing mobile or residual NAPL).
- The potential for a continuing source due to leaking tanks or pipelines, or other site activity.
- Aquifer geochemical parameters.
- Regional hydrogeology, including:
  - Drinking water aquifers, and
  - Regional confining units.
- Local and site-specific hydrogeology, including:
  - Local drinking water aquifers,
  - Location of industrial, agricultural, and domestic water wells,
  - Patterns of aquifer use (current and future),
  - Lithology,
  - Site stratigraphy, including identification of transmissive and nontransmissive units,
  - Grain-size distribution (sand *vs.* silt *vs.* clay),
  - Aquifer hydraulic conductivity,
  - Groundwater hydraulic information,
  - Preferential flow paths,
  - Locations and types of surface water bodies, and
  - Areas of local groundwater recharge and discharge.
- Identification of current and future potential exposure pathways, receptors, and exposure points.

The following sections describe the methodologies that should be implemented to allow successful site characterization in support of natural attenuation.

2.3.1 Soil Characterization

In order to adequately define the subsurface hydrogeologic system and to determine the amount and three-dimensional distribution of mobile and residual NAPL that can act as a continuing source of groundwater contamination, extensive soil characterization must be

completed. As appropriate, soil gas data may be collected and analyzed to better characterize soil contamination. Depending on the status of the site, this work may have been completed during previous remedial investigation work. The results of soils characterization will be used as input into a solute fate and transport model to help define a contaminant source term and to support the natural attenuation investigation.

The purpose of soil sampling is to determine the subsurface distribution of hydrostratigraphic units and the distribution of mobile and residual NAPL. These objectives can be achieved through the use of conventional soil borings or direct-push methods (e.g., Geoprobe® or cone penetrometer testing), and through collection of soil gas samples. All soil samples should be collected, described, analyzed, and disposed of in accordance with local, state, and federal guidance. Appendix A contains suggested procedures for soil sample collection. These procedures may require modification to comply with local, state, and federal regulations or to accommodate site-specific conditions.

The analytical protocol to be used for soil and soil gas sample analyses is presented in Table 2.1. This analytical protocol includes all of the parameters necessary to document natural attenuation, including the effects of sorption and biodegradation. Each analyte is discussed separately below.

- **Volatile Organic Compounds**: Knowledge of the location, distribution, concentration, and total mass of contaminants of regulatory concern sorbed to soils or present as mobile or immobile NAPL is required to calculate contaminant partitioning from NAPL into groundwater.
- **Total Organic Carbon**: Knowledge of the TOC content of the aquifer matrix is important for sorption and solute-retardation calculations. TOC samples should be collected from a background location in the stratigraphic horizon(s) where most contaminant transport is expected to occur.
- **Oxygen and Carbon Dioxide**: Oxygen and carbon dioxide soil gas measurements can be used to identify areas in the unsaturated zone where biodegradation is occurring. This can be a useful and relatively inexpensive way to track contamination and degradation in the subsurface.
- **Fuel and Chlorinated Volatile Organic Compounds**: Knowledge of the distribution of contaminants in soil gas can be used as a cost-effective way to estimate the extent of soil contamination.

2.3.2 Groundwater Characterization

To adequately determine the amount and three-dimensional distribution of dissolved contamination and to document the occurrence of natural attenuation, groundwater samples must be collected and analyzed. Biodegradation of organic compounds, whether natural or anthropogenic, brings about measurable changes in the chemistry of groundwater in the affected area. By measuring these changes, it is possible to document and quantitatively evaluate the importance of natural attenuation at a site.

Groundwater sampling is conducted to determine the concentrations and distribution of contaminants, daughter products, and groundwater geochemical parameters. Groundwater samples may be obtained from monitoring wells or with point-source sampling devices such as a Geoprobe®, Hydropunch®, or cone penetrometer. All groundwater samples should be collected, handled, and disposed of in accordance with local, state, and federal guidelines. Appendix A contains suggested procedures for groundwater sample collection. These procedures may need to be modified to comply with local, state, and federal regulations or to accommodate site-specific conditions.

The analytical protocol for groundwater sample analysis is presented in Table 2.1. This analytical protocol includes all of the parameters necessary to delineate dissolved contamination and to document natural attenuation, including the effects of sorption and biodegradation. Data obtained from the analysis of groundwater for these analytes is used to scientifically document natural attenuation and can be used as input into a solute fate and transport model. The following paragraphs describe each groundwater analytical parameter and the use of each analyte in the natural attenuation demonstration.

2.3.2.1 Volatile and Semivolatile Organic Compounds

These analytes are used to determine the type, concentration, and distribution of contaminants and daughter products in the aquifer. At a minimum, the volatile organic compound (VOC) analysis (Method SW8260a) should be used, with the addition of the trimethylbenzene isomers if fuel hydrocarbons are present or suspected. The combined dissolved concentrations of BTEX and trimethylbenzenes should not be greater than about 30 mg/L for a JP-4 spill (Smith *et al.*, 1981) or about 135 mg/L for a gasoline spill (Cline *et al.*, 1991; American Petroleum Institute, 1985). If these compounds are found in higher concentrations, sampling errors such as emulsification of LNAPL in the groundwater sample likely have occurred and should be investigated.

Maximum concentrations of chlorinated solvents dissolved in groundwater from neat solvents should not exceed their solubilities in water. Appendix B contains solubilities for common contaminants. If contaminants are found in concentrations greater than their solubilities, then sampling errors such as emulsification of NAPL in the groundwater sample have likely occurred and should be investigated.

2.3.2.2 Dissolved Oxygen

Dissolved oxygen is the most thermodynamically favored electron acceptor used by microbes for the biodegradation of organic carbon, whether natural or anthropogenic. Anaerobic bacteria generally cannot function at dissolved oxygen concentrations greater than about 0.5 mg/L and hence reductive dechlorination will not occur. This is why it is important to have a source of carbon in the aquifer that can be used by aerobic microorganisms as a primary substrate. During aerobic respiration, dissolved oxygen concentrations decrease. After depletion of dissolved oxygen, anaerobic microbes will use nitrate as an electron acceptor, followed by iron (III), then sulfate, and finally carbon dioxide (methanogenesis). Each sequential reaction drives the ORP of the groundwater downward into the range within which reductive dechlorination can occur. Reductive dechlorination is most effective in the ORP range corresponding to sulfate reduction and methanogenesis, but dechlorination of PCE and TCE also may occur in the ORP range associated with denitrification or iron (III) reduction. Because reductive dechlorination is most effective in the sulfate-reduction and methanogenesis ORP range, competitive exclusion between sulfate reducers, methanogens, and reductive dechlorinators can occur.

Dissolved oxygen measurements should be taken during well purging and immediately before and after sample acquisition using a direct-reading meter. Because most well purging techniques can allow aeration of collected groundwater samples, it is important to minimize the potential for aeration as described in Appendix A.

2.3.2.3 Nitrate

After dissolved oxygen has been depleted in the microbiological treatment zone, nitrate may be used as an electron acceptor for anaerobic biodegradation of organic carbon via denitrification. In order for reductive dechlorination to occur, nitrate concentrations in the contaminated portion of the aquifer must be less than 1.0 mg/L.

2.3.2.4 Iron (II)

In some cases iron (III) is used as an electron acceptor during anaerobic biodegradation of organic carbon. During this process, iron (III) is reduced to iron (II), which may be soluble in water. Iron (II) concentrations can thus be used as an indicator of anaerobic degradation of fuel compounds and VC.

2.3.2.5 Sulfate

After dissolved oxygen and nitrate have been depleted in the microbiological treatment zone, sulfate may be used as an electron acceptor for anaerobic biodegradation. This process is termed sulfate reduction and results in the production of sulfide.

2.3.2.6 Methane

During methanogenesis acetate is split to form carbon dioxide and methane, or carbon dioxide is used as an electron acceptor, and is reduced to methane. Methanogenesis generally occurs after oxygen, nitrate, and sulfate have been depleted in the treatment zone. The presence of methane in groundwater is indicative of strongly reducing conditions. Because methane is not present in fuel, the presence of methane above background concentrations in groundwater in contact with fuels is indicative of microbial degradation of fuel hydrocarbons. Methane also is associated with spills of pure chlorinated solvents. It is not known if the methane comes from chlorinated solvent carbon or from native dissolved organic carbon.

2.3.2.7 Alkalinity

The total alkalinity of a groundwater system is indicative of a water's capacity to neutralize acid. Alkalinity is defined as the net concentration of strong base in excess of strong acid with a pure carbon dioxide-water system as the point of reference (Domenico and Schwartz, 1990). Alkalinity results from the presence of hydroxides, carbonates, and bicarbonates of elements such as calcium, magnesium, sodium, potassium, or ammonia. These species result from the dissolution of rock (especially carbonate rocks), the transfer of carbon dioxide from the atmosphere, and respiration of microorganisms. Alkalinity is important in the maintenance of groundwater pH because it buffers the groundwater system against acids generated during both aerobic and anaerobic biodegradation. In the experience of the authors, biodegradation of organic compounds rarely, if ever, generates enough acid to impact the alkalinity of groundwater.

2.3.2.8 Oxidation-Reduction Potential

The ORP of groundwater (Eh) is a measure of electron activity and is an indicator of the relative tendency of a solution to accept or transfer electrons. Oxidation-reduction reactions in groundwater containing organic compounds (natural or anthropogenic) are usually biologically mediated, and therefore, the ORP of a groundwater system depends upon and influences rates of biodegradation. Knowledge of the ORP of groundwater also is important because some biological processes operate only within a prescribed range of ORP conditions. The ORP of groundwater generally ranges from -400 millivolts (mV) to 800 mV.

ORP measurements can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. Mapping the ORP of the groundwater while in the field helps the field scientist to determine the approximate location of the contaminant plume. To map the ORP of the groundwater while in the field, it is important to have at least one ORP measurement (preferably more) from a well located upgradient from the plume. ORP measurements should be taken during well purging and immediately before and after sample acquisition using a direct-reading meter. Because most well purging techniques can allow aeration of collected groundwater samples (which can affect ORP measurements), it is important to minimize potential aeration by following the steps outlined in Appendix A.

2.3.2.9 Dissolved Hydrogen

Concentrations of dissolved hydrogen can also be used to evaluate redox processes in groundwater systems (Lovley and Goodwin, 1988; Lovley et al., 1994; Chapelle et al., 1995). H_2 is continuously produced in anoxic groundwater systems by fermentative microorganisms that decompose natural and anthropogenic organic matter. This H_2 is then consumed by respiratory microorganisms that use nitrate, Fe(III), sulfate, or CO_2 as terminal electron acceptors. This continuous cycling of H_2 is called *interspecies hydrogen transfer.* Significantly, nitrate-, Fe(III)-, sulfate- and CO_2-reducing (methanogenic) microorganisms exhibit different efficiencies in utilizing the H_2 that is being continually produced. Nitrate reducers are highly efficient H_2 utilizers and maintain very low steady-state H_2 concentrations. Fe(III) reducers are slightly less efficient and thus maintain somewhat higher H_2 concentrations. Sulfate reducers an methanogenic bacteria are progressively less efficient and maintain even higher H_2 concentrations. Because each terminal electron accepting process has a characteristic H_2 concentration associated with it, H_2 concentrations can be an indicator of predominant redox processes. These characteristic ranges are given in Table 2.4. An analytical protocol for quantifying H_2 concentrations in ground water is given in Appendix II.

Table 2.4

Range of Hydrogen Concentrations for a Given Terminal Electron-Accepting Process

Terminal Electron Accepting Process	Hydrogen (H_2) Concentration (nanomoles per liter)
Denitrification	< 0.1
Iron (III) Reduction	0.2 to 0.8
Sulfate Reduction	1 to 4
Methanogenesis	5-20

In practice, it is preferable to interpret H_2 concentrations in the context of electron acceptor (oxygen, nitrate, Fe(III), sulfate) availability and the presence of the final products (Fe(II), hydrogen sulfide, methane) of microbial metabolism (Chapelle *et al.*, 1995). For example, if sulfate concentrations in ground water are less than 0.5 mg/L, methane concentrations are greater than 0.5 mg/L, and H_2 concentrations are in the 5-20 nM range, it can be concluded with a high degree of certainty that methanogenesis is the predominant redox process in the aquifer. Similar logic can be applied to identifying denitrification (presence of nitrate, H_2<0.1 nM), Fe(III) reduction (production of Fe(II), H_2 0.2 to 0.8 nM), and sulfate reduction (presence of sulfate, production of sulfide, H_2 1-4 nM).

2.3.2.10 pH, Temperature, and Conductivity

Because the pH, temperature, and conductivity of a groundwater sample can change significantly within a short time following sample acquisition, these parameters must be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for dissolved oxygen and ORP analyses. The measurements should be made in a clean glass container separate from those intended for laboratory analysis, and the measured values should be recorded in the groundwater sampling record.

The pH of groundwater has an effect on the presence and activity of microbial populations in groundwater. This is especially true for methanogens. Microbes capable of degrading chlorinated aliphatic hydrocarbons and petroleum hydrocarbon compounds generally prefer pH values varying from 6 to 8 standard units.

Groundwater temperature directly affects the solubility of oxygen and other geochemical species. The solubility of dissolved oxygen is temperature-dependent, with oxygen being more soluble in cold water than in warm water. Groundwater temperature also affects the metabolic

activity of bacteria. Rates of hydrocarbon biodegradation roughly double for every 10°C increase in temperature ("Q"$_{10}$ rule) over the temperature range between 5 and 25°C.

Conductivity is a measure of the ability of a solution to conduct electricity. The conductivity of groundwater is directly related to the concentration of ions in solution; conductivity increases as ion concentration increases. Conductivity measurements are used to ensure that groundwater samples collected at a site are representative of the water comprising the saturated zone in which the dissolved contamination is present. If the conductivities of samples taken from different sampling points are radically different, the waters may be from different hydrogeologic zones and they should not be compared to evaluate contaminant attenuation. This is particularly true when the conductivity of the contaminated water sample is high and the conductivity of the clean sample is low.

2.3.2.11 Chloride

Elemental chlorine is the most abundant of the halogens. Although chlorine can occur in oxidation states ranging from Cl^- to Cl^{+7}, the chloride form (Cl^-) is the only form of major significance in natural waters (Hem, 1985). Chloride forms ion pairs or complex ions with some of the cations present in natural waters, but these complexes are not strong enough to be of significance in the chemistry of fresh water (Hem, 1985). The chemical behavior of chloride is neutral. Chloride ions generally do not enter into oxidation-reduction reactions, form no important solute complexes with other ions unless the chloride concentration is extremely high, do not form salts of low solubility, are not significantly adsorbed on mineral surfaces, and play few vital biochemical roles (Hem, 1985). Thus, physical processes control the migration of chloride ions in the subsurface. Kaufman and Orlob (1956) conducted tracer experiments in groundwater, and found that chloride moved through most of the soils tested more conservatively (i.e., with less retardation and loss) than any of the other tracers tested.

During biodegradation of chlorinated hydrocarbons dissolved in groundwater, chloride is released into the groundwater. This results in chloride concentrations in groundwater in the contaminant plume that are elevated relative to background concentrations. Because of the neutral chemical behavior of chloride, it can be used as a conservative tracer to estimate biodegradation rates, as discussed in Appendix C.

2.3.3 Aquifer Parameter Estimation

Estimates of aquifer parameters are necessary to accurately evaluate contaminant fate and transport.

2.3.3.1 Hydraulic Conductivity

Hydraulic conductivity is a measure of an aquifer's ability to transmit water, and is perhaps the most important aquifer parameter governing fluid flow in the subsurface. The velocity of groundwater and dissolved contamination is directly related to the hydraulic conductivity of the saturated zone. In addition, subsurface variations in hydraulic conductivity directly influence contaminant fate and transport by providing preferential paths for contaminant migration. Estimates of hydraulic conductivity are used to determine residence times for contaminants and tracers, and to determine the seepage velocity of groundwater.

The most common methods used to quantify hydraulic conductivity are aquifer pumping tests and slug tests (Appendix A). Another method that may be used to determine hydraulic conductivity is the borehole dilution test. One drawback to these methods is that they average hydraulic properties over the screened interval. To help alleviate this potential problem, the screened interval of the test wells should be selected after consideration is given to subsurface stratigraphy. Information about subsurface stratigraphy should come from geologic logs for continuous cores or from cone penetrometer tests. The rate of filling of a Hydropunch can be used to determine local hydraulic conductivity at the same time the water sample is collected. An alternate method to delineate zones with high hydraulic conductivity is to use pressure dissipation data from cone penetrometer tests.

2.3.3.1.1 Pumping Tests

Pumping tests generally give the most reliable information on hydraulic conductivity, but are difficult to conduct in contaminated areas because the water produced during the test generally must be contained and treated. In addition, a minimum 4-inch-diameter well is generally required to complete pumping tests in highly transmissive aquifers because the 2-inch submersible pumps available today are not capable of producing a flow rate large enough for meaningful pumping tests. In areas with fairly uniform aquifer materials, pumping tests can be completed in uncontaminated areas, and the results can be used to estimate hydraulic conductivity in the contaminated area. Pumping tests should be conducted in wells that are screened in the most transmissive zones in the aquifer. If pumping tests are conducted in wells with more than fifteen feet of screen, a down-hole flowmeter test can be used to determine the interval actually contributing to flow.

2.3.3.1.2 Slug Tests

Slug tests are a commonly used alternative to pumping tests. One commonly cited drawback to slug testing is that this method generally gives hydraulic conductivity information only for the area immediately surrounding the monitoring well. Slug tests do, however, have two distinct advantages over pumping tests: they can be conducted in 2-inch monitoring wells, and they produce no water. If slug tests are going to be relied upon to provide information on the three-dimensional distribution of hydraulic conductivity in an aquifer, multiple slug tests must be performed. It is not advisable to rely on data from one slug test in one monitoring well. Because of this, slug tests should be conducted at several monitoring wells at the site. Like pumping tests, slug tests ideally should be conducted in wells that are narrowly screened in the most transmissive zones in the aquifer.

2.3.3.1.3 Downhole Flowmeter

Borehole flowmeter tests are conducted to investigate the relative vertical distribution of horizontal hydraulic conductivity in the screened interval of a well or the uncased portion of a borehole. These tests can be done to identify any preferential flow pathways within the portion of an aquifer intersecting the test well screen or the open borehole. The work of Molz and Young (1993), Molz *et al.* (1994) , Young and Pearson (1995), and Young (1995) describes the means by which these tests may be conducted and interpreted.

In general , measurements of ambient groundwater flow rates are collected at several regularly spaced locations along the screened interval of a well. Next, the well is pumped at a steady rate, and the measurements are repeated. The test data may be analyzed using the methods described by Molz and Young (1993) and Molz *et al.* (1994) to define the relative distribution of horizontal hydraulic conductivity within the screened interval of the test well. Estimates of bulk hydraulic conductivity from previous aquifer tests can be used to estimate the absolute hydraulic conductivity distribution at the test well.

Using flowmeter test data, one may be able to more thoroughly quantify the three-dimensional hydraulic conductivity distribution at a site. This is important for defining contaminant migration pathways and understanding solute transport at sites with heterogeneous aquifers. Even at sites where the hydrogeology appears relatively homogeneous, such data may point out previously undetected zones or layers of higher hydraulic conductivity that control contaminant migration. In addition, groundwater velocities calculated from hydraulic conductivity data may be used to evaluate site data or for simple transport calculations. In these cases, it is also important to have

the best estimate possible of hydraulic conductivity for those units in which the contaminants are migrating.

2.3.3.2 Hydraulic Gradient

The horizontal hydraulic gradient is the change in hydraulic head (feet of water) divided by the distance of groundwater flow between head measurement points. To accurately determine the hydraulic gradient, it is necessary to measure groundwater levels in all monitoring wells and piezometers at a site. Because hydraulic gradients can change over a short distance within an aquifer, it is essential to have as much site-specific groundwater elevation information as possible so that accurate hydraulic gradient calculations can be made. In addition, seasonal variations in groundwater flow direction can have a profound influence on contaminant transport. Sites in upland areas are less likely to be affected by seasonal variations in groundwater flow direction than low-elevation sites situated near surface water bodies such as rivers and lakes.

To determine the effect of seasonal variations in groundwater flow direction on contaminant transport, quarterly groundwater level measurements should be taken over a period of at least 1 year. For many sites, these data may already exist. If hydraulic gradient data over a 1-year period are not available, natural attenuation can still be implemented pending an analysis of seasonal variation in groundwater flow direction.

2.3.3.3 Processes Causing an Apparent Reduction in Total Contaminant Mass

Several processes cause reductions in contaminant concentrations and apparent reductions in the total mass of contaminant in a system. Processes causing apparent reductions in contaminant mass include dilution, sorption, and hydrodynamic dispersion. In order to determine the mass of contaminant removed from the system it is necessary to correct observed concentrations for the effects of these processes. This is done by incorporating independent assessments of these processes into the comprehensive solute transport model. The following sections give a brief overview of the processes that result in apparent contaminant reduction. Appendix B describes these processes in detail.

Dilution results in a reduction in contaminant concentrations and an apparent reduction in the total mass of contaminant in a system due to the introduction of additional water to the system. The two most common causes of dilution (real or apparent) are infiltration and sampling from monitoring wells screened over large vertical intervals. Infiltration can cause an apparent reduction in contaminant mass by mixing unaffected waters with the contaminant plume, thereby causing dilution. Monitoring wells screened over large vertical distances may dilute groundwater

samples by mixing water from clean aquifer zones with contaminated water during sampling. To avoid potential dilution during sampling, monitoring wells should be screened over relatively small vertical intervals (less than 5 feet). Nested wells should be used to define the vertical extent of contamination in the saturated zone. Appendix C contains example calculations showing of how to correct for the effects of dilution.

The retardation of organic solutes caused by sorption is an important consideration when simulating the effects of natural attenuation over time. Sorption of a contaminant to the aquifer matrix results in an apparent decrease in contaminant mass because dissolved contamination is removed from the aqueous phase. The processes of contaminant sorption and retardation are discussed in Appendix B.

The dispersion of organic solutes in an aquifer is another important consideration when simulating natural attenuation. The dispersion of a contaminant into relatively pristine portions of the aquifer allows the solute plume to mix with uncontaminated groundwater containing higher concentrations of electron acceptors. Dispersion occurs vertically as well as parallel and perpendicular to the direction of groundwater flow.

To accurately determine the mass of contaminant transformed to innocuous byproducts, it is important to correct measured contaminant concentrations for those processes that cause an apparent reduction in contaminant mass. This is accomplished by normalizing the measured concentration of each of the contaminants to the concentration of a tracer that is biologically recalcitrant. Because chloride is produced during the biodegradation of chlorinated solvents, this analyte can be used as a tracer. For chlorinated solvents undergoing reductive dechlorination, it is also possible to use the carbon component of the total chlorinated contaminants as a tracer because carbon is not removed as the parent solvent is systematically dechlorinated. Trimethylbenzene and tetramethylbenzene are two chemicals found in fuel hydrocarbon plumes that also may be useful as tracers. These compounds are difficult to biologically degrade under anaerobic conditions, and frequently persist in groundwater longer than BTEX. Depending on the composition of the fuel that was released, other tracers may be used.

2.3.4 Optional Confirmation of Biological Activity

Extensive evidence can be found in the literature showing that biodegradation of chlorinated solvents and fuel hydrocarbons frequently occurs under natural conditions. Many references from the large body of literature in support of natural attenuation are listed in Section 3 and discussed in Appendix B. The most common technique used to show explicitly that microorganisms capable of degrading contaminants present at a site is the microcosm study.

If additional evidence (beyond contaminant and geochemical data and supporting calculations) supporting natural attenuation is required, a microcosm study using site-specific aquifer materials and contaminants can be undertaken.

If properly designed, implemented, and interpreted, microcosm studies can provide very convincing documentation of the occurrence of biodegradation. Such studies are the only line of evidence that allows an unequivocal mass-balance determination based on the biodegradation of environmental contaminants. The results of a well-designed microcosm study will be easy for decision makers with nontechnical backgrounds to interpret. Results of such studies are strongly influenced by the nature of the geological material submitted for study, the physical properties of the microcosm, the sampling strategy, and the duration of the study. Because microcosm studies are time-consuming and expensive, they should be undertaken only at sites where there is considerable uncertainty concerning the biodegradation of contaminants.

Biodegradation rate constants determined by microcosm studies often are higher than rates achieved in the field. The collection of material for the microcosm study, the procedures used to set up and analyze the microcosm, and the interpretation of the results of the microcosm study are presented in Appendix C.

2.4 REFINE CONCEPTUAL MODEL, COMPLETE PRE-MODELING CALCULATIONS, AND DOCUMENT INDICATORS OF NATURAL ATTENUATION

Site investigation data should first be used to refine the conceptual model and quantify groundwater flow, sorption, dilution, and biodegradation. The results of these calculations are used to scientifically document the occurrence and rates of natural attenuation and to help simulate natural attenuation over time. It is the responsibility of the proponent to "make the case" for natural attenuation. This being the case, all available data must be integrated in such a way that the evidence is sufficient to support the conclusion that natural attenuation is occurring.

2.4.1 Conceptual Model Refinement

Conceptual model refinement involves integrating newly gathered site characterization data to refine the preliminary conceptual model that was developed on the basis of previously collected site-specific data. During conceptual model refinement, all available site-specific data should be integrated to develop an accurate three-dimensional representation of the hydrogeologic and contaminant transport system. This refined conceptual model can then be used for contaminant fate and transport modeling. Conceptual model refinement consists of several steps, including preparation of geologic logs, hydrogeologic sections, potentiometric surface/water table maps,

contaminant and daughter product contour (isopleth) maps, and electron acceptor and metabolic byproduct contour (isopleth) maps.

2.4.1.1 Geologic Logs

Geologic logs of all subsurface materials encountered during the soil boring phase of the field work should be constructed. Descriptions of the aquifer matrix should include relative density, color, major textural constituents, minor constituents, porosity, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, relative permeability, and any other significant observations such as visible contaminants or contaminant odor. It is also important to correlate the results of VOC screening using soil sample headspace vapor analysis with depth intervals of geologic materials. The depth of lithologic contacts and/or significant textural changes should be recorded to the nearest 0.1 foot. This resolution is necessary because preferential flow and contaminant transport paths may be limited to thin stratigraphic units.

2.4.1.2 Cone Penetrometer Logs

Cone penetrometer logs express stratigraphic information as the ratio of sleeve friction to tip pressure. Cone penetrometer logs also may contain fluid resistivity data and estimates of aquifer hydraulic conductivity. To provide meaningful data, the cone penetrometer must be capable of providing stratigraphic resolution on the order of 3 inches. To provide accurate stratigraphic information, cone penetrometer logs must be correlated with continuous subsurface cores. At a minimum, there must be one correlation for every hydrostratigraphic unit found at the site. Cone penetrometer logs, along with geologic boring logs, can be used to complete the hydrogeologic sections discussed in Section 2.4.1.3.

2.4.1.3 Hydrogeologic Sections

Hydrogeologic sections should be prepared from boring logs and/or CPT data. A minimum of two hydrogeologic sections are required; one parallel to the direction of groundwater flow and one perpendicular to the direction of groundwater flow. Hydraulic head data including potentiometric surface and/or water table elevation data should be plotted on the hydrogeologic section. These sections are useful in locating potential preferential contaminant migration paths and in simulating contaminant transport using solute fate and transport models.

2.4.1.4 Potentiometric Surface or Water Table Map(s)

A potentiometric surface or water table map is a two-dimensional graphic representation of equipotential lines shown in plan view. These maps should be prepared from water level measurements and surveyor's data. Because groundwater flows from areas of higher hydraulic head to areas of lower hydraulic head, such maps are used to estimate the probable direction of plume migration and to calculate hydraulic gradients. These maps should be prepared using water levels measured in wells screened in the same relative position within the same hydrogeologic unit. To determine vertical hydraulic gradients, separate potentiometric maps should be developed for different horizons in the aquifer to document vertical variations in groundwater flow. Flow nets should also be constructed to document vertical variations in groundwater flow. To document seasonal variations in groundwater flow, separate potentiometric surface or water table maps should be prepared for quarterly water level measurements taken over a period of at least 1 year. In areas with mobile LNAPL, a correction must be made for the water table deflection caused by the LNAPL. This correction and potentiometric surface map preparation are discussed in Appendix C.

2.4.1.5 Contaminant and Daughter Product Contour Maps

Contaminant and daughter product contour maps should be prepared for all contaminants present at the site for each discrete sampling event. Such maps allow interpretation of data on the distribution and the relative transport and degradation rates of contaminants in the subsurface. In addition, contaminant contour maps are necessary so that contaminant concentrations can be gridded and used for input into a numerical model. Detection of daughter products not present in the released NAPL (e.g., *cis*-1,2-DCE, VC, or ethene) provides evidence of reductive dechlorination.

If mobile and residual NAPLs are present at the site, a contour map showing the thickness and vertical and horizontal distribution of each should be prepared. These maps will allow interpretation of the distribution and the relative transport rate of NAPLs in the subsurface. In addition, these maps will aid in partitioning calculations and solute fate and transport model development. It is important to note that, because of the differences between the magnitude of capillary suction in the aquifer matrix and the different surface tension properties of fuel and water, LNAPL thickness observations made at monitoring points may not provide an accurate estimate of the actual volume of mobile and residual LNAPL in the aquifer. To accurately determine the distribution of NAPLs, it is necessary to take continuous soil cores or, if confident that chlorinated solvents present as NAPL are commingled with fuels, to use cone penetrometer

testing coupled with laser-induced fluorescence. Appendix C discusses the relationship between actual and apparent NAPL thickness.

2.4.1.6 Electron Acceptor, Metabolic Byproduct, and Alkalinity Contour Maps

Contour maps should be prepared for electron acceptors consumed (dissolved oxygen, nitrate, and sulfate) and metabolic byproducts produced [iron (II), chloride, and methane] during biodegradation. In addition, a contour map should be prepared for alkalinity and ORP. The electron acceptor, metabolic byproduct, alkalinity, and ORP contour maps provide evidence of the occurrence of biodegradation at a site.

Contour maps should be prepared for electron acceptors, including dissolved oxygen, nitrate, and sulfate. During aerobic biodegradation, dissolved oxygen concentrations will decrease to levels below background concentrations. Similarly, during anaerobic degradation, the concentrations of nitrate and sulfate will be seen to decrease to levels below background. The electron acceptor contour maps allow interpretation of data on the distribution of the electron acceptors and the relative transport and degradation rates of contaminants in the subsurface. Thus, electron acceptor contour maps provide visual evidence of biodegradation and a visual indication of the relationship between the contaminant plume and the various electron acceptors.

Contour maps should be prepared for the metabolic byproducts iron (II), chloride, and methane. During anaerobic degradation, the concentrations of these parameters will be seen to increase to levels above background. These maps allow interpretation of data on the distribution of metabolic byproducts resulting from the microbial degradation of fuel hydrocarbons and the relative transport and degradation rates of contaminants in the subsurface. Thus, metabolic byproduct contour maps provide visual evidence of biodegradation and a visual indication of the relationship between the contaminant plume and the various metabolic byproducts.

A contour map should be prepared for total alkalinity (as $CaCO_3$). Respiration of dissolved oxygen, nitrate, iron (III), and sulfate tends to increase the total alkalinity of groundwater. Thus, the total alkalinity inside the contaminant plume generally increases to levels above background. This map will allow visual interpretation of alkalinity data by showing the relationship between the contaminant plume and alkalinity.

2.4.2 Pre-Modeling Calculations

Several calculations must be made prior to implementation of the solute fate and transport model. These calculations include sorption and retardation calculations, NAPL/water partitioning calculations, groundwater flow velocity calculations, and biodegradation rate-constant

calculations. Each of these calculations is discussed in the following sections. The specifics of each calculation are presented in the appendices referenced below.

2.4.2.1 Analysis of Contaminant, Daughter Product, Electron Acceptor, Metabolic Byproduct, and Total Alkalinity Data

The extent and distribution (vertical and horizontal) of contamination, daughter product, and electron acceptor and metabolic byproduct concentrations are of paramount importance in documenting the occurrence of biodegradation and in solute fate and transport model implementation.

Comparison of contaminant, electron acceptor, electron donor, and metabolic byproduct distributions can help identify significant trends in site biodegradation. Dissolved oxygen concentrations below background in an area with organic contamination are indicative of aerobic biodegradation of organic carbon. Similarly, nitrate and sulfate concentrations below background in an area with contamination are indicative of anaerobic biodegradation of organic carbon. Likewise, elevated concentrations of the metabolic byproducts iron (II), chloride, and methane in areas with contamination are indicative of biodegradation of organic carbon. In addition, elevated concentrations of total alkalinity (as $CaCO_3$) in areas with contamination are indicative of biodegradation of organic compounds via aerobic respiration, denitrification, iron (III) reduction, and sulfate reduction. If these trends can be documented, it is possible to quantify the relative importance of each biodegradation mechanism, as described in Appendices B and C. The contour maps described in Section 2.4.1 can be used to provide graphical evidence of these relationships.

Detection of daughter products not present in the released NAPL (e.g., *cis*-1,2-DCE, VC, or ethene) provides evidence of reductive dechlorination. The contour maps described in Section 2.4.1 in conjunction with NAPL analyses can be used to show that reductive dechlorination is occurring.

2.4.2.2 Sorption and Retardation Calculations

Contaminant sorption and retardation calculations should be made based on the TOC content of the aquifer matrix and the organic carbon partitioning coefficient (K_{OC}) for each contaminant. The average TOC concentration from the most transmissive zone in the aquifer should be used for retardation calculations. A sensitivity analysis should also be performed during modeling using a range of TOC concentrations, including the lowest TOC concentration measured at the site. Sorption and retardation calculations should be completed for all contaminants and any tracers. Sorption and retardation calculations are described in Appendix C.

2.4.2.3 NAPL/Water Partitioning Calculations

If NAPL remains at the site, partitioning calculations should be made to account for the partitioning from this phase into groundwater. Several models for NAPL/water partitioning have been proposed in recent years, including those by Hunt *et al.* (1988), Bruce *et al.* (1991), Cline *et al.* (1991), and Johnson and Pankow (1992). Because the models presented by Cline *et al.* (1991) and Bruce *et al.* (1991) represent equilibrium partitioning, they are the most conservative models. Equilibrium partitioning is conservative because it predicts the maximum dissolved concentration when NAPL in contact with water is allowed to reach equilibrium. The results of these equilibrium partitioning calculations can be used in a solute fate and transport model to simulate a continuing source of contamination. The theory behind fuel/water partitioning calculations is presented in Appendix B, and example calculations are presented in Appendix C.

2.4.2.4 Groundwater Flow Velocity Calculations

The average linear groundwater flow velocity of the most transmissive aquifer zone containing contamination should be calculated to check the accuracy of the solute fate and transport model and to allow calculation of first-order biodegradation rate constants. An example of a groundwater flow velocity calculation is given in Appendix C.

2.4.2.5 Biodegradation Rate-Constant Calculations

Biodegradation rate constants are necessary to accurately simulate the fate and transport of contaminants dissolved in groundwater. In many cases, biodegradation of contaminants can be approximated using first-order kinetics. In order to calculate first-order biodegradation rate constants, the apparent degradation rate must be normalized for the effects of dilution, sorption, and volatilization. Two methods for determining first-order rate constants are described in Appendix C. One method involves the use of a biologically recalcitrant compound found in the dissolved contaminant plume that can be used as a conservative tracer. The other method, proposed by Buscheck and Alcantar (1995) involves interpretation of a steady-state contaminant plume and is based on the one-dimensional steady-state analytical solution to the advection-dispersion equation presented by Bear (1979).

2.5 SIMULATE NATURAL ATTENUATION USING SOLUTE FATE AND TRANSPORT MODELS

Simulating natural attenuation allows prediction of the migration and attenuation of the contaminant plume through time. Natural attenuation modeling is a tool that allows site-specific

data to be used to predict the fate and transport of solutes under governing physical, chemical, and biological processes. Hence, the results of the modeling effort are not in themselves sufficient proof that natural attenuation is occurring at a given site. The results of the modeling effort are only as good as the original data input into the model; therefore, an investment in thorough site characterization will improve the validity of the modeling results. In some cases, straightforward analytical models of solute transport are adequate to simulate natural attenuation.

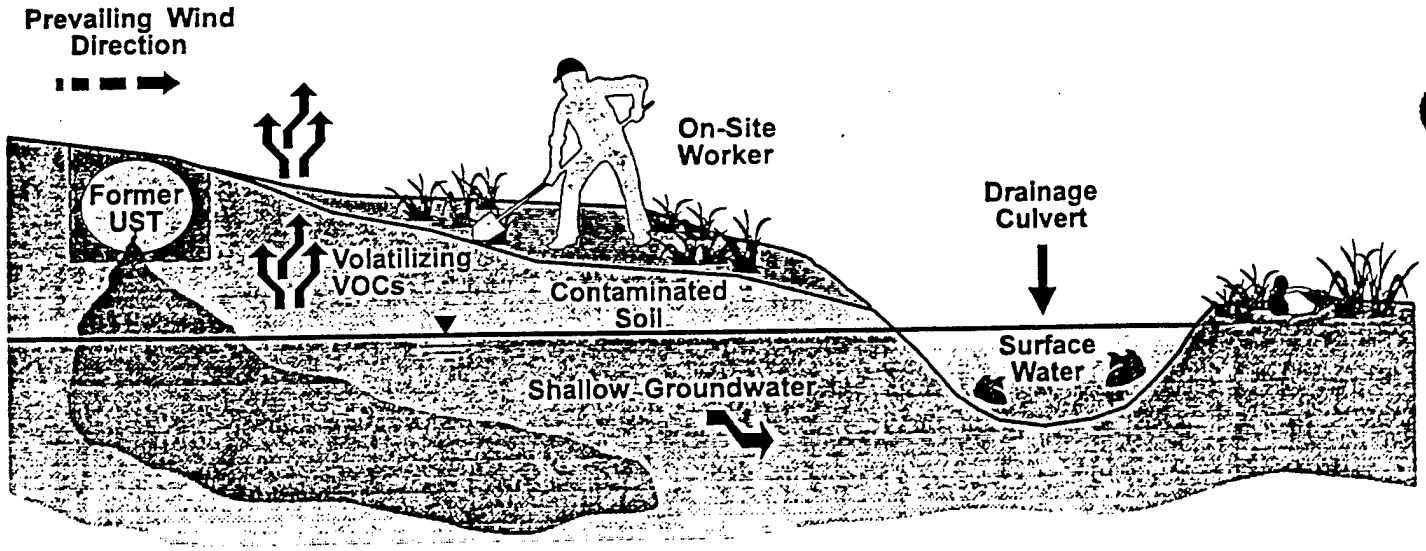
Several well-documented and widely accepted solute fate and transport models are available for simulating the fate and transport of contaminants under the influence of advection, dispersion, sorption, and biodegradation. Solute fate and transport modeling is described in Appendix D.

2.6 CONDUCT A RECEPTOR EXPOSURE PATHWAYS ANALYSIS

After the rates of natural attenuation have been documented, and predictions of the future extent and concentrations of the contaminant plume have been made using the appropriate solute fate and transport model, the proponent of natural attenuation should combine all available data and information to negotiate for implementation of this remedial option. Supporting the natural attenuation option generally will involve performing a receptor exposure pathways analysis. This analysis includes identifying potential human and ecological receptors and points of exposure under current and future land and groundwater use scenarios. Figure 2.5 presents some of the potential migration pathways, exposure routes, and potential receptors for contaminants associated with fuels and chlorinated solvents. The results of solute fate and transport modeling are central to the exposure pathways analysis. If conservative model input parameters are used, the solute fate and transport model should give conservative estimates of contaminant plume migration. From this information, the potential for impacts on human health and the environment from contamination present at the site can be assessed.

2.7 EVALUATE SUPPLEMENTAL SOURCE REMOVAL OPTIONS

Source removal or reduction may be necessary to reduce plume expansion if the exposure pathways analysis suggests that one or more exposure pathways may be completed before natural attenuation can reduce chemical concentrations below federal, state, or risk-based levels of concern. Further, some regulators may require source removal in conjunction with natural attenuation. Several technologies suitable for source reduction or removal are listed on Figure 2.1. Other technologies also may be used as dictated by site conditions and local regulatory requirements. The authors' experience suggests that source removal can be very effective at limiting plume migration and decreasing the remediation time frame, especially at sites



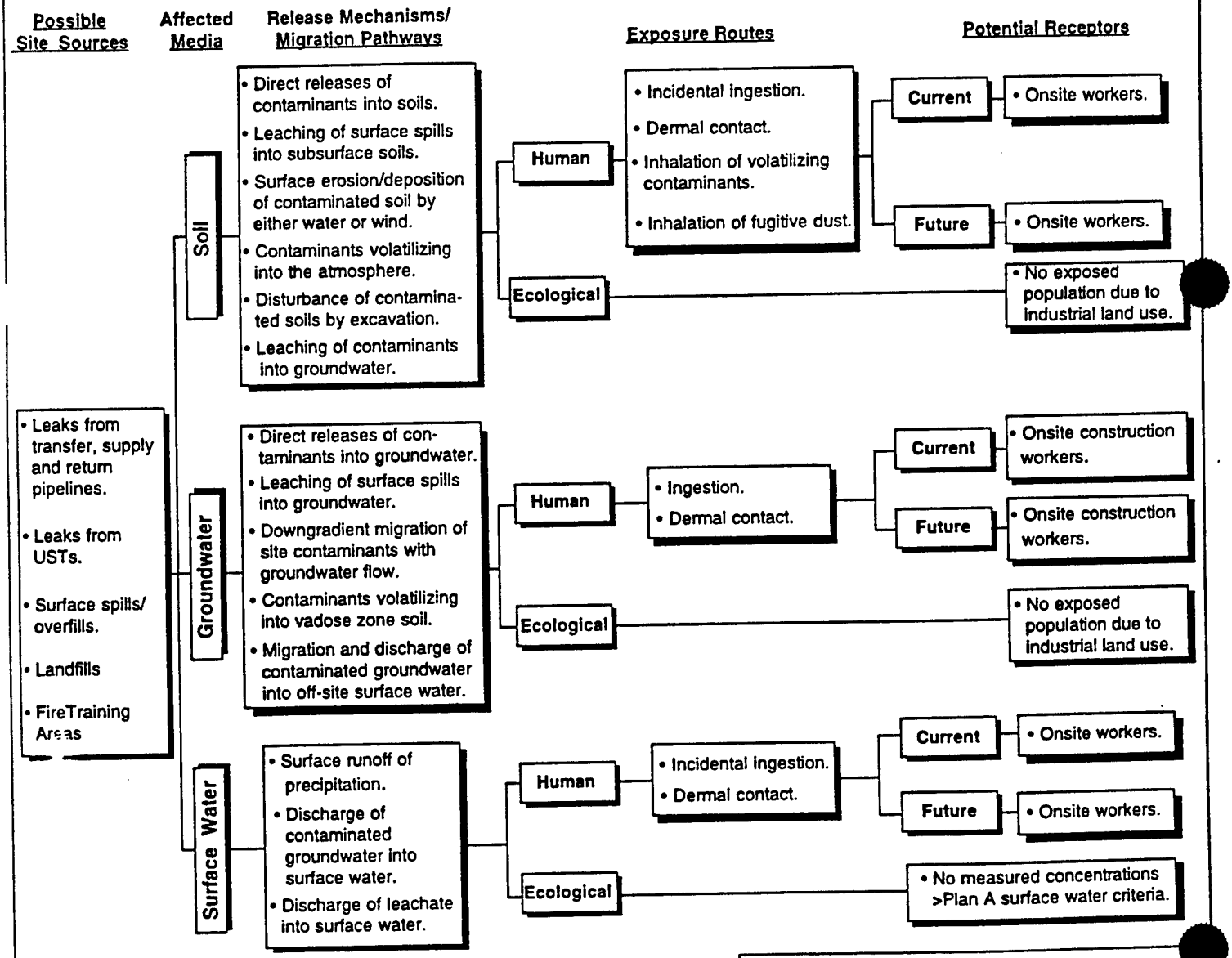


Figure 2.5
Example Migration Pathways and Exposure Routes for Potential Receptors of Fuel Hydrocarbons and Chlorinated Solvents

where biodegradation is contributing to natural attenuation of a dissolved contaminant plume. If a solute fate and transport model has been prepared for a site, the impact of source removal can readily be evaluated by modifying the contaminant source term; this will allow for a reevaluation of the exposure pathways analysis.

2.8 PREPARE LONG-TERM MONITORING PLAN

Groundwater flow rates at many Air Force sites studied to date are such that many years will be required before contaminated groundwater could potentially reach the Air Force installation boundary. Thus, there frequently is sufficient time and space for natural attenuation alone to reduce contaminant concentrations in groundwater to acceptable levels. Experience at 40 Air Force sites contaminated with fuel hydrocarbons evaluated using the protocol presented by Wiedemeier *et al.* (1995d) suggests that many fuel hydrocarbon plumes are relatively stable, or are moving slowly with respect to groundwater flow. This information is complemented by data collected by Lawrence Livermore National Laboratories in a study of over 1,100 leaking underground fuel tank sites performed for the California State Water Resources Control Board (Rice *et al.*, 1995). These examples demonstrate the efficacy of using long-term monitoring to track plume migration and to validate or refine modeling results. There is not a large enough database available at this time to assess the stability of chlorinated solvent plumes, but it is the experience of the authors that chlorinated solvent plumes are likely to migrate further downgradient than fuel hydrocarbon plumes before reaching steady-state equilibrium or before receding.

The long-term monitoring plan consists of locating groundwater monitoring wells and developing a groundwater sampling and analysis strategy. This plan is used to monitor plume migration over time and to verify that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors. The long-term monitoring plan should be developed based on site characterization data, the results of solute fate and transport modeling, and the results of the receptor exposure pathways analysis.

The long-term monitoring plan includes two types of monitoring wells. Long-term monitoring wells are intended to determine if the behavior of the plume is changing. Point-of-compliance (or point-of-action) wells are intended to detect movements of the plume outside the negotiated perimeter of containment, and to trigger an action to manage the risk associated with such expansion. Figure 2.6 depicts 1) an upgradient well in unimpacted groundwater; 2) a well in the NAPL source area; 3) a well downgradient of the NAPL source area in a zone of anaerobic treatment; 4) a well in the zone of aerobic treatment, along the periphery of the plume; 5) a well located downgradient from the plume where contaminant concentrations are below regulatory

acceptance levels and soluble electron acceptors are depleted with respect to unimpacted groundwater; and 6) three point-of-compliance wells.

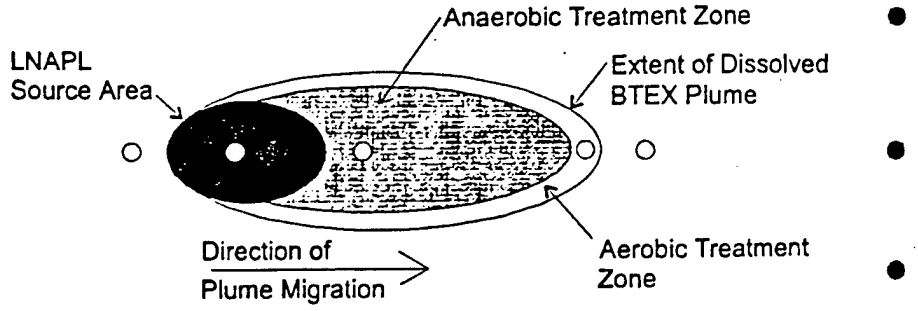


Figure 2.6
Hypothetical Long-Term Monitoring Strategy

Although the final number and placement of long-term monitoring and point-of-compliance/action wells should be determined through regulatory negotiation, the locations of long-term monitoring wells should be based on the behavior of the plume as revealed during the initial site characterization and on regulatory considerations. Point-of-compliance wells are placed 500 feet downgradient from the leading edge of the plume or the distance traveled by the groundwater in 2 years, whichever is greater. If the property line is less than 500 feet downgradient, the point-of-compliance wells often are placed near and upgradient from the property line. The final number and location of point-of-compliance monitoring wells also will depend on regulatory considerations. Local practice may be more stringent than this recommendation.

The results of a solute fate and transport model can be used to help site the long-term monitoring and point-of-compliance wells. In order to provide a valid monitoring system, all monitoring wells must be screened in the same hydrogeologic unit as the contaminant plume. This generally requires detailed stratigraphic correlation. To facilitate accurate stratigraphic correlation, detailed visual descriptions of all subsurface materials encountered during borehole drilling or cone penetrometer testing should be prepared prior to monitoring well installation.

A groundwater sampling and analysis plan should be prepared in conjunction with point-of-compliance and long-term monitoring well placement. For long-term monitoring wells, groundwater analyses should include VOCs, dissolved oxygen, nitrate, iron (II), sulfate, and methane. For point-of-compliance wells, groundwater analyses should be limited to determining VOC and dissolved oxygen concentrations. Any state-specific analytical requirements also should be addressed in the sampling and analysis plan to ensure that all data required for regulatory decision making are collected. Water level and LNAPL thickness measurements must be made during each sampling event. Except at sites with very low hydraulic conductivity and gradients, quarterly sampling of long-term monitoring wells is recommended during the first year to help determine the direction of plume migration and to determine baseline data. Based on the results of the first year's sampling, the sampling frequency may be reduced to annual sampling in the quarter showing the greatest extent of the plume. Sampling frequency is dependent on the final placement of the point-of-compliance monitoring wells and groundwater flow velocity. The final sampling frequency should be determined in collaboration with regulators.

2.9 CONDUCT REGULATORY NEGOTIATIONS

The purpose of regulatory negotiations is to provide scientific documentation that supports natural attenuation as the most appropriate remedial option for a given site. All available site-specific data and information developed during the site characterization, conceptual model development, pre-modeling calculations, biodegradation rate calculation, groundwater modeling, model documentation, and LTM plan preparation phases of the natural attenuation investigation should be presented in a consistent and complementary manner at the regulatory negotiations. Of particular interest to the regulators will be proof that natural attenuation is occurring at rates sufficient meet regulatory compliance levels at the POC and to protect human health and the environment. The regulators must be presented with a "weight-of-evidence" argument in support of this remedial option. For this reason, all model assumptions should be conservative, and all available evidence in support of natural attenuation must be presented at the regulatory negotiations.

A comprehensive LTM and contingency plan also should be presented to demonstrate a commitment to proving the effectiveness of natural attenuation as a remedial option. Because LTM and contingency plans are very site-specific, they should be addressed in the individual reports generated using this protocol. See Sections 6 and 7 of the two case studies presented in Appendices E and F for examples of such plans.

SECTION 3

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APPENDIX E

PROGRAM HASP AND MSDS'S

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PROGRAM HEALTH AND SAFETY PLAN
FOR THE DEMONSTRATION OF
REMEDIATION BY THE RISK-BASED APPROACH

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Prepared by:

PARSONS ENGINEERING SCIENCE, INC.
1700 Broadway, Suite 900
Denver, Colorado 80290

Reviewed and Approved By:

	Name	Date
Project Manager	Dan Denny	2/7/97
Office H & S Representative	Timothy S. Mustard	2/7/97

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SECTION 1

PURPOSE AND POLICY

The purpose of this program health and safety plan is to establish personnel protection standards and mandatory safety practices for all Parsons Engineering Science, Inc. (Parsons ES) and subcontractor personnel involved in the risk-based remediation demonstrations at numerous United States Air Force (USAF) installations. This plan provides guidance for general operations on risk-based demonstration sites and provides for contingencies that may arise during field operations. Site-specific information is not included in this plan and will be addressed in the formal health and safety plan addenda. All Parsons ES field team members and subcontractors are responsible for reading and conforming to this plan and the associated addenda. No employee will perform a project activity that he or she believes may endanger his or her health and safety or the health and safety of others. All personnel will strive for a record of zero accidents on this project. To the greatest extent possible, work tasks will be designed and conducted to minimize or eliminate hazards to personnel.

A project description and scope of work summary for the project are provided in Section 2. Section 3 presents the project team organization, personnel responsibilities, and lines of authority. Training and medical monitoring requirements are contained in Section 4. Section 5 presents a safety and health risk analysis. Section 6 contains the program emergency response plan. Program requirements for levels of protection are included in Section 7, and air monitoring procedures are provided in Section 8. Site control measures, including designation of site work zones, are contained in Section 9, and Section 10 provides decontamination procedures. Section 11 contains information on the use and calibration of air monitoring equipment. Appendix A contains an example of an Emergency Contacts Form to be used in each formal health and safety plan addendum prepared for all USAF risk-based demonstration sites. Appendix B contains a Plan Acceptance Form, Site-Specific Training Record Form, Field Experience Documentation Form, Air Monitoring Data Forms, Accident Report Form, Near-Miss Incident Form, Shipping Paper, Daily Vehicle Inspection Report, and Respirator Use Forms.

SECTION 2

PROJECT DESCRIPTION AND SCOPE OF WORK

2.1 PROJECT DESCRIPTION

Under this contract, Parsons ES will provide services to the Air Force Center for Environmental Excellence (AFCEE) that will demonstrate the use of the risk-based approach to reduce contaminant concentrations of fuel hydrocarbons and chlorinated solvents in the groundwater at various USAF installations nationwide.

The purpose of the demonstrations is to develop a closure plan with a new approach to site remediation which focuses on risk reduction rather than arbitrary numerical cleanup standards, and emphasizes natural biodegradation and other natural attenuation mechanisms to reduce risk.

2.2 SCOPE OF WORK

Site characterization activities in support of the risk-based demonstrations may include excavating; auger drilling; use of the Geoprobe®, cone penetrometer (CPT), and Hydropunch® direct-push technologies, monitoring well and monitoring point installation; soil, soil gas, surface water, and groundwater sampling; and aquifer testing.

SECTION 3

PROGRAM TEAM ORGANIZATION

The Parsons ES team assigned to the risk-based demonstrations, their responsibilities, and lines of authority are outlined below.

Name	Task Assigned
Ms. Leigh Benson	Technical Director
Mr. Doug Downey	Project Manager
Mr. Timothy Mustard	Program Health and Safety Manager
To be assigned	Site Managers
To be assigned	Site Health and Safety Officer
To be assigned	Alternate Health and Safety Officer
Mr. Patrick Haas	AFCEE/ERT Point of Contact

The technical director, Ms. Leigh Benson, is responsible for conduct and review of all technical work on this project to ensure technical accuracy and adequacy. She will provide advice to the project manager and project personnel on technical issues.

The project manager, Mr. Doug Downey, is directly responsible for the execution of all phases of this project. He is responsible for planning, staffing, assuring adequate planning for health and safety and quality assurance/quality control (QA/QC), execution of each phase, coordination with AFCEE, and interpretation of data and reporting. The project manager will also coordinate with the site manager to obtain permission for site access, coordination of activities with appropriate officials, and serve as the liaison with public officials. The project manager will also ensure that quality work is accomplished on schedule.

The program health and safety manager, Mr. Timothy Mustard, will ensure that all field activities are performed with strict adherence to OSHA requirements and the program health and safety plan. He will be responsible for updating and revising the program health and safety plan, as needed, and for ensuring that all field team members meet health and safety training and medical monitoring requirements.

The site health and safety officer (SHSO) along with the project manager is responsible for ensuring that day-to-day project activities are performed in strict conformance with the program health and safety plan. The SHSO, project manager, and program health and safety manager have the authority to stop work if actions or conditions are judged to be unsafe or not in conformance with the program health and safety plan. The SHSO will also be responsible for ensuring that field personnel are in

compliance with Occupational Safety and Health Administration (OSHA) requirements for training and medical monitoring prior to and for the duration of the field activities.

The site manager will support the project manager for the specific work the team will accomplish at each site and will be responsible for scheduling and coordinating the testing activities at the respective sites. The site manager will assist the project manager in the day-to-day organization and execution of the various project tasks.

SECTION 4

SITE-SPECIFIC EMPLOYEE TRAINING AND MEDICAL MONITORING REQUIREMENTS

The Parsons ES corporate health and safety manual, incorporated by reference, presents general requirements for Parsons ES employee training and medical monitoring. All field team members will have completed the 40-hour basic health and safety training as specified by OSHA in Title 29, Code of Federal Regulations, Part 1910.120, paragraph (e) (29 CFR 1910.120[e]) and the 8-hour annual refresher training thereafter. All supervisory personnel onsite will be required to have completed an 8-hour supervisor course as required in 29 CFR 1910.120(e).

In addition to the 40-hour course, all field employees will be required to have completed a minimum of 3 days onsite training under the supervision of a trained and experienced supervisor, not necessarily at one of the risk-based demonstration sites. If this training is received during a risk-based demonstration, the training will be documented on the Field Experience Documentation Form provided in Appendix B. Employees will not participate in field activities until they have been trained to the level required by their job function and responsibility. In addition, at least one person on every Parsons ES field crew will have completed Red Cross or equivalent first-aid and cardiopulmonary resuscitation (CPR) courses. All training documentation for Parsons ES personnel will be verified by the SHSO and maintained by the health and safety manager.

All Parsons ES field team members will be on current medical monitoring programs in accordance with federal OSHA requirements (29 CFR 1910.120) and Parsons ES corporate policies. Listed below are additional health and safety training and medical monitoring requirements for this project.

4.1 ADDITIONAL SAFETY TRAINING REQUIREMENTS

If Level B (self-contained breathing apparatus [SCBA]) respiratory protection is used, additional training may be required for those personnel involved. This training will be conducted onsite as necessary by a qualified, Level B-experienced supervisor. Employees will also be trained in use, care, maintenance, limitations, and disposal of personal protective equipment (PPE) in accordance with 29 CFR 1910.132. All field team members must have site-specific training as discussed in the following subsection.

4.1.1 Site-Specific Safety Briefings

Site-specific safety and health briefings will be conducted by the Parsons ES site manager or SHSO for all personnel who will engage in any risk-based demonstration activities. Site-specific safety briefings will address the activities, procedures, monitoring, and equipment applicable to the site operations, as well as site or facility layout, potential hazards, and emergency response services at the site. Additional topics that will be addressed at the safety briefings will include:

- Names of responsible health and safety personnel;
- Identification of site hazards;
- Site contingencies and emergency procedures;
- Exposure risk;
- Symptoms of exposure and exposure treatment for chemical contaminants;
- Use, care, maintenance, and limitations of PPE;
- Decontamination procedures to be followed;
- Location of safety equipment;
- Review of planned activities;
- Defined safety procedures to be followed during field activities; and
- Emergency and evacuation procedures.

Safety briefings will be conducted daily prior to commencement of field activities. Documentation of training and briefings, including agenda and signatures of attending personnel, will be maintained onsite. Site-specific training forms are provided in Appendix B.

4.2 MEDICAL MONITORING REQUIREMENTS

Prior to being assigned to the field activities, each Parsons ES employee will receive a preassignment or baseline physical examination. Preassignment screening has two major functions: 1) determination of an individual's fitness for duty, including the ability to perform work while wearing PPE; and 2) provision of baseline data for comparison with future medical data. Medical qualification/certification documentation will be maintained by the program health and safety manager. All medical examinations and procedures will be performed by or under the supervision of a licensed physician, preferably an occupational physician. The examination content will be determined by the examining physician in accordance with 29 CFR 1910.120(f).

SECTION 5

SAFETY AND HEALTH RISK ANALYSIS

5.1 CHEMICAL HAZARDS

The chemicals of primary concern occurring at the USAF sites include diesel fuel; gasoline; jet propulsion fuel grade four (JP-4); the associated petroleum hydrocarbon constituents benzene, toluene, ethylbenzene, and xylenes (BTEX); and various chlorinated solvents.

Table 5.1 summarizes the health hazards and properties of the aforementioned compounds. If other compounds are discovered at these sites, the pertinent information about these compounds will be provided in Table 5.1 of the site-specific addenda. The health hazards or other physical/chemical hazards (e.g., corrosiveness, flammability) of the compounds will then be communicated to the onsite employees.

Hazardous substances of primary concern identified are those potentially occurring in contaminated groundwater, soils, sediment, surface water, air, buildings, or abandoned structures.

5.2 PHYSICAL HAZARDS

In addition to the hazardous substances potentially present at the USAF sites, other physical hazards or hazardous conditions may be expected at the sites during the course of performing risk-based demonstration activities. These hazards include possible risks from injury while working around motor vehicles including the auger drilling rig, Geoprobe® unit, and the CPT rig; stationary or moving equipment; fire or explosion hazards; slip, trip, and fall hazards; electrical hazards; and excessive noise conditions. Additional physical hazards include heat stress and cold-related exposures.

The guidelines presented in this section are applicable to all types of equipment that may be used during risk-based demonstration activities at the USAF installations. Individual equipment types or certain specialized equipment may require additional safety considerations or specialized training prior to its use. Should any specialized equipment be required during the performance of a task, the program health and safety manager will ensure that operators receive appropriate training. The program health and safety manager is also responsible for ensuring that all equipment is routinely inspected and that any piece of equipment considered unsafe is not used until the unsafe conditions are corrected or repaired.

Revised
02/14/96

TABLE 5.1 HEALTH HAZARD QUALITIES OF HAZARDOUS SUBSTANCES OF CONCERN

Compound	PEL [a] (ppm)	TLV [b] (ppm)	IDLH [c] (ppm)	Odor Threshold [d] (ppm)	Ionization Potential [e] (eV)	Physical Description/Health Effects/Symptoms
Benzene	1 (29 CFR 1910.1028) [f]	10	500	4.7	9.24	Colorless to light-yellow liquid (solid < 42°F) with an aromatic odor. Eye, nose, skin, and respiratory system irritant. Causes giddiness, headaches, nausea, staggered gait, fatigue, anorexia, exhaustion, dermatitis, bone marrow depression, and leukemia. Mutagen, experimental teratogen, and carcinogen.
1,1-Dichloroethene (DCE) (Vinylidene Chloride)	1	5	NA [g]	NA	10.00	Colorless liquid or gas (> 89°F) with a mild, sweet, chloroform-like odor. Irritates eyes, skin, and throat. Causes dizziness, headaches, nausea, shortness of breath, liver and kidney dysfunctions, and lung inflammation. Mutagen and carcinogen.
1,2-Dichloroethene (DCE) (cis- and trans-isomers)	200	200	1,000	0.085-500	9.65	Colorless liquid (usually a mixture of cis- and trans- isomers), with a slightly acrid, chloroform-like odor. Irritates eyes and respiratory system. CNS depressant. Cis- isomer is a mutagen.
Diesel Fuel	400 [h]	400 [h]	1,100 [h]	0.08	NA	Colorless to brown, slightly viscous liquid with a gasoline- or kerosene-like odor. Irritates eyes, nose, and throat. Causes dizziness, drowsiness, headaches, nausea, dry cracked skin, and chemical pneumonia.
Ethylbenzene	100	100	800	0.25-200	8.76	Colorless liquid with an aromatic odor. Irritates eyes, skin, and mucous membranes. Causes dermatitis, headaches, narcosis, and coma. Mutagen and experimental teratogen.
Gasoline	300	300	NA	0.005-10	NA	Clear/amber flammable, volatile liquid with a characteristic odor. Irritates eyes, skin, and mucous membranes. Causes dermatitis, headaches, fatigue, blurred vision, dizziness, slurred speech, confusion, convulsions, chemical pneumonia, and possible liver and kidney damage. In animals, causes liver and kidney cancer. Monitor for BTEX constituents. Carcinogen.
Jet Fuel	400 [h]	400 [h]	1,000 [h]	0.08-1	NA	Colorless to light-brown liquid with a fuel-like odor. Long-term effects include liver, kidney, and CNS damage. JP-4 is a questionable carcinogen.
2-Methylnaphthalene	NA	NA	NA	0.003-0.04	7.96	Colorless gas or solid with a disagreeable garlic or rotten cabbage odor. Irritates eyes, skin, nose, and throat.

TABLE 5.1 HEALTH HAZARD QUALITIES OF HAZARDOUS SUBSTANCES OF CONCERN

Compound	PEL [a] (ppm)	TLV [b] (ppm)	IDLH [c] (ppm)	Odor Threshold [d] (ppm)	Ionization Potential [e] (eV)	Physical Description/Health Effects/Symptoms
Naphthalene	10	10	250	0.3	8.1	Colorless to brown solid (shipped as a molten liquid) with a mothball-like odor. Irritates eyes, skin, and bladder. Causes headaches, confusion, excitement, convulsions, coma, vague discomfort, nausea, vomiting, abdominal pain, profuse sweating, jaundice, hematoma, hemoglobin in the urine, renal shutdown, dermatitis, optic nerve disorders, and corneal and liver damage. Experimental teratogen and questionable carcinogen.
Perchlorethylene (Tetrachloroethene or PCE)	25 [i]	25	150	5-50	9.32	Colorless liquid with a mild chloroform odor. Eye, nose, skin and throat irritant. Causes nausea, flushed face and neck, vertigo, dizziness, headaches, hallucinations, incoordination, drowsiness, coma, pulmonary changes, and skin redness. Cumulative liver, kidney, and CNS damage. In animals, causes liver tumors. Mutagen, experimental teratogen, and carcinogen.
Toluene	100	50 (skin) [j]	500	0.2-40 [k]	8.82	Colorless liquid with sweet, pungent, benzene-like odor. Irritates eyes and nose. Causes fatigue, weakness, dizziness, headaches, hallucinations or distorted perceptions, confusion, euphoria, dilated pupils, nervousness, tearing, muscle fatigue, insomnia, skin tingling, dermatitis, bone marrow changes, and liver and kidney damage. Mutagen and experimental teratogen.
1,1,1-Trichloroethane (TCA) (Methyl Chloroform)	350	350	700	20-500	11.00	Colorless liquid with a mild chloroform-like odor. Irritates eyes and skin. Causes headaches, exhaustion, CNS depression, poor equilibrium, dermatitis, liver damage, cardiac arrhythmia, hallucinations or distorted perceptions, motor activity changes, aggression, diarrhea, and nausea or vomiting. Mutagen, experimental teratogen, and questionable carcinogen.
Trichloroethene (TCE)	50	50	1,000	21.4-400	9.45	Clear, colorless or blue liquid with chloroform-like odor. Irritates skin and eyes. Causes fatigue, giddiness, headaches, vertigo, visual disturbances, tremors, nausea, vomiting, drowsiness, dermatitis, skin tingling, cardiac arrhythmia, and liver injury. In animals, causes liver and kidney cancer. Mutagen, experimental teratogen, and carcinogen.

TABLE 5.1 HEALTH HAZARD QUALITIES OF HAZARDOUS SUBSTANCES OF CONCERN

Compound	PEL [a/] (ppm)	TLV [b/] (ppm)	IDLH [c/] (ppm)	Odor Threshold [d/] (ppm)	Ionization Potential [e/] (eV)	Physical Description/Health Effects/Symptoms
1,2,3-Trimethylbenzene (Hemellitol)	25	25	NA	0.027 [l/]	8.48	Clear, colorless liquid with a distinctive aromatic odor. Irritates eyes, skin, nose, throat, and respiratory system. Causes bronchitis, hypochromic anemia, headaches, drowsiness, fatigue, dizziness, nausea, incoordination, vomiting, confusion, and chemical pneumonia.
1,2,4-Trimethylbenzene (Pseudocumene)	25	25	NA	0.027	8.27	Colorless liquid with a distinctive, aromatic odor. Irritates eyes, skin, nose, throat, and respiratory system. Causes bronchitis, hypochromic anemia, headaches, drowsiness, fatigue, dizziness, nausea, incoordination, vomiting, confusion, CNS depression, and chemical pneumonia.
1,3,5-Trimethylbenzene (Mesitylene)	25 [l/]	25 [l/]	NA	0.027 [l/]	8.39	Colorless liquid with a distinctive, aromatic odor. Irritates eyes, skin, nose, throat, and respiratory system. Causes bronchitis, hypochromic anemia, headaches, drowsiness, fatigue, dizziness, nausea, incoordination, vomiting, confusion, and chemical pneumonia. Mutagen.
Vinyl Chloride	1 (29 CFR 1910.1017) [f/]	5	NA	260	9.99	Colorless gas (liquid <7°F) with a pleasant odor at high concentrations. Severe irritant to skin, eyes, and mucous membranes. Causes weakness, abdominal pain, gastrointestinal bleeding, enlarged liver, pallor or blue skin on the extremities, liver cancer, and frostbite (liquid). Also attacks lymphatic system. Mutagen, experimental teratogen, and carcinogen.
Xylene (o-, m-, and p-isomers)	100	100	900	0.05-200 [k/]	8.56 8.44 (p)	Colorless liquid with aromatic odor. P-isomer is a solid <56°F. Irritates eyes, skin, nose, and throat. Causes dizziness, drowsiness, staggered gait, incoordination, irritability, excitement, corneal irregularities, conjunctivitis, dermatitis, anorexia, nausea, vomiting, abdominal pain, and olfactory and pulmonary changes. Also targets blood, liver, and kidneys. Mutagen and experimental teratogen.

a/ PEL = Permissible Exposure Limit. OSHA-enforced average air concentration to which a worker may be exposed for an 8-hour workday without harm. Expressed as parts per million (ppm) unless noted otherwise. PELs are published in the *NIOSH Pocket Guide to Chemical Hazards*, 1994. Some states (such as California) may have more restrictive PELs. Check state regulations.

b/ TLV = Threshold Limit Value - Time-Weighted Average. Average air concentration (same definition as PEL, above) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH), *1994-1995 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.*

c/ IDLH = Immediately Dangerous to Life or Health. Air concentration at which an unprotected worker can escape without debilitating injury or health effects. Expressed as ppm unless noted otherwise. IDLH values are published in the *NIOSH Pocket Guide to Chemical Hazards*, 1994.

TABLE 5.1 HEALTH HAZARD QUALITIES OF HAZARDOUS SUBSTANCES OF CONCERN

Compound	PEL [a/] (ppm)	TLV [b/] (ppm)	IDLH [c/] (ppm)	Odor Threshold [d/] (ppm)	Ionization Potential [e/] (eV)	Physical Description/Health Effects/Symptoms

d/ When a range is given, use the highest concentration.
e/ Ionization Potential, measured in electron volts (eV), used to determine if field air monitoring equipment can detect substance. Values are published in the *NIOSH Pocket Guide to Chemical Hazards*, June 1994.
f/ Refer to expanded rules for this compound.
g/ Based on exposure limits for petroleum distillates (petroleum naphtha).
h/ NA = Not available.
i/ NIOSH recommends reducing exposure to the lowest feasible concentration, and limiting the number of workers exposed.
j/ (skin) = Refers to the potential contribution to the overall exposure by the cutaneous route.
k/ Olfactory fatigue has been reported for the compound and odor may not serve as an adequate warning property.
l/ Based on 1,2,4-Trimethylbenzene.

5.2.1 General Vehicle Operations

The following safety procedures will be followed when operating a motor vehicle within a USAF installation:

- Seat belts will be worn at all times.
- Obey all traffic and speed limit signs.
- Park in designated areas.
- Be aware of construction equipment and other vehicles operating in the area.
- Be aware of pedestrian traffic.
- Acquire eye contact and permission from the vehicle/equipment operator to enter an area around operating vehicles.
- Never crouch down in front of or behind a vehicle.
- Drivers must visually check around the vehicle before moving it.
- Vehicles will never be loaded beyond the designed passenger capacity or beyond the rated load capacity.
- Vehicles will never be loaded in a manner that obscure the driver's front or side views.

The daily vehicle maintenance report located in Appendix B must be completed by the vehicle drivers for all field vehicles (including rented vehicles) upon initial receipt of the vehicle and every morning thereafter, prior to use, that the vehicle is used on a Parsons ES project.

5.2.2 Large Motor Vehicles including Drilling Rigs

Working with large motor vehicles could be a major hazard at these sites. Injuries can result from equipment dislodging and striking unsuspecting personnel, and impacts from flying objects or overturning of vehicles. Vehicles and heavy equipment design and operation will be in accordance with 29 CFR, Subpart O, 1926.600 through 1926.602. In particular, the following precautions will be used to help prevent injuries and accidents:

- Do not back up large motor vehicles unless the vehicle has backup warning lights and a reverse signal alarm audible above the surrounding noise level, or an observer signals it is safe to do so.
- Motor vehicle cabs will be kept free of all nonessential items and all loose items will be secured.

- Drilling rig masts will be lowered to the ground and parking brakes will be set before shutting off the vehicle.

- Drilling rig brakes, cables, kill switches, hydraulic lines, light signals, fire extinguishers, fluid levels, steering, tires, horn, and other safety devices will be inspected daily.

- All personnel working at and around the drilling rig must be informed of the locations of the kill switches.

- Only qualified operators will be allowed to operate the drilling rig or other heavy equipment.

- When working near a backhoe, field personnel will maintain sight contact with the operator.

- The limits of the swing radius of the backhoe must be marked on the ground with cones or boundary tape. Personnel will not enter this bounded area until the backhoe has been shut down, and the operator signals that it is acceptable to enter. Backhoe operations will resume only after personnel have left the area within the swing radius.

5.2.3 Hazards Associated with the Geoprobe® Unit

The Geoprobe® unit consists of a hydraulically-driven press mounted on the bed of a pick-up truck, with power supplied to the cylinder via a power-take-off on the truck. A list of safety instructions provided by the Geoprobe® manufacturer is provided below, and will be followed by all Parsons ES and subcontractor personnel.

- Never operate the controls without proper training.

- Always take the vehicle out of gear and set the emergency brake before engaging the remote ignition.

- If the vehicle is parked on a loose or soft surface, do not fully raise the rear of the vehicle with the probe foot, as the vehicle may fall or move, causing injury.

- Always extend the probe unit out from the vehicle, and deploy the foot to clear the vehicle roof line before folding the probe unit out.

- Operators must wear OSHA-approved steel-toed shoes, and keep feet clear of the probe foot.

- Only one person should operate the probe machine and assemble/disassemble the probe rods and accessories.

- Never place hands on top of a rod while it is under the machine.

- Turn off the hydraulic system while changing rods, inserting the hammer anvil or attaching accessories.

- While operating the controls, the operator must stand to the control side of the probe machine, clear of the probe foot and mast.
- Wear safety glasses at all times during the operation of this machine.
- Never exert down pressure on the probe rod so as to lift the machine base over six inches off the ground.

5.2.4 Hazards Associated with the Cone Penetrometer Equipment

The CPT equipment is typically housed in a stainless-steel body mounted on a triple-axle truck chassis. Caution will be exercised by personnel assisting in the positioning of the truck at each sampling location. The truck is not always equipped with an audible back-up signal. Movement of the truck and push rod coupling and uncoupling will be performed only by the equipment operators. Caution will also be exercised while climbing in and out of the CPT truck. The safety railing at the back of the CPT truck will be in the upright position when personnel are in the truck.

5.2.5 Subsurface Hazards

Before intrusive field activities are performed, efforts must be made to determine if underground installations (i.e., sewers, and telephone, water, fuel, and electrical lines) will be encountered and if so, where such underground installations are located. The site manager will ensure that all underground installations have been identified prior to any intrusive operations.

5.2.6 Electrical Hazards

Some of the equipment used during the risk-based demonstrations is powered by electricity. Maintenance and daily activities require personnel to use, handle, and control this equipment. Safe work practices must be strictly observed to avoid serious injury and death.

According to 29 CFR 1910.269(l), only qualified employees may work on or with exposed energized lines or parts of equipment, or in areas containing unguarded, uninsulated, energized lines or parts of equipment operating at 50 volts (V) or more. Qualified employees must be trained in accordance with 29 CFR 1910.269(a) and certified as such by the employer.

Ordinary 120 V electricity may be fatal. Extensive studies have shown that currents as low as 10 to 15 milliamps (mA) can cause loss of muscle control and that 12 V may, on good contact, cause injury. Therefore, all voltages should be considered dangerous.

Electricity can paralyze the nervous system and stop muscular action. Frequently, electricity may affect the breathing center at the base of the brain and interrupt the transmission of the nerve impulses to the muscles responsible for breathing. In other cases, the electrical current directly affects the heart, causing it to cease pumping blood. Death follows due to a lack of oxygen in the body. Therefore, a victim must be freed from the live conductor promptly by use of a nonconducting implement, such

as a piece of wood, or by turning off the electricity to at least this point of contact. Bare hands should never be used to remove a live wire from a victim or a victim from an electrical source. Artificial respiration or CPR should be applied immediately and continuously until breathing is restored, or until a physician or emergency medical technician arrives.

General rules for recognizing electrical safety are provided below.

- Only authorized and qualified personnel will perform electrical installations or repairs.
- All electrical wires and circuits will be assumed to be "live," unless it can be positively determined they are not.
- Appropriate protective clothing will be worn by personnel performing electrical work.
- All electrical equipment will be properly grounded and class-approved for the location.
- Ground fault circuit interrupter receptacles and circuit breakers will be installed where required by the National Electric Code and 29 CFR 1926.404.
- Electrical control panels will not be opened unless necessary.
- No safety device will be made inoperative by removing guards, using oversized fuses, or by blocking or bypassing protective devices, unless it is absolutely essential to the repair or maintenance activity, and then only after alerting operating personnel and the maintenance supervisor.
- All power tools will have insulated handles, be electrically grounded, or be double insulated.
- Fuse pullers will be used to change fuses.
- Metal ladders, metal tape measures, and other metal tools will not be used around electrical equipment or overhead electrical lines.
- Wires and extension cords will be placed or arranged so as to not pose a tripping hazard.

5.2.7 Slip, Trip, and Fall Hazards

Existing site conditions may pose a number of slip, trip, and fall hazards, such as:

- Open excavations, pits, or trenches;
- Slippery surfaces;
- Steep or uneven grades;

- Surface obstructions; and
- Construction materials or debris.

The extension cords connecting pumps to power supplies also provide a trip and fall hazard. Caution must be exercised and unnecessary personnel should avoid the area of the cord.

All field team members will be instructed to be cognizant of potential safety hazards and immediately inform the SHSO or the site manager about any new hazards. If the hazard cannot be immediately removed, actions must be taken to warn site workers about the hazard. The site will be kept in a neat, organized, and orderly fashion. Rubbish, trash, or debris generated by the project team shall be picked up and properly disposed of on a daily basis. Items such as tools, equipment, and hoses will be properly stored when not in use.

5.2.8 Noise-Induced Hearing Loss

Work onsite may involve the use of equipment such as drilling rigs, pumps, and generators. The exposure of unprotected site workers to this noise or to aircraft noise during site activities can result in noise-induced hearing loss. Heavy equipment can emit noise levels exceeding the federal OSHA time-weighted average (TWA) limit of 85 decibels (dB). Noise levels in the area of the drilling rig and Geoprobe® unit will be presumed in exceedance of the OSHA TWA, and hearing protection will be required. Foam ear plugs will generally provide adequate protection. The SHSO will ensure that either ear muffs or disposable foam earplugs are made available to, and are used by, all personnel in the vicinity of the operation of equipment, aircraft noise or other sources of high intensity noise.

5.2.9 Fire or Explosion Hazards

Fuels and solvents have been released into the soils at many of the USAF installations and vapors from these fuels may be flammable or explosive. In addition, drilling or other intrinsic activities may be performed in former or existing landfill areas. Therefore, precautions will be taken when performing risk-based demonstration activities to ensure that combustible or explosive vapors have not accumulated, or that an ignition source is not introduced into a flammable atmosphere.

OSHA standards for fire protection and prevention are included in 29 CFR Subpart F, 1926.150 through 1926.154. Of particular concern on these sites are:

- Proper storage of flammables;
- Adequate numbers and types of fire extinguishers;
- Use of intrinsically safe (explosion-proof) equipment where appropriate; and
- Monitoring for development of an explosive atmosphere.

The SHSO will ensure that the above concerns are adequately mitigated.

5.2.10 Electric Power Line Clearance and Thunderstorms

Extra precautions will be exercised when drilling near overhead electrical lines. As stated in 29 CFR 1926.550, the minimum clearance between overhead electrical lines of 50 kilovolts (kV) or less and the drill rig is 10 feet. For lines rated over 50 kV, the minimum clearance between the lines and any part of the rig is 10 feet plus 0.4 inches for each kV over 50 kV. Drilling operations must cease during thunderstorms.

The SHSO will provide onsite surveillance of the drilling subcontractor to ensure that personnel meet these requirements. If deficiencies are noted, work will be stopped and corrective actions implemented. Reports of health and safety deficiencies and the corrective actions taken will be forwarded to the installation manager by the SHSO.

5.2.11 Effects and Prevention of Heat Stress

Adverse weather conditions are important considerations in planning and conducting site operations. Hot or cold weather can cause physical discomfort, loss of efficiency, and personal injury. These condition are discussed further below.

If the body's physiological processes fail to maintain a normal body temperature because of excessive heat, a number of physical reactions can occur. They can range from mild symptoms such as fatigue; irritability; anxiety; and decreased concentration, dexterity, or movement; to death. Medical help must be obtained for the more serious cases of heat stress. One or more of the following actions will help reduce heat stress:

- Provide plenty of liquids. To replace body fluids (water and electrolytes) lost due to perspiration, each employee must drink 1 to 1.5 gallons of water or commercial electrolyte mix per day. Workers are encouraged to frequently drink small amounts, i.e. one cup every 15-20 minutes.

- Field personnel are cautioned to minimize alcohol intake during off-duty hours.

- Provide cooling devices (e.g., water jackets or ice vests) to aid natural body ventilation. These devices, however, add weight, and their use should be balanced against worker mobility.

- Wear long cotton underwear, which acts as a wick to help absorb moisture and protect the skin from direct contact with heat-absorbing protective clothing.

- Install portable emergency showers and/or hose-down facilities to reduce body temperature and to cool protective clothing.

- In extremely hot weather, conduct non-emergency response operations in the early morning or evening.

- Ensure that adequate shelter is available to protect personnel against sun, heat, or other adverse weather conditions which decrease physical efficiency and increase the probability of accidents.

- In hot weather, rotate workers wearing protective clothing.

- Maintain good hygienic standards by frequent changing of clothing and daily showering. Clothing should be permitted to dry during rest periods. Workers who notice skin problems should immediately consult the SHSO.

5.2.11.1 Heat-Related Problems

- Heat rash: Caused by continuous exposure to heat and humid air, and aggravated by chafing clothes. Decreases ability to tolerate heat and is a nuisance.
- Heat cramps: Caused by profuse perspiration with inadequate fluid intake and chemical replacement, especially salts. Signs include muscle spasms and pain in the extremities and abdomen.
- Heat exhaustion: Caused by increased stress on various organs to meet increased demands to cool the body. Signs include shortness of breath; increased pulse rate (120-200 beats per minute); pale, cool, moist skin; profuse sweating; and dizziness and exhaustion.
- Heat stroke: The most severe form of heat stress. Body must be cooled immediately to prevent severe injury and/or death. Signs include red, hot, dry skin; no perspiration; nausea; dizziness and confusion; strong, rapid pulse; and possibly coma. Medical help must be obtained immediately.

5.2.11.2 Heat-Stress Monitoring

Monitoring of personnel wearing impermeable clothing will begin when the ambient temperature is 70°F (21°C) or above. Table 5.2 presents the suggested frequency for such monitoring. Monitoring frequency will increase as the ambient temperature increases or as slow recovery rates are observed. Heat-stress monitoring will be performed by a person with current first-aid certification who is trained to recognize heat-stress symptoms. For monitoring the body's recuperative capabilities in response to excess heat, one or more of the techniques listed below will be used. Other methods of heat-stress monitoring may also be used, such as the wet-bulb globe temperature index from the American Conference of Governmental Industrial Hygienists (ACGIH) (1994-1995) Threshold Limit Value (TLV) Booklet.

TABLE 5.2

SUGGESTED FREQUENCY OF PHYSIOLOGICAL MONITORING FOR FIT AND ACCLIMATIZED WORKERS[a/]

Adjusted Temperature[b/]	Normal Work Ensemble[c/]	Impermeable Ensemble[d/]
90°F (32.2°C) or above	After each 45 minutes of work	After each 15 minutes of work
87.5° - 90°F (30.8°-32.2° C)	After each 60 minutes of work	After each 30 minutes of work
82.5° -87.5° F (28.1°-30.8°C)	After each 90 minutes of work	After each 60 minutes of work
77.5°-82.5° F (25.3°-28.1°C)	After each 120 minutes of work	After each 90 minutes of work
72.5°-77.5°F (22.5°-25.3°C)	After each 150 minutes of work	After each 120 minutes of work

a/ For work levels of 250 kilocalories/per hour.

b/ Calculate the adjusted air temperature (ta adj) by using this equation: ta adj = ta °F + (13 x sunshine multiplier [i.e., 50 percent sunshine equals a .5 multiplier]). Measure air temperature (ta) with a standard mercury-in-glass thermometer, with the bulb shielded from radiant heat. Estimate the sunshine multiplier by judging what percent of time the sun is not covered by clouds that are thick enough to produce a shadow (100 percent sunshine - no cloud cover and a sharp, distinct shadow; 0 percent sunshine = no shadows).

c/ A normal work ensemble consists of cotton coveralls or other cotton clothing with long sleeves and trousers.

d/ Saranex®, Poly-Coated Tyvek®, Etc.

To monitor the worker, measure:

- Heart rate: Count the radial pulse during a 30-second period as early as possible during the rest period.
  - If the heart rate exceeds 110 beats per minute at the beginning of the rest period, the next work cycle will be shortened by one-third and the rest period will remain the same.
  - If the heart rate still exceeds 110 beats per minute at the next rest period, the following work cycle will be reduced by one-third.
- Oral temperature: Use a clinical thermometer (3 minutes under the tongue) or similar device to measure the oral temperature at the end of the work period (before drinking).
  - If oral temperature exceeds 99.6° (37.6°C), the next work cycle will be reduced by one-third without changing the rest period.
  - If oral temperature still exceeds 99.6°F (37.6°C) at the beginning of the next rest period, the following work cycle will be reduced by one-third.
  - No worker will be permitted to wear a semipermeable or impermeable garment when oral temperature exceeds 100.6°F (38.1°C).

5.2.12 Cold Exposure

It is possible that work on this project may be conducted during the winter months; therefore, injury due to cold exposure may become a problem for field personnel. Cold exposure symptoms, including hypothermia and frostbite, will be monitored when personnel are exposed to low temperatures for extended periods of time.

Persons working outdoors in temperatures at or below freezing may suffer from cold exposure. During prolonged outdoor periods with inadequate clothing, effects of cold exposure may even occur at temperatures well above freezing. Cold exposure may cause severe injury by freezing exposed body surfaces (frostbite), or may result in profound generalized cooling (hypothermia), possibly causing death. Areas of the body which have high surface area-to-volume ratios such as fingers, toes, and ears are the most susceptible to frostbite.

Two factors influence the development of a cold injury: ambient temperature and wind velocity. Wind chill is used to describe the chilling effect of moving air in combination with low temperature. For example, 14°F with a wind speed of 15 miles per hour (mph) is equivalent in chilling effect to still air at -18°F. Cold exposure is particularly a threat to site workers if the body cools suddenly when chemical-protective equipment is removed, and the clothing underneath is perspiration-soaked. The presence of wind greatly increases the rate of cooling.

Local injury resulting from cold is included in the generic term frostbite. There are several degrees of damage. Frostbite of the extremities can be categorized into:

- Frost nip or incipient frostbite: characterized by suddenly blanching or whitening of skin.
- Superficial frostbite: skin has a waxy or white appearance and is firm to the touch, but tissue beneath is resilient.
- Deep frostbite: tissues are cold, pale, and solid; an extremely serious injury.

Systemic hypothermia, or lowering of the core body temperature, is caused by exposure to freezing or rapidly dropping temperatures. Symptoms are usually exhibited in five stages:

- Shivering and uncoordination;
- Apathy, listlessness, sleepiness, and (sometimes) rapid cooling of the body to less than 95°F (35°C);
- Unconsciousness, glassy stare, slow pulse, and slow respiratory rate;
- Freezing of the extremities; and
- Death.

5.2.12.1 Evaluation and Control

TLVs recommended for properly clothed workers for periods of work at temperatures below freezing are shown in Table 5.3. For exposed skin, continuous exposure should not be permitted when the air speed and temperature results in an equivalent chill temperature of -32°C (-25.6°F). Superficial or deep local tissue freezing will occur only at temperatures below -1°C (30.3°F) regardless of wind speed.

Special protection of the hands is required to maintain manual dexterity for the prevention of accidents. If fine work is to be performed with bare hands for more than 10 to 20 minutes in an environment below 16°C (60.8°F), special provisions should be established for keeping the workers' hands warm. For this purpose, warm air jets, radiant heaters (fuel burner or electric radiator), or contact warm plates may be used. At temperatures below -1°C (30.2°F), metal handles of tools and control bars should be covered by thermal insulating material.

To prevent contact frostbite, workers should wear gloves. When cold surfaces below -7°C (19.4°F) are within reach, a warning will be given to the workers by the supervisor or SHSO to prevent inadvertent contact with bare skin. If the air temperature is -17.5°C (0°F) or less, the hands should be protected by mittens. Machine controls and tools for use in cold conditions should be designed so that they can be handled without removing the mittens.

TABL.

THRESHOLD LIMIT VALUES WORK/
WARM-UP SCHEDULE FOR FOUR-HOUR SHIFT

Air Temperature-Sunny Sky		No Noticeable Wind		5 mph Wind		10 mph Wind		15 mph Wind		20 mph Wind	
°C(approx.)	°F (approx.)	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks
-26° to -28 °	-15° to -19 °	(Norm Breaks)	1	(Norm Breaks)	1	75 min	2	55 min	3	40 min	4
-29° to -31°	-20° to -24 °	(Norm Breaks)	1	75 min	2	55 min	3	40 min	4	30 min	5
-32° to -34°	-25° to -29 °	75 min	2	55 min	3	40 min	4	30 min	5	Non-emergency work should cease	
-35° to -37°	-30° to -34°	55 min	3	40 min	4	30 min	5	Non-emergency work should cease			
-38° to -39°	-35° to -39°	40 min	4	30 min	5	Non-emergency work should cease					
-40° to -42°	-40° to -44°	30 min	5	Non-emergency work should cease							
-43° & below	-45° & below	Non-emergency work should cease									

Notes for Tables 5.3

1. Schedule applies to any 4-hour work period with moderate to heavy work activity, with warm-up periods in a warm location and with an extended break (e.g., lunch) at the end of the 4-hour work period in a warm location. For light-to-moderate (limited physical movement): apply the schedule one step lower. For example, at -35°C (-30°F) with no noticeable wind (Step 4), a worker at a job with little physical movement should have a maximum work period of 40 minutes with 4 breaks in a 4-hour period (Step 5)

2. The following is suggested as a guide for estimating wind velocity if accurate information is not available: 5 mph; light flag moves; 10 mph: light flag fully extended; 15 mph: raises newspaper sheet; 20 mph: blowing and drifting snow.

3. In general the warm-up schedule provided above slightly under-compensates for the wind at the warmer temperatures, assuming acclimatization and clothing appropriate for winter work. On the other hand, the chart slightly over-compensates for the actual temperatures in the colder ranges, since windy conditions rarely prevail at extremely low temperatures.

4. TLVs apply only for workers in dry clothing.

Provisions for additional total body protection are required if work is performed in an environment at or below 4°C (39.2°F). The workers will wear cold protective clothing appropriate for the level of cold and physical activity. If the air velocity at the job site is increased by wind, draft, or artificial ventilating equipment, the cooling effect of the wind should be reduced by shielding the work area or by wearing an easily removable windbreak garment. If the available clothing does not give adequate protection to prevent hypothermia or frostbite, work will be modified or suspended until adequate clothing is made available or until weather conditions improve.

5.2.12.2 Work-Warming Regimen

If work is performed continuously in the cold at an equivalent chill temperature (ECT) below -7°C (19.4°F), heated warming shelters (tents, cabins, rest rooms) will be made available nearby. The workers will be encouraged to use these shelters at regular intervals, the frequency depending on the severity of the environmental exposure. The onset of heavy shivering, frostnip, the feeling of excessive fatigue, drowsiness, irritability, or euphoria are indications for immediate return to the shelter. When entering the heated shelter, the outer layer of clothing should be removed and the remainder of the clothing loosened to permit sweat evaporation, or a change of dry work clothing should be provided. A change of dry work clothing may be necessary to prevent workers from returning to work with wet clothing. Dehydration, or the loss of body fluids, occurs insidiously in the cold environment and may increase the susceptibility of the worker to cold injury due to a significant change in blood flow to the extremities. Warm sweet drinks and soups should be provided at the work site to provide caloric intake and fluid volume. The intake of coffee should be limited because of the diuretic and circulatory effects.

For work practices at or below -12°C (10.4°F) ECT, the following should apply:

- The workers will be under constant protective observation (buddy system or supervision).
- The work rate should not be so high as to cause heavy sweating that will result in wet clothing; if heavy work must be done, rest periods will be taken in unheated shelters, and the opportunity for changing into dry clothing should be provided.
- New employees should not be required to work full-time in the cold during the first days of employment until they become accustomed to the working conditions and required protective clothing.
- The weight and bulkiness of clothing should be included in estimating the required work performances and weights to be lifted by the worker.
- The work should be arranged in such a way that sitting still or standing still for long periods is minimized. Unprotected metal chair seats will not be used. The worker should be protected from drafts to the greatest extent possible.
- The workers will be instructed in safety and health procedures relative to cold exposures.

5.3 BIOLOGICAL HAZARDS

Various biological hazards may be encountered at the USAF installations. These hazards include pathogenic organisms or diseases such as Bubonic Plague, Equine Encephalitis, and Lyme Disease. Other biological hazards include insects, snakes, spiders, and cactuses.

Bubonic plague is a bacterial disease which is spread to humans by fleas that have bitten an infected animal. Bubonic plague displays symptoms rapidly. Chills and fever are soon accompanied by swelling of the lymph nodes, usually on one side of the body. These painful swellings are usually dark blue to black, hence the other common name for this disease, "black death." The disease is treatable with antibiotics. Field personnel must wear Tyvek® suits with leg seams taped to boots or boot covers to minimize contact with fleas while working in prairie dog towns.

Equine encephalitis, an inflammation of the brain, can be carried by mosquitoes. Field personnel must wear long-sleeved clothing and/or use insect repellents if they are working in areas of mosquito infestations.

Bites from wood ticks may result in the transmission of Lyme disease - a serious and often fatal bacterial disease. The Borrelia burgdorferi bacteria infects wood ticks, which can bite humans and transfer the bacteria into the bloodstream. Transmission of Lyme disease is most likely in late spring, summer, and early fall.

There are three stages of Lyme disease, although not everyone will proceed through all the stages or experience all the symptoms. The initial symptoms may include a red rash that is circular and blotchy and expands around the tick bite, and flu-like symptoms such as fatigue, headaches, fever, swollen glands, and stiffness and pain in muscles and joints. The next stage can occur from a few days to a few weeks after the initial stage. Symptoms of this phase may include irregular heartbeat, facial paralysis, joint pain, irritability, headaches, dizziness, poor coordination, weakness, severe fatigue, and memory loss. The third stage may occur weeks to years after the second stage. Arthritis, often in the knees, is the most common symptom of this stage. The arthritis may disappear and recur many times, and chronic arthritis may develop.

Prompt medical treatment with antibiotics is usually successful in preventing further complications from this disease. Lyme disease becomes more difficult to treat the longer treatment is delayed. Long-sleeved shirts with snug collar and cuffs, pants tucked into socks, and personal protective equipment will offer some protection. However, the use of tick repellent may also be warranted. Personnel should perform self-checks for ticks at the end of each work day.

The potential exists for contact with snakes or insects which may cause injury or disease when performing RNA investigation activities at USAF installations. There are plants which may be injurious (i.e., thorns) as well. Sturdy work clothes and shoes will be worn by field personnel to help prevent injuries. Personnel should be aware that rattlesnakes, water moccasins or alligators may be present in an area and should therefore exercise caution, especially when working in previously undisturbed areas and locations around animal dens and wetland habitats.

An abundance of red fire ants may be observed at the USAF installations, especially in the vicinity of the existing monitoring wells. Do not stand on, place equipment on or otherwise disturb the ant hills. It is also advisable to place a four foot square piece of plywood where personnel need to stand. An insect repellent may be used if it does not interfere with the desired groundwater sampling analyses. Latex booties taped at the top or Tyvek® suits may also be used. Frequent self-checks for crawling ants should also be performed.

Poison ivy, poison oak, and poison sumac can be encountered at many USAF installations. Poison ivy is a woody vine leaves are divided into three leaflets. Poison oak is a low branching shrub with leaflets also in threes. Poison sumac is a shrub or small tree occurring in swamps. Poison sumac have 7 to 13 leaflets which resemble those of green ash trees. All of these species are poisonous and can cause contact dermatitis. Personnel must wear Tyvek® suits or other protective clothing when working in areas containing these plant species.

Black widow spiders and scorpions may also be present onsite. The black widow spider has a shiny black body about the size of a pea, with a red or yellow hourglass-shaped mark on its abdomen. It weaves shapeless diffuse webs in undisturbed areas. A bite may result in severe pain, illness, and possible death from complications, but usually not from the bite itself. There are several types of scorpions native to the United States. Scorpions may be brown to yellowish in color, and range from 1/2 inch to 8 inches in length. Their bodies are divided into two parts: a short, thick upper body, and a long abdomen with a six-segment tail. A scorpion has six pairs of jointed appendages: one pair of small pincers, one pair of large claws, and four pairs of jointed legs. They are most active at night. A scorpion sting is very painful, but usually will not result in death.

In addition to spiders and scorpions, bees and wasps may be nuisances to field personnel. Properly trained personnel will administer first aid should a bee or wasp sting occur.

SECTION 6

EMERGENCY RESPONSE PLAN

All hazardous waste site activities will present a degree of risk to onsite personnel. During routine operations, risk is minimized by establishing good work practices, staying alert, and using proper PPE. Unpredictable events such as physical injury, chemical exposure, or fire may occur and must be anticipated. The sections below establish procedures and guidelines for emergencies.

6.1 GUIDELINES FOR PRE-EMERGENCY PLANNING AND TRAINING

Employees must read this program health and safety plan and the appropriate site-specific addendum to this plan, and familiarize themselves with the information provided. Prior to project initiation, the SHSO will conduct a meeting with the field team members to review the provisions of this program health and safety plan and the addendum, and to review the emergency response plan. Employees are required to have a copy of the emergency contacts and telephone numbers immediately accessible onsite and know the route to the nearest emergency medical services. The emergency contacts, telephone numbers, and routes to the hospital will be provided in the site-specific health and safety plan addendum prepared for each risk-based demonstration site. Appendix A provides a guideline for preparing this information.

6.2 EMERGENCY RECOGNITION AND PREVENTION

Emergency conditions are considered to exist if:

- Any member of the field crew is involved in an accident or experiences any adverse effects or symptoms of exposure while onsite.
- A condition is discovered that suggests the existence of a situation more hazardous than anticipated (e.g. flammable atmospheres).
- Concentrations of combustible vapors reach or exceed 10 percent of the lower explosive limit (LEL).
- A fire or explosion hazard exists.
- Concentrations of organic vapors measured in the worker breathing zone by a photoionization detector (PID) are above background air concentrations greater than an amount equal to the lowest permissible exposure limit (PEL) of a contaminant of concern onsite.

- A vehicle accident occurs.

Preventive measures are listed below.

- Site workers must maintain visual contact and should remain close together to assist each other during emergencies. (Use the buddy system.)
- During continual operations, onsite workers act as safety backup to each other. Offsite personnel provide emergency assistance.
- All field crew members should make use of all of their senses to alert themselves to potentially dangerous situations to avoid (e.g., presence of strong and irritating or nauseating odors).
- Personnel will practice unfamiliar operations prior to performing them in the field.
- Field crew members will be familiar with the physical characteristics of investigations and field demonstrations, including:
  - Wind direction in relation to contamination zones;
  - Accessibility to co-workers, equipment, vehicles and communication devices;
  - Communication signals and devices;
  - Hot zone locations (areas of known or suspected contamination);
  - Site access; and
  - Nearest water sources.
- Personnel and equipment in the designated work area should be minimized, consistent with effective site operations.

The discovery of any condition that would suggest the existence of a situation more hazardous than anticipated, will result in the reevaluation of the hazard and the level of protection required, and may result in a temporary evacuation of the field team from the immediate work area. Such conditions may include an adverse effect or symptom of exposure experienced by a field team member, or the exceedance of the action levels for organic vapors and/or combustible vapors. If the action levels for organic vapors and/or combustibles are exceeded, procedures will be followed as stated in Section 7 of this health and safety plan.

In the event of an accident, the SHSO or site manager will complete the Accident Report Form provided in Appendix B. Copies of the completed forms will be maintained by the program health and safety manager in the health and safety file of the affected employee. Follow-up action should be taken to correct the situation that caused the accident.

Near-miss incidents will also be documented using the form provided in Appendix B, and filed with the onsite health and safety records, as well as with the program health and safety manager. Near-miss incidents are defined as any incident which could have led to injury or property damage, but for whatever reason, did not. The assessment of near-miss incidents provides a better measure of safety program effectiveness than simply tracking accidents, since near-misses tend to occur at much higher frequencies than actual accidents.

6.3 PERSONNEL ROLES, LINES OF AUTHORITY, AND COMMUNICATION PROCEDURES DURING AN EMERGENCY

When an emergency occurs, decisive action is required. Rapidly made choices may have far-reaching, long-term consequences. Delays of minutes can create or exacerbate life-threatening situations. Personnel must be ready to respond to emergency situations immediately. All personnel will know their own responsibilities during an emergency, know who is in charge during an emergency, and the extent of that person's authority. This section outlines personnel roles, lines of authority, and communication procedures during emergencies.

In the event of an emergency situation at the site, the site manager will assume total control and will be responsible for onsite decision-making. The designated alternate for the site manager will be the SHSO. These individuals have the authority to resolve all disputes about health and safety requirements and precautions. They will also be responsible for coordinating all activities until emergency response teams (ambulance, fire department, etc.) arrive onsite.

The site manager and/or SHSO will ensure that the necessary USAF personnel, Parsons ES personnel, and agencies are contacted as soon as possible after the emergency occurs. All onsite personnel must know the location of the nearest phone and the location of the emergency phone number list.

6.4 EVACUATION ROUTES AND PROCEDURES, SAFE DISTANCES, AND PLACES OF REFUGE

In the event of emergency conditions, decontaminated employees will evacuate the area as instructed, transport decontaminated injured personnel, or take other measures to ameliorate the situation. Evacuation routes and safe distances will be decided upon and posted by the field team prior to initiating work.

6.5 DECONTAMINATION OF PERSONNEL DURING AN EMERGENCY

Procedures for leaving a contaminated area must be planned and implemented prior to going onsite. Decontamination areas and procedures will be established based on anticipated site conditions. If a member of the field crew is exposed to chemicals, the emergency procedures outlined below will be followed:

- Another team member (buddy) will assist or remove the individual from the immediate area of contamination to an upwind location.

- Precautions will be taken to avoid exposure of other individuals to the chemical.
- If the chemical is on the individual's clothing, the clothing will be removed if it is safe to do so.
- Administer first aid and transport the victim to the nearest medical facility, if necessary.

If uninjured employees are required to evacuate a contaminated area in an emergency situation, emergency decontamination procedures will be followed. At a minimum, these would involve moving into a safe area and removing protective equipment. Care will be taken to minimize contamination of the safe area and personnel. Contaminated clothing will be placed in plastic garbage bags or other suitable containers. Employees will wash or shower as soon as possible.

6.6 EMERGENCY SITE SECURITY AND CONTROL

For this project, the site manager (or designated representative) must know who is onsite and who is in the work area. Personnel access into the work area will be controlled. In an emergency situation, only necessary rescue and response personnel will be allowed into the exclusion zone.

6.7 PROCEDURES FOR EMERGENCY MEDICAL TREATMENT AND FIRST AID

6.7.1 Chemical Exposure

In the event of chemical exposure (skin contact, inhalation, ingestion) the following procedures will be implemented:

- Another team member (buddy) will assist or remove the individual from the immediate area of contamination to an upwind location.
- Precautions will be taken to avoid exposure of other individuals to the chemical.
- If the chemical is on the individual's clothing, the clothing will be removed if it is safe to do so.
- If the chemical has contacted the skin, the skin will be washed with copious amounts of water, preferably under a shower.
- In case of eye contact, an emergency eyewash will be used. Eyes will be washed for at least 15 minutes. Emergency eyewashes will comply with ANSI Z-358.1 and filled with tempered water maintained no cooler than 60°F and no warmer than 95°F. Eyewashes will be capable of delivering 0.4 to 0.8 gallons of water to both eyes for a minimum of 15 minutes. Each jobsite will have at least one emergency eyewash station. Each crew will have, at a minimum, an ANSI-approved personal eyewash suitable for initial eye flushing while the injured person is moved to an emergency eyewash station or medical facility.

- If necessary, the victim will be transported to the nearest hospital or medical center. If necessary, an ambulance will be called to transport the victim.

6.7.2 Personal Injury

In the event of personal injury:

- Field team members trained in first aid can administer treatment to an injured worker.
- The victim will be transported to the nearest hospital or medical center. If necessary, an ambulance will be called to transport the victim.
- The SHSO or site manager is responsible for the completion of the appropriate accident report form.

6.7.3 Fire or Explosion

In the event of fire or explosion, personnel will evacuate the area immediately. Administer necessary first aid to injured employees. Personnel will proceed to a safe area and telephone the emergency support services designated in the appropriate sit-specific addendum. Upon contacting the emergency support services, state your name, nature of the hazard (fire, high combustible vapor levels), the location of the incident, and whether there were any physical injuries requiring an ambulance. Do not hang up until the emergency support services personnel have all of the additional information they may require.

SECTION 7

LEVELS OF PROTECTION AND PERSONAL PROTECTIVE EQUIPMENT REQUIRED FOR SITE ACTIVITIES

7.1 PERSONAL PROTECTIVE EQUIPMENT

The personal protection level prescribed for the risk-based demonstrations is OSHA Level D (no respiratory or chemical protective clothing), with a contingency for the use of OSHA Level C or B as site conditions require (Figure 7.1). Unless certain compounds are ruled out through use of appropriate air monitoring techniques such as Dräger® tubes, portable sampling pumps, or an onsite gas chromatograph (GC), Level C respiratory protection (air-purifying respirator [APR]) cannot be used. Level C protection may only be used on this project when vapors in air are adequately identified and quantified and Level C respirator-use criteria are met. Level B (supplied air) respiratory protection must be used on this project in the presence of unknown vapor constituents or if benzene is detected at or above 1 part per million, volume per volume (ppmv). This is based on the toxicity and warning properties (high odor threshold) for benzene. Air monitoring must be conducted in the worker breathing zone when the potential occurrence of these compounds exists.

Ambient air monitoring of organic gases/vapors (using photoionization detectors such as an HNU® or Photovac® MicroTIP®, or by colorimetric analysis with Dräger® tubes) will be used to select the appropriate level of personal protection. The flow chart presented in Figure 7.1 will be used to select respiratory protection against volatile hydrocarbon constituents. If the portable air monitoring equipment indicates organic vapor concentrations of 0-5 meter units (mu), site workers will continue air monitoring in a Level D ensemble. If organic vapors reach 5-25 mu for more than 30 seconds, and benzene concentrations exceed 1 ppmv, site workers will evacuate the area or upgrade to Level B ensemble, if trained to do so. If benzene concentrations are less than 1 ppmv in the breathing zone, and vapors are in the range of 5-25 mu, the site crews may continue in Level D ensembles with periodic air monitoring. If organic vapor concentrations reach 25-50 mu for more than 30 seconds and benzene concentrations exceed 1 ppmv in the worker breathing zone, site crews will evacuate the area or upgrade to Level B ensembles. If benzene concentrations are less than 1 ppmv, and vapors are in the range of 25-50 mu, site workers will don full facepiece APRs equipped with organic vapor cartridges (National Institute for Occupational Safety and Health [NIOSH]-approved), and continue periodic monitoring. If organic vapor concentrations reach 50-500 mu for more than 30 seconds, site crews will evacuate the site or upgrade to Level B ensembles. If organic vapor concentrations exceed 500 mu for more than 30 seconds, site crews will evacuate the site.

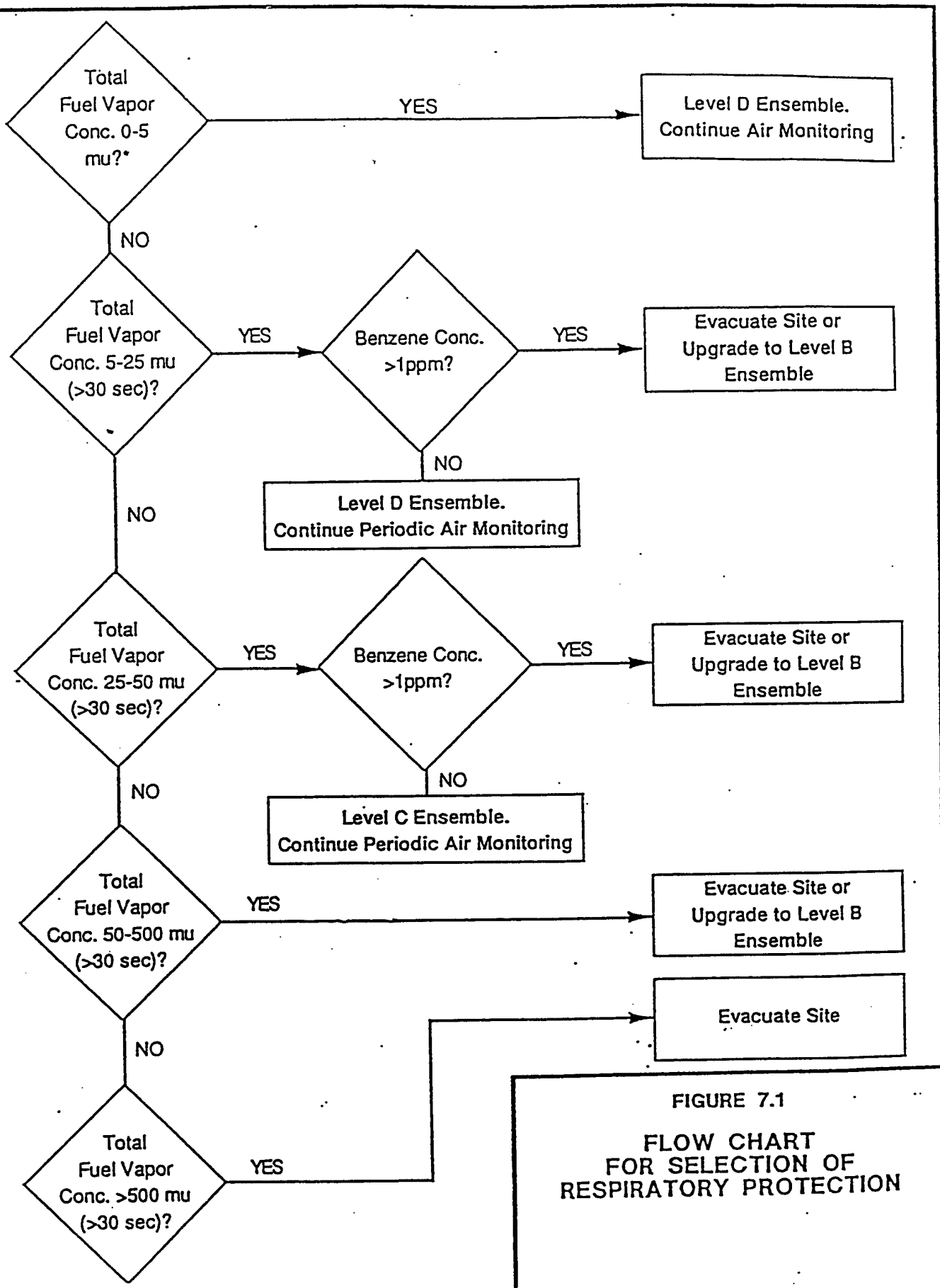


FIGURE 7.1

FLOW CHART FOR SELECTION OF RESPIRATORY PROTECTION

* mu = Meter Units

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Denver, Colorado

Before work can be performed in Level B respiratory protection, the project manager must be notified. He will initiate the change order process with the USAF or decide to halt activities at that site. (Level B operations require approval from Parsons ES corporate health and safety.) The SHSO will determine whether it is safe to continue activities without respiratory protection or assign an upgrade to Level C protection.

The use of PPE will be required when handling contaminated samples and working with potentially contaminated materials. The SHSO must ensure that all field personnel are properly trained in use, maintenance, limitations (including breakthrough time), and disposal of PPE assigned to them, in accordance with federal OSHA regulations in 29 CFR 1910.132. Disposable PPE will be used whenever possible to simplify decontamination, to reduce generation of contaminated washwater, and to avoid potential problems with chemical permeation (breakthrough). Single-use PPE (such as Tyvek®) will be disposed of whenever personnel go through decontamination. At most, a single item of disposable PPE (including respirator cartridges) will be used for no more than one day and will then be disposed of. Double layers of gloves will be used when personnel are handling contaminated soil or water, or equipment to minimize breakthrough. If personnel note chemical odors on their hands, clothing or skin after wearing PPE, or develop skin irritation or rashes, consult with the SHSO and decide on alternate actions and/or seek medical attention.

Respirator and other PPE selection will be determined for each of the USAF sites individually. Variations from what is specified in this plan will be presented in the site-specific addenda. The criteria will be based on previously collected data indicating the contaminants of concern and their concentrations. Respiratory protection against chlorinated solvents will be discussed in the site-specific addenda. Hard hats will be worn in the vicinity of the auger drilling rig and Geoprobe® unit. Steel-toed, steel-shank leather workboots will be worn by all field personnel.

The following personal protective ensemble is required only when handling contaminated samples or equipment.

Mandatory Equipment	Optional Equipment
• Vinyl or latex inner gloves	• Air-purifying respirator (equipped with organic vapor/high-efficiency particulate air [HEPA] cartridges)
• 4H or SilverShield® outer gloves	• Self-contained breathing apparatus or air-line respirator in pressure-demand mode
	• Rubber safety boots

- Disposable Tyvek® coveralls
- Outer disposable boot covers
- Saranex® suits
- Chemical goggles

7.2 EQUIPMENT NEEDS

Each field team will have the following items readily available:

- Copy of this program health and safety plan, site-specific addendum, and a separate list of emergency contacts;
- First aid kit which includes PPE for bloodborne pathogens;
- Eyewash bottle;
- Paper towels;
- Duct tape;
- Water (for drinking and washing);
- Plastic garbage bags;
- Fire extinguisher; and
- Earplugs.

7.3 EQUIPMENT DISPOSAL

All reusable PPE (such as hard hats and respirators), if contaminated, will be decontaminated in accordance with procedures specified in Section 10 of this health and safety plan. Contaminated single-use PPE (such as Tyvek® suits and protective gloves) will be properly disposed of according to USAF requirements.

SECTION 8

FREQUENCY AND TYPES OF AIR MONITORING

Air monitoring will be used to identify and quantify airborne levels of hazardous substances. Periodic monitoring is required during on site activities. The types of monitoring and equipment to be used are as follows:

Type of Equipment	Minimum Calibration Frequency	Parameter(s) to be Measured	Minimum Sampling Frequency	Sampling Locations
Photoionization Detector	1/day	Benzene Organic Vapors	2/hour for general site activities	Breathing Zone
Explosivity Meter	1/day	Combustible Gases	2/hour	Soil Borings Monitoring Wells
Sensidyne® or Drager® Tubes	None (check manufacturer's requirements)	Benzene Organic Vapors	When PID exceeds lowest PEL of the contaminants of concern	Breathing Zone
Dosimeter Badges	None	Benzene Organic Vapors	As needed on workers with greatest exposure to contamination initially detected by Drager® tubes	Breathing Zone
Portable Air Sampling Pumps	Prior to and after each use	Benzene Organic Vapors	As needed on workers with greatest exposure to contamination initially detected by Drager® tubes	Breathing Zone

During RNA investigation activities, a photoionization detector (such as an HNU® or MicroTIP®) will be used to measure ambient air concentrations in the worker breathing zone. The size of the PID lamp will be determined for each USAF site

individually, based on the ionization potential of the contaminants. This information will be presented in the site-specific addenda.

Evacuation may be necessary if the lowest PEL of a contaminant of concern is exceeded above background in the breathing zone of the site workers. This evacuation will be necessary until the area is well ventilated or the respiratory protection is upgraded, if possible. Any detectable concentration above background concentrations in the breathing zone will necessitate following the respiratory protection flowchart (Figure 7.1). The explosivity meter will be used at last twice per hour to measure combustible gas levels at the wellhead or borehole when a potential exists for combustible vapors. During drilling or other intrinsic activities in former or existing landfill areas, monitoring with an explosivity meter will be performed at the ground surface and in the worker breathing zone. At 10 percent of the LEL, evacuate the area and allow the borehole to ventilate.

Worker exposure monitoring will be conducted to document any exposures of Parsons ES site personnel to organic vapors. Portable air sampling pumps or dosimeter badges will be used for personal exposure monitoring, if necessary. The following general protocols will be followed if badges or pumps are used.

Passive Dosimeter Badges

An organic vapor monitoring badge will be attached in the worker's breathing zone for an eight-hour period when the potential for exposure exists. The exposed badges and a blank will be sent to the laboratory for analysis. These personal dosimeter badges work by means of diffusion eliminating the need for a pump, calibration or batteries.

Portable Sampling Pumps

- The portable pump will be calibrated to the required flow rate (in liters per minute) following the manufacturer's calibration procedures.
- The pump will be equipped with the appropriate sorbent tube for the particular organic compounds to be monitored (e.g., charcoal for volatile organics).
- A personal air monitoring data sheet (provided in Appendix B) listing pump flow rates, start and stop times, sorbent tube used, etc. will be completed.
- The pump will undergo a post calibration to determine final flow rates.
- The laboratory analytical results will be disclosed to the employee(s) monitored.
- The analytical results will be placed in the employee's permanent medical file for documentation of any exposures received.

SECTION 9

SITE CONTROL MEASURES

The following site control measures will be followed to minimize potential contamination of workers, protect the public from potential site hazards, and control access to the sites. Site control involves the physical arrangement and control of the operation zones and the methods for removing contaminants from workers and equipment. The first aspect, site organization, is discussed in this section. The second aspect, decontamination, is considered in the next section.

9.1 SITE ORGANIZATION-OPERATION ZONES

The following organization-operation zones will be established on the site or around a particular site feature (e.g., the drill rig).

- Exclusion Zone (Contamination Zone),
- Contamination Reduction Zone, and
- Support Zone.

The site manager and/or SHSO will be responsible for establishing the size and distance between zones at the site or around the site feature. Considerable judgment is required to ensure safe working distances for each zone are balanced against practical work considerations.

9.1.1 Exclusion Zone (Contamination Zone)

The exclusion zone includes the areas where active investigation or cleanup operations take place. Within the exclusion zone, prescribed levels of PPE must be worn by all personnel. The hotline, or exclusion zone boundary, is initially established based upon the presence of actual wastes or apparent spilled material, or through air monitoring, and is placed around all physical indicators of hazardous substances. For drilling operations, the hotline will be located at a distance equal to the drilling rig boom height or 25 feet, whichever is greater, from the drill rig. For backhoe operations, the hotline will be located at a distance from the backhoe equal to the limits of the swing radius. The hotline will consist of an easily identifiable physical boundary (e.g., cones or bright orange or yellow flagging attached to stakes, and may be readjusted based upon subsequent observations and measurements. This boundary will be physically secured and posted or well-defined by physical and geographic boundaries.

Under some circumstances, the exclusion zone may be subdivided into zones based upon environmental measurements or expected onsite work conditions.

9.1.2 Contamination Reduction Zone

If decontamination is required, a contamination reduction zone will be established between the exclusion zone and the support zone. This zone provides an area to prevent or reduce the transfer of hazardous materials which may have been picked up by personnel or equipment leaving the exclusion area. All decontamination activities occur in this area. The organization of the contamination reduction zone, and the control of decontamination operations, are described in Section 10.

9.1.3 Support Zone

The support zone is the outermost area of the site and is considered a noncontaminated or clean area. The support zone contains the command post for field operations, first-aid stations, and other investigation and cleanup support. Normal work clothes are appropriate apparel within this zone; potentially contaminated personnel, clothing or equipment are not permitted.

9.2 SITE SECURITY

Site security is necessary to prevent exposure of unauthorized, unprotected individuals in the work area. The areas immediately surrounding the work area will be clearly marked through use of warning signs, traffic cones, barrier tape, rope, or other suitable means.

Site security will be enforced by the SHSO or a designated alternate who will ensure that only authorized personnel are allowed in the work area and that entry personnel have the required level of PPE, are trained under the requirements of 29 CFR 1910.120, and are on a current medical monitoring program.

9.3 SITE COMMUNICATION

Internal site communication is necessary to alert field team members in the exclusion and contamination reduction zones to:

- Emergency conditions;
- To convey safety information; and
- Communicate changes or clarification in the work to be performed.

For internal site communication, the field team members will use prearranged hand signals (and responses). Radios and/or compressed air horns may also be used for communication.

External site communication is necessary to coordinate emergency response teams and to maintain contact with essential offsite personnel. A telephone will be available for use in external site communication. A list of emergency contact telephone numbers will be provided in subsequent addenda.

9.4 SAFE WORK PRACTICES

To ensure a strong safety-awareness program during field operations, field personnel will be adequately trained for their particular tasks. In addition, standing work orders will be developed and communicated to all field personnel, as will the provisions of this program health and safety plan and the appropriate addenda. Sample standing work orders for personnel entering the contamination reduction zone and exclusion zone are as follows:

- No smoking, eating, drinking or chewing of tobbaco or gum;
- No matches or lighters;
- No personal vehicles;
- Check in/check out at access control points;
- Use the buddy system;
- Wear appropriate PPE;
- Avoid walking through puddles or stained soil;
- Upon discovery of unusual or unexpected conditions, immediately evacuate and reassess the site conditions and health and safety practices;
- Conduct safety briefings prior to onsite work;
- Conduct daily safety meetings; and
- Take precautions to reduce injuries resulting from heavy equipment and other tools.

SECTION 10

DECONTAMINATION PROCEDURES

10.1 PERSONNEL DECONTAMINATION PROCEDURES

An exclusion zone, contamination reduction zone, and support zone will be established whenever field personnel are using PPE. Decontamination station layout will be made on a site-specific basis and will be based on the level of PPE used, the types of chemical hazards encountered, and the site conditions, including topography, wind direction, and traffic patterns. Defined site access and egress points will be established and personnel will enter and exit only through these points. As a general rule, persons assisting in the decontamination station may be in one level lower of respiratory protection than required in the work zone.

A guideline for personnel decontamination is presented in Figure 10.1. This procedure may be modified by the SHSO if necessary.

If personnel are in Level D-modified protection (no respirator but using protective gloves and/or suits and other equipment), a portable decontamination station will be set up at the site. The decontamination station will include provisions for collecting disposable PPE (e.g., garbage bags); washing boots, gloves, vinyl rain suits, field instruments and tools; and washing hands, face, and other exposed body parts. Onsite personnel will shower at the end of the work day. Refuse from decontamination will be properly disposed of in accordance with USAF installation protocols.

Decontamination equipment will include:

- Plastic buckets and pails;
- Scrub brushes and long-handle brushes;
- Detergent;
- Containers of water;
- Paper towels;
- Plastic garbage bags;
- Plastic or steel 55-gallon barrels;

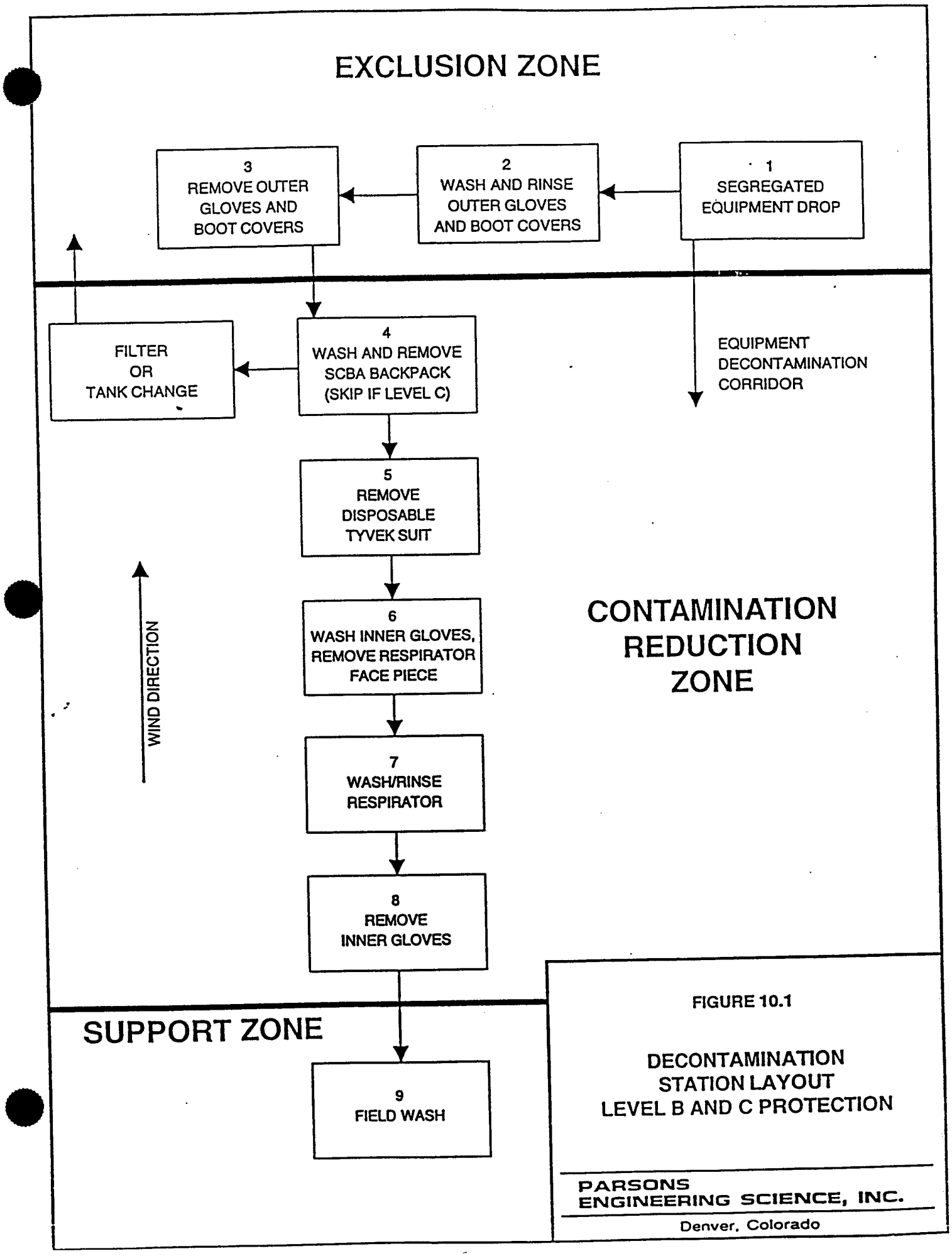


FIGURE 10.1

DECONTAMINATION STATION LAYOUT
LEVEL B AND C PROTECTION

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- Distilled water; and
- An eyewash station.

10.2 DECONTAMINATION OF EQUIPMENT

Decontamination of drilling rigs will be conducted at a designated location. High-pressure steam-cleaning of the rig will be necessary prior to the beginning of the drilling operation, between borehole locations, and before the drilling rig leaves the project site. All sampling equipment will be decontaminated prior to use, between samples, and between sampling locations.

SECTION 11

AIR MONITORING EQUIPMENT USE AND CALIBRATION PROCEDURES

11.1 PHOTOVAC MICROTIP® AIR ANALYZER

The MicroTIP® is a direct-reading instrument used in conjunction with the span gas kit. To calibrate the MicroTIP® press the power switch. Allow the MicroTIP® to warm up; the display will read "Ready." Press the calibration switch; the display will read "Connect zero gas then press enter." Connect the bag of zero gas to the MicroTIP® inlet (or allow the MicroTIP® to sample clean air) and press enter; the display will read "Calibrating now please wait." The display will then read "Span Conc.?" Enter the span concentration (usually 100 ppmv isobutylene). Connect the bag of span gas to the tip inlet and press enter; the display will read "Connect span gas then press enter." The MicroTIP® will then calibrate. When the display reads "Ready," the MicroTIP® has completed the calibration and is ready for use. Repeat the calibration daily.

To use the MicroTIP®, press the power switch and wait for the instrument to display the date, time, event number, current detected concentrations, and instrument status "ready." The minimum, maximum, and average concentrations measured in each 15-second period are automatically recorded in memory. The keyboard also allows for direct numeric entry.

Since a calibration gas (i.e., isobutylene) is used which typically differs from the contaminants of concern, it may be necessary to combine the instrument reading with a response factor to more closely approximate the concentration of the contaminants of concern.

Relative response factors are found in Table 11.1 for MicroTIP® models MP-100 and HL-200 with a 10.6 eV lamp. For these instruments, a more accurate concentration may be obtained by dividing the instrument reading by the appropriate relative response factor from Table 11.1 for the contaminant of concern.

For MicroTIP® instrument models MP-1000, HL-2000, IS-3000, and EX-4000 with a 10.6 eV lamp, the instrument reading is multiplied by the appropriate response factor from Table 11.2 for the contaminant of concern.

TABLE 11.1

MICROTIP® RELATIVE RESPONSE FACTORS (10.6 eV LAMP) INSTRUMENT MODELS MP-100 & HL-200

Compound	Relative Response Factor	Compound	Relative Response Factor
Acetaldehyde	0.17	Hydrogen Sulfide	0.25
Acetic Acid	0.09	Isobutyl Acetate	0.52
Acetone	0.86	Isobutyraldehyde	1.02
Acetone Cyanohydrin	0.93	Isopentane	0.12
Acrolein	0.28	Isoprene	2.12
Allyl Chloride	0.26	Isopropyl Acetate	0.43
Ammonia	0.10	Isopropyl Alcohol	0.23
Benzene	1.78	Methyl Bromide	0.45
1,3-Butadiene	1.43	Methyl tert-Butyl Ether	1.22
n-Butanol	0.27	Methyl Ethyl Ketone	1.10
see-Butanol	0.36	Methyl Isobutyl Ketone	0.87
n-Butyl Acetate	0.35	Methyl Mercaptan	1.60
n-Butyl Acrylate	0.53	Methyl Methacrylate	0.67
n-Butyl Mercaptan	1.36	Monoethylamine	1.25
n-Butylaldehyde	0.65	Monomethylamine	1.06
Carbon Disulfide	0.65	n-Octane	0.39
Chlorobenzene	2.24	n-Pentane	0.09
Cyclohexane	0.53	Perchloroethylene	1.40
Cyclohexanone	1.11	n-Propyl Acetate	0.31
1,2-Dichlorobenzene (ortho)	2.25	n-Propyl Alcohol	0.18
cis-1,2-Dichloroethylene	1.20	Propionaldehyde	0.56
trans-1,2-Dichloroethylene	2.21	Propylene	0.87
Diisobutylene	2.10	Propylene Oxide	0.13
1,4-Dioxane	0.83	Styrene	2.20
Epichlorohydrin	0.11	Tetrahydrofuran	0.65
Ethyl Alcohol	0.13	Toluene	1.91
Ethyl Acetate	0.25	Trichloroethylene	1.61
Ethyl Acrylate	0.30	Trimethylamine	1.35
Ethylene	0.09	Vinyl Acetate	0.84
Ethyl Mercaptan	1.82	Vinyl Bromide	2.24
Furfuryl Alcohol	1.43	Vinyl Chloride	0.51
n-Heptane	0.27	Vinylidene Chloride (1,1-DCE)	1.16
n-Hexane	0.20		

Note: Concentration = $\frac{\text{Instrument Reading}}{\text{Relative Response Factor}}$

TABLE 11.2

MICROTIP® RESPONSE FACTORS (10.6 eV LAMP)
INSTRUMENT MODELS MP-1000, HL-2000, IS-3000 & EX-4000

Compound	Response Factor	Compound	Response Factor
Acetaldehyde	6.6	n-Hexane	5.6
Acetic Acid	18.9	Hydrogen Sulfide	3.7
Acetone	1.2	Isobutyl Acetate	2.3
Acetone Cyanohydrin	1.2	Isobutyraldehyde	1.1
Acrolein	3.7	Isopentane	7.8
Allyl Chloride	4.3	Isoprene	0.6
Ammonia	10.1	Isopropyl Acetate	2.4
Benzene	0.6	Isopropyl Alcohol	4.5
1,3-Butadiene	0.7	Methyl Bromide	2.3
n-Butanol	4.6	Methyl tert-Butyl Ether	0.8
see-Butanol	3.0	Methyl Ethyl Ketone	0.9
n-Butyl Acetate	2.9	Methyl Isobutyl Ketone	1.1
n-Butyl Acrylate	1.9	Methyl Mercaptan	0.6
n-Butyl Mercaptan	0.7	Methyl Methacrylate	1.5
n-Butylaldehyde	1.9	Monoethylamine	0.8
Carbon Disulfide	1.4	Monomethylamine	1.0
Chlorobenzene	0.4	n-Octane	2.6
Cyclohexane	1.9	n-Pentane	10.8
Cyclohexanone	0.9	Perchloroethylene	0.7
1,2-Dichlorobenzene (ortho)	0.4	n-Propyl Acetate	3.5
cis-1,2-Dichloroethylene	0.8	n-Propyl Alcohol	6.3
trans-1,2-Dichloroethylene	0.4	Propionaldehyde	1.9
Diisobutylene	0.6	Propylene Oxide	7.1
Dimethylamine	1.5	Styrene	0.5
Di-n-propylamine	0.5	Tetrahydrofuran	1.5
1,4-Dioxane	1.2	Toluene	0.5
Epichlorohydrin	10.3	Trichloroethylene	0.6
Ethanol	11.1	Trimethylamine	0.9
Ethyl Acetate	4.2	Vinyl Acetate	1.2
Ethyl Acrylate	3.3	Vinyl Bromide	0.4
Ethylene	10.0	Vinyl Chloride	2.0
Ethyl Mercaptan	0.6	Vinylidene Chloride (1,1-DCE)	0.9
n-Heptane	3.7		

Note: Concentration = Instrument Reading x Response Factor

11.2 HNU® PHOTOIONIZATION DETECTOR

To calibrate the HNU®, turn the function switch to the "standby" mode and use the zero control to zero the instrument. Connect a bag of span gas (usually 100 ppmv isobutylene). Turn the function switch to the 0-200 range position and adjust the span control setting to read the ppmv concentration of the standard. Recheck the zero setting as previously described. If readjustment is needed, repeat the calibration step. This provides a two-point calibration to zero and the gas-standard point. Repeat the calibration daily. If the span setting from calibration is 0.0 or if calibration cannot be achieved, then the lamp must be cleaned.

To use the HNU® connect the probe to the instrument by matching the alignment slot in the probe connector to the key in the 12-pin connector on the control panel. Twist the probe connector until a distinct snap and lock is felt. Turn the function switch to battery check position. The needle should read within or above the green battery arc on the scale plate. If the needle is in the lower position of the battery arc, the instrument should be recharged before use. If the red light comes on, the battery should be recharged. Next, turn the functions switch to the on position, and the instrument is ready to take direct air readings.

11.3 EXPLOSIVITY METER

An explosivity meter is used to measure oxygen and combustible gas levels. The instrument provides characteristic warning signals when deficient oxygen conditions or unacceptable levels of combustible gas are detected.

To use the explosivity meter, turn the unit on and wait a few seconds for the readings to stabilize. Check the battery charge and the alarms before using the instrument. Set the LEL indicator to zero and the oxygen indicator to 20.9 percent.

To calibrate the instrument, attach a bag, bulb or balloon of span gas and wait for the readings to stabilize. Adjust the instrument to read the LEL percent of the calibration gas. Remove the span gas and allow the instrument to exhaust. The combustible sensor will read 000-percent LEL in clean air.

11.4 SENSIDYNE® OR DRÄGER® COLORIMETRIC GAS ANALYSIS TUBES

Colorimetric tubes can be used to give an instantaneous reading of various organic compounds. Their aim is to determine very small concentrations of a compound in the shortest amount of time. To sample with a colorimetric tube use the Dräger® or Sensidyne®bellows pump and select the appropriate tube (for example, a tube marked benzene to look for benzene). Break off both ends on the pump's break-off plate. Insert the tube into the pump head (the tube should be inserted with the arrow pointing towards the pump). There is a specific number of suction strokes for each tube/compound. Each box of tubes will have instructions for how many suction strokes are required for that compound.

APPENDIX A

EMERGENCY CONTACTS

APPENDIX A

EMERGENCY CONTACTS

In the event of any situation or unplanned occurrence requiring assistance, the appropriate contact(s) should be made from a list similar to this which will be prepared in the health and safety plan addenda. For emergency situations, telephone or radio contact should be made with the site point of contact or site emergency personnel who will then contact the appropriate response teams.

Contingency Contacts	Telephone Number
Nearest phone located at the work site	_____
Site Fire Department	_____
Site Contact	_____
Site Medical Services	_____
Site Emergency Telephone Number	_____
Site Security/Police	_____
Medical Emergency	
Hospital Name	_____
Hospital Address	_____
Hospital Telephone Number	_____
Ambulance Service	_____
Airlift Helicopter	_____

Directions and/or Map to the Hospital

Parsons ES Contacts

Doug Downey Project Manager	(303) 831-8100 (work) (303) 670-0512 (home)
Timothy Mustard, CIH (Denver) Program Health and Safety Manager	(303) 831-8100 (work) (303) 450-9778 (home)

Edward Grunwald, CIH (Atlanta) Corporate Health and Safety Manager	(404) 235-2300 (work) (404) 299-9970 (home)
Judy Blakemore (Denver) Assistant Program Health and Safety Manager	(303) 831-8100 (work) (303) 828-4028 (home) (303) 817-9743 (mobile)

APPENDIX B

PROJECT HEALTH AND SAFETY FORMS

PLAN ACCEPTANCE FORM

PROJECT HEALTH AND SAFETY PLAN

Instructions: This form is to be completed by each person to work on the subject project work site and returned to the safety manager.

I have read and agree to abide by the contents of the Health and Safety Plan for the following project:

_____

_____

_____

Signed

_____

Date

RETURN TO:

Office Health and
Safety Representative
Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, CO 80290

SITE SPECIFIC TRAINING RECORD

Project:_____
Project No.:_____
Date:_____
Trainer:_____

On this date, the following individuals were provided site-specific training in accordance with OSHA regulations contained in 29CFR1910.120(e):

Name (Print)	Employee No.	Employee Signature

Forward this form to:

Office Health and Safety Representative
Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290

PARSONS ENGINEERING SCIENCE, INC.

FIELD EXPERIENCE

DOCUMENTATION FORM

OSHA requires (29CFR1910.120(e)) that personnel involved in hazardous waste operations have 40-hours of initial training and a minimum of three days field experience working under the direction of a trained and experienced supervisor. This form serves to document the three days of additional field training/experience.

Employee Name:_____

Employee Number (or Social Security No.):_____

Project Name(s):_____

Project Number(s):_____

Dates of Field Training:_____

Summary of Activities Performed:_____

_____

_____

Levels of Respiratory Protection Used:_____

_____

Comments:

Field Supervisor Signature:_____

Date:_____

Return this form to the Office Health and Safety Representative

PARSONS ENGINEERING SCIENCE, INC.

DAILY VEHICLE INSPECTION REPORT

[✓] = OK [☒] = Adjustment Made [R] = Repair Needed

Date:_____ Time: _____ License Plate Number:_____

Vehicle Make and Type:_____ Rental Agency _____

General Vehicle Inspection:

1. Windshield ☐ 3. Vehicle Interior ☐
2. Vehicle Exterior ☐ 4. Leaks under Vehicle ☐

Check that the following are in proper working order:

1. Lights:
   - a. Headlights ☐
   - b. Taillights ☐
   - c. Turn Signals ☐
   - d. Brake Lights ☐
   - e. Back-up Lights ☐
   - f. Interior Lights ☐
2. Brakes ☐
3. Horn ☐
4. Tires properly inflated (refer to sticker on door or vehicle manual) ☐
5. Spare tire present and properly inflated ☐
6. Windshield wipers ☐
7. Windshield washers ☐
8. Defrosters/Defoggers ☐
9. Battery terminals free of corrosion ☐
10. Cooling system hoses ☐
11. Belts ☐
12. Fluid levels: (Circle approximate level)
    - a. Oil: Full 1 Quart low Does not register
    - b. Coolant: Full cool Needs some coolant Does not register
    - c. Transmission: Full 1 Pint low Does not register
      (NOTE: Check transmission fluid while vehicle is running!)
    - d. Fuel: E 1/4 1/2 3/4 F

Please note any problems, unusual conditions, repairs made or fluids added (except fuel):

_____

_____

_____

AIR PURIFYING RESPIRATOR
(APR)

LOG

SITE:

LOCATION:

DATES OF INVESTIGATION:

User	Date of Use	Cleaned and Inspected Prior To Use (Initials)	Cartridges Changed Prior to Use (Yes, No, N/A)	Total Hours on Cartridge

APR Performance Comments:

Project H&S Officer or Parsons ES Project Manager — Date

Return to the Office Health and Safety Representative at the Completion of field activities.

PARSONS ENGINEERING SCIENCE COMPANIES

ACCIDENT REPORT FORM

Project: _____

EMPLOYER

1. Name: _____
2. Mail Address: _____
   (No. and Street) (City or Town) (State and Zip)
3. Location (if different from mail address: _____

_____

INJURED OR ILL EMPLOYEE

4. Name: _____ Social Security No.: _____
   (first) (middle) (last)
5. Home Address: _____
   (No. and Street) (City or Town) (State and Zip)
6. Age: _____ 7. Sex: male ( ) female ( )
8. Occupation: _____
   (specific job title, not the specific activity employee was performing at time of injury)
9. Department: _____
   (enter name of department in which injured person is employed, even though they may have been temporarily working in another department at the time of injury)

THE ACCIDENT OR EXPOSURE TO OCCUPATIONAL ILLNESS

10. Place of accident of exposure: _____
    (No. and Street) (City or Town) (State and Zip)
11. Was place of accident or exposure on employer's premises? Yes ( ) No ( )
12. What was the employee doing when injured? _____
    (be specific--was employee using tools or equipment

_____

or handling material?)

_____

13. How did the accident occur? _____
    (describe fully the events that resulted in the injury or occupational illness.

_____

Tell what happened and how. Name objects and substances involved. Give details on all factors that led to

_____

accident. Use separate sheet for additional space).

14. Time of accident: _____

15. ES WITNESS TO ACCIDENT _____
(Name) (Affiliation) (Phone No.)

_____
(Name) (Affiliation) (Phone No.)

_____
(Name) (Affiliation) (Phone No.)

OCCUPATIONAL INJURY OR OCCUPATIONAL ILLNESS

16. Describe injury or illness in detail; indicate part of body affected:

_____

_____

17. Name the object or substance that directly injured the employee. (for example, object that struck employee; the vapor or poison inhaled or swallowed; the chemical or radiation that irritated the skin; or in cases of strains, hernias, etc., the object the employee was lifting, pulling, etc.).

_____

_____

18. Date of injury or initial diagnosis of occupational illness: _____
(date)

19. Did the accident result in employee fatality? Yes ( ) No ( )

20. Number of lost days ____/restricted workdays ____ resulting from injury or illness?

OTHER

21. Name and address of physician:_____
(No. and Street) (City or Town) (State and Zip)

22. If hospitalized, name and address:_____
(No. and Street) (City or Town) (State and Zip)

Date of report: _____ Prepared by:_____

Official position:_____

AIR PURIFYING RESPIRATOR
(APR)

LOG

SITE:

LOCATION:

DATES OF INVESTIGATION:

User	Date of Use	Cleaned and Inspected Prior To Use (Initials)	Cartridges Changed Prior to Use (Yes, No, N/A)	Total Hours on Cartridge

APR Performance Comments:

Project H&S Officer or Parsons ES Project Manager — Date

Return to the Office Health and Safety Representative at the Completion of field activities.

SUPPLIED AIR RESPIRATOR
(SAR)

LOG

SITE:

LOCATION:

DATES OF INVESTIGATION:

User	Date of Use	SAR#	Satisfactory (Yes/No)	Check-Out Initials	Date Cleaned

SAR Performance Comments:

Project H&S Officer
or
Parsons ES Project Manager

Date

Return to Office Health and Safety Representative
at the completion of field activities.

SELF-CONTAINED BREATHING APPARATUS
(SCBA)

LOG

SITE:

LOCATION:

DATES OF INVESTIGATION:

User	Date of Use	SCBA#	Satisfactory (Yes/No)	Check-Out Initials	Date Cleaned

SCBA Performance Comments:

Project H&S Officer
or
Parsons ES Project Manager

Date

Return to Office Health and Safety Representative
at the completion of field activities.

PARSONS ENGINEERING SCIENCE

SHIPPING PAPER

Shipping Paper No.:_____

Page 1 of _____ Parsons Engineering Science Date:_____

(name of carrier)

Consignee: Phone:		Shipper: Phone:	
Street:		Street:	
City: State: Zip:		City: State: Zip:	
Route		Vehicle License	

No. of Units and Packaging Type	HM	Basic Description (proper shipping name, hazard class, subsidiary risk, identification No. [UN], and packaging group)	Total Quantity (weight, volume, etc.)

PLACARDS TENDERED: **yes** ☐ **no** ☐

I HEREBY DECLARE THAT THE CONTENTS OF THIS CONSIGNMENT ARE FULLY AND ACCURATELY DESCRIBED ABOVE BY PROPER SHIPPING NAME AND ARE CLASSIFIED, PACKED, MARKED, AND LABELED, AND ARE IN ALL RESPECTS IN PROPER CONDITION FOR TRANSPORT ACCORDING TO THE APPLICABLE INTERNATIONAL AND NATIONAL GOVERNMENT REGULATIONS.

Name and Title of Shipper	Place and date
Emergency Telephone Number CHEM-TEL, 800/255-3924	Signature of Shipper

ATTACH MATERIAL SAFETY DATA SHEETS

K:\HS\FORMS\SHIPTEMP.WW2

ENGINEERING-SCIENCE, INC.
AIR MONITORING DATA FORM

Project: _____ Date: _____

Project No.: _____ Name(s): _____

Sample No	Pump No.	Sorbant/ Cartridge	Initial Flow Rate	Final Flow Rate	Ave. Flow Rate	Start Time	Stop Time	Total Elapsed Time	Total Volume Air	Analyses Performed	Notes

PARSONS ENGINEERING SCIENCE, INC.
PERSONAL AIR MONITORING DATA FORM

PROJECT NAME_____ PROJECT NUMBER:_____

Person Sampling	Person(s) Sampled/Location	Date	Time	PID/BG** (PPM)	Dräger (PPM)	LEL/BG (%)	O_2/BG (%)	Other	Notes

PID

Model_____

Serial #_____

Cal.* Gas_____

Cal. Reading_____

BG Reading_____

Explosimeter

Model_____

Serial #_____

Cal Gas_____

Cal. Reading_____

BG Reading_____

Other

Model_____

Serial #_____

Cal Gas_____

Cal. Reading_____

BG Reading_____

* Cal = Calibration

**BG = Background

CAT. NO. 1037

MATERIAL SAFETY DATA SHEET

POB: SASKIA HOFFER
HACH ORDER#: 044879

MSDS DATE: 9/12/95
CHANGE NO.: 8745

For Assistance, Contact:
Regulatory Affairs Dept.
PO Box 907 Ames, IA 50010
(800) 227-4224

HACH COMPANY
PO BOX 907
AMES, IA 50010

Emergency Telephone #
Rocky Mountain Poison Ctr.
(303) 623-5716

I. PRODUCT IDENTIFICATION

PRODUCT NAME: Ferrous Iron Reagent
CAS NO.: NA CHEMICAL NAME: Not applicable
FORMULA: Not applicable CHEMICAL FAMILY: Not applicable

II. INGREDIENTS

Sodium Bicarbonate
PCT: <100 CAS NO.: 144-55-8 SARA: NOT LISTED
TLV: Not established PEL: Not established
HAZARD: Moderately toxic

1,10-Phenanthroline, Monohydrate
PCT: <10 CAS NO.: 5144-89-8 SARA: NOT LISTED
TLV: Not established PEL: Not established
HAZARD: Very toxic; irritating

III. PHYSICAL DATA

STATE: solid APPEARANCE: White powder ODOR: Not determined
SOLUBILITY IN: WATER: Slightly soluble ACID: Slightly soluble
OTHER: Not determined BOILING POINT: NA MELTING PT.: 50C decomp.
SPEC GRAVITY: 2.10 pH: Not determined VAPOR PRESSURE: Not applicable
VAPOR DENSITY (air=1): NA EVAPORATION RATE: NA
METAL CORROSIVITY - ALUMINUM: ND STEEL: ND
STABILITY: See Conditions to Avoid
STORAGE PRECAUTIONS: Store in a cool, dry place.

IV. FIRE, EXPLOSION HAZARD AND REACTIVITY DATA

FLASH PT.: Not applicable METHOD: NA
FLAMMABILITY LIMITS - LOWER: NA UPPER: NA
SUSCEPTIBILITY TO SPONTANEOUS HEATING: None
SHOCK SENSITIVITY: None AUTOIGNITION PT.: ND
EXTINGUISHING MEDIA: water, carbon dioxide, or dry chemical
FIRE/EXPLOSION HAZARDS: May emit toxic fumes and acrid smoke in fire
HAZARDOUS DECOMP. PRODUCTS: May emit toxic fumes and acrid smoke in fire
OXIDIZER: No NFPA Codes: Health: 1 Flammability: 0 Reactivity: 0
CONDITIONS TO AVOID: Heat, moisture, contact with oxidizers, phosphates

V. HEALTH HAZARD DATA

THIS PRODUCT MAY BE: irritating to eyes, skin and respiratory tract.
ACUTE TOXICITY: Moderately toxic
ROUTES OF EXPOSURE: Ingestion, inhalation
TARGET ORGANS: Not determined
CHRONIC TOXICITY: Not determined
ROUTES OF EXPOSURE: Not determined
TARGET ORGANS: Not determined
CANCER INFORMATION: Not applicable
ROUTES OF EXPOSURE: Not applicable
TARGET ORGANS: Not applicable
OVEREXPOSURE: May cause eye, skin and respiratory tract irritation. Ingestion of large doses may cause stomach distention and rupture and systemic alkalosis.
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: Pre-existing eye, skin and respiratory tract conditions

VI. PRECAUTIONARY MEASURES

Avoid contact with eyes and skin.
Do not breathe dust.
Wash thoroughly after handling.
PROTECTIVE EQUIPMENT: adequate ventilation, lab grade goggles, disposable latex gloves

VII. FIRST AID

EYE AND SKIN CONTACT: Immediately flush eyes with water for 15 minutes. Ca physician. Wash skin with soap and plenty of water.
INGESTION: Give large quantities of water. Call physician immediately.
INHALATION: Remove to fresh air.

VIII. SPILL AND DISPOSAL PROCEDURES

IN CASE OF SPILL OR RELEASE: Sweep up powder. Avoid breathing material. Dissolve in water. Flush down the drain with excess water.
DISPOSE OF IN ACCORDANCE WITH ALL FEDERAL, STATE, AND LOCAL REGULATIONS.

IX. TRANSPORTATION DATA

D.O.T. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

I.C.A.O. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

I.M.O. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

X. REFERENCES

1) TLV's Threshold Limit Values and Biological Exposure Indices for 1988-1989. American Conference of Governmental Industrial Hygienists, 1988.
2) Air Contaminants, Federal Register, Vol. 54, No. 12, Thursday, January 19, 1989. pp. 2332-2983.
3) In-house information
4) Technical judgment
5) Sax, N. Irving. Dangerous Properties of Industrial Materials, 6th Ed. New York: Van Nostrand Reinhold Co. 1984.

THE INFORMATION CONTAINED HEREIN IS BASED ON DATA CONSIDERED TO BE ACCURATE. HOWEVER, NO WARRANTY IS EXPRESSED OR IMPLIED (C) HACH CO. 1994

CAT. NO. 21076

MATERIAL SAFETY DATA SHEET

POS: SASKIA HOFFER
HACH ORDER#: 046649

MSDS DATE: 10/07/93
CHANGE NO.: 12068

For Assistance, Contact:
Regulatory Affairs Dept.
PO Box 907 Ames, IA 50010
(800) 227-4224

HACH COMPANY
PO BOX 907
AMES, IA 50010

Emergency Telephone #
Rocky Mountain Poison Ctr.
(303) 623-5716

I. PRODUCT IDENTIFICATION

PRODUCT NAME: Buffer Powder Pillows, Citrate Type, for Manganese
CAS NO.: NA CHEMICAL NAME: Not applicable
FORMULA: Not applicable CHEMICAL FAMILY: Not applicable

II. INGREDIENTS

Sodium Phosphate, Dibasic, Anhydrous
PCT: <55 CAS NO.: 7558-79-4 SARA: NOT LISTED
TLV: Not established PEL: Not established
HAZARD: May cause eye and respiratory tract irritation

Citric Acid, Anhydrous
PCT: <25 CAS NO.: 77-92-9 SARA: NOT LISTED
TLV: Not established PEL: Not established
HAZARD: Causes severe eye irritation. May cause skin irritation.

Sodium Sulfate, Anhydrous
PCT: <35 CAS NO.: 7757-82-6 SARA: NOT LISTED
TLV: Not established PEL: Not established
HAZARD: May cause irritation

III. PHYSICAL DATA

STATE: solid APPEARANCE: White crystalline powder ODOR: None
SOLUBILITY IN: WATER: Soluble ACID: Not determined
OTHER: Not determined BOILING POINT: NA MELTING PT.: 160°C
SPEC GRAVITY: 2.30 pH: 6.35 (1%soln @23°C)
VAPOR PRESSURE: Not applicable VAPOR DENSITY (air=1): NA
EVAPORATION RATE: NA METAL CORROSIVITY - ALUMINUM: 0.022 in/yr
STEEL: 0.000 in/yr STABILITY: Stable
STORAGE PRECAUTIONS: Store tightly closed in a cool, dry place.

IV. FIRE, EXPLOSION HAZARD AND REACTIVITY DATA

FLASH PT.: Not applicable METHOD: NA
FLAMMABILITY LIMITS - LOWER: NA UPPER: NA
SUSCEPTIBILITY TO SPONTANEOUS HEATING: None
SHOCK SENSITIVITY: None AUTOIGNITION PT.: ND EXTINGUISHING MEDIA: water
FIRE/EXPLOSION HAZARDS: May emit toxic fumes
HAZARDOUS DECOMP. PRODUCTS: Highly toxic fumes of phosphorus oxides, sulfur oxides and sodium oxide in fire.
OXIDIZER: No NFPA Codes: Health: 1 Flammability: 1 Reactivity: 0
CONDITIONS TO AVOID: Heat, flames, exposure to moisture, contact with metal nitrates, contact with molten aluminum

V. HEALTH HAZARD DATA

THIS PRODUCT MAY BE: Irritating to eyes, skin and respiratory tract.
ACUTE TOXICITY: Slightly toxic
ROUTES OF EXPOSURE: Not determined
TARGET ORGANS: Not determined
CHRONIC TOXICITY: Not determined
ROUTES OF EXPOSURE: Not determined
TARGET ORGANS: Not determined
CANCER INFORMATION: Not applicable
ROUTES OF EXPOSURE: Not applicable
TARGET ORGANS: Not applicable
OVEREXPOSURE: Causes eye irritation
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: None reported

VI. PRECAUTIONARY MEASURES

Wash thoroughly after handling.
Avoid contact with eyes, skin and clothing
Do not breathe dust.
PROTECTIVE EQUIPMENT: adequate ventilation, lab grade goggles, disposable latex gloves

VII. FIRST AID

EYE AND SKIN CONTACT: Immediately flush eyes with water for 15 minutes. Co physician. Flush skin with plenty of water.
INGESTION: Give large quantities of water. Call physician immediately.
INHALATION: Remove to fresh air.

VIII. SPILL AND DISPOSAL PROCEDURES

IN CASE OF SPILL OR RELEASE: Sweep up powder. Avoid breathing material. Dissolve in water. Flush down the drain with excess water.
DISPOSE OF IN ACCORDANCE WITH ALL FEDERAL, STATE, AND LOCAL REGULATIONS.

IX. TRANSPORTATION DATA

D.O.T. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

I.C.A.O. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

I.M.O. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

X. REFERENCES

1) TLV's Threshold Limit Values and Biological Exposure Indices for 1988-1989. American Conference of Governmental Industrial Hygienists, 1988.
2) Air Contaminants, Federal Register, Vol. 54, No. 12, Thursday, January 19, 1989. pp. 2332-2983.
3) In-house information
4) Technical judgment
5) Sax, N. Irving. Dangerous Properties of Industrial Materials, [illegible] and The Merck Index, 10th Ed.
6) Sax, N. Irving. Dangerous Properties of Industrial Materials, [illegible] New York: Van Nostrand Reinhold Co. 1984.
7) Fire Protection Guide to Hazardous Materials, 10th Ed., Quincy, MA; National Fire Protection Association, 1991.

THE INFORMATION CONTAINED HEREIN IS BASED ON DATA CONSIDERED TO BE ACCURATE. HOWEVER, NO WARRANTY IS EXPRESSED OR REGARDING THE ACCURACY OF THESE DATA OR THE RESULTS TO BE OBTAINED FROM THE USE THEREOF.

(C) HACH CO. 199

CAT. NO. 21077

MATERIAL SAFETY DATA SHEET

POS: SASKIA HOFFER
HACH ORDERS: 666949

MSDS DATE: 12/16/93
[redacted]GE NO.: 12068

For Assistance, Contact:
Regulatory Affairs Dept.
PO Box 907 Ames, IA 50010
(800) 227-4224

HACH COMPANY
PO BOX 907
AMES, IA 50010

Emergency Telephone #
Rocky Mountain Poison Ctr.
(303) 623-5716

I. PRODUCT IDENTIFICATION

PRODUCT NAME: Sodium Periodate Powder Pillows
CAS NO.: 7790-28-5 CHEMICAL NAME: Sodium Periodate
FORMULA: NaIO4 CHEMICAL FAMILY: Oxidizing Agents

II. INGREDIENTS

Sodium m-Periodate
PCT: 100 CAS NO.: 7790-28-5 SARA: NOT LISTED
TLV: Not established PEL: Not established
HAZARD: Powerful oxidizer; causes irritation

III. PHYSICAL DATA

STATE: solid APPEARANCE: White crystalline powder ODOR: None
SOLUBILITY IN: WATER: Soluble ACID: Soluble OTHER: Not determined
BOILING POINT: NA MELTING PT.: 300C decomp. SPEC GRAVITY: 3.865
pH: of 5% soln. = 4-4.5 VAPOR PRESSURE: Not applicable
VAPOR DENSITY (air=1): NA EVAPORATION RATE: NA
METAL CORROSIVITY - ALUMINUM: ND STEEL: ND STABILITY: Stable
STORAGE PRECAUTIONS: Store in a cool, dry place away from oxidizable material.

IV. FIRE, EXPLOSION HAZARD AND REACTIVITY DATA

FLASH PT.: Not applicable METHOD: NA
FLAMMABILITY LIMITS - LOWER: NA UPPER: NA
SUSCEPTIBILITY TO SPONTANEOUS HEATING: May occur in contact with oxidizable materials.
SHOCK SENSITIVITY: None AUTOIGNITION PT.: ND
EXTINGUISHING MEDIA: water, dry chemical, alcohol foam or carbon dioxide
FIRE/EXPLOSION HAZARDS: Powerful oxidizer; may decompose explosively in case of fire
HAZARDOUS DECOMP. PRODUCTS: May emit toxic fumes of Iodine,Iodine compounds and sodium oxides in fire
OXIDIZER: strong NFPA Codes: Health: 2 Flammability: 0 Reactivity: 2
NFPA Symbol: oxy
CONDITIONS TO AVOID: Heat, flames; contact with ammonium compounds, organic material, finely-powdered metals and any other reducers

V. HEALTH HAZARD DATA

THIS PRODUCT MAY BE: irritating to eyes, skin and respiratory tract.
ACUTE TOXICITY: Very toxic
ROUTES OF EXPOSURE: ingestion, inhalation
TARGET ORGANS: central nervous system, red blood cells
CHRONIC TOXICITY: Not determined
ROUTES OF EXPOSURE: Not determined
TARGET ORGANS: Not determined
CANCER INFORMATION: Not applicable
ROUTES OF EXPOSURE: Not applicable
TARGET ORGANS: Not applicable
OVEREXPOSURE: Causes irritation, changes in red blood cells, central nervous system paralysis
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: None reported

VI. PRECAUTIONARY MEASURES

Avoid contact with eyes and skin.
Do not breathe dust.
Wash thoroughly after handling.
Protect from moisture
PROTECTIVE EQUIPMENT: adequate ventilation, lab grade goggles, disposable latex gloves

VII. FIRST AID

EYE AND SKIN CONTACT: Immediately flush eyes and skin with water for 15 minutes. Remove contaminated clothing. Call physician.
INGESTION: Give large quantities of water. Call physician immediately.
INHALATION: Remove to fresh air.

VIII. SPILL AND DISPOSAL PROCEDURES

IN CASE OF SPILL OR RELEASE: In small batches, dilute with excess water in beaker. Neutralize to a pH between 6 and 9 with soda ash. Flush to drain with excess water.
DISPOSE OF IN ACCORDANCE WITH ALL FEDERAL, STATE, AND LOCAL REGULATIONS.

IX. TRANSPORTATION DATA

D.O.T. PROPER SHIPPING NAME: Oxidizing Substances, Solid, N.O.S. (Sodium Periodate)
HAZARD CLASS: 5.1 ID: UN1479 GROUP: II

I.C.A.O. PROPER SHIPPING NAME: Oxidizing Solid, N.O.S. (Sodium Periodate)
HAZARD CLASS: 5.1 ID: UN1479 GROUP: II

I.M.O. PROPER SHIPPING NAME: Oxidizing Substances, Solid, N.O.S. (Sodium Periodate)
HAZARD CLASS: 5.1 ID: UN1479 GROUP: II

X. REFERENCES

1) TLV's Threshold Limit Values and Biological Exposure Indices for 1988-1989. American Conference of Governmental Industrial Hygienists, 1988.
2) Air Contaminants, Federal Register, Vol. 54, No. 12, Thursday, January 19, 1989. pp. 2332-2983.
3) The Merck Index, 11th Ed. Rahway, New Jersey: Merck and Co., Inc., 1989
4) Gessner G. Hawley, revised by, The Condensed Chemical Dictionary, Eleventh Ed., New York: Van Nostrand Reinhold Co., 1987
5) Fire Protection Guide to Hazardous Materials, 10th Ed., Quincy, MA; National Fire Protection Association, 1991.
6) Sax, N. Irving. Dangerous Properties of Industrial Materials, 6th Ed. New York: Van Nostrand Reinhold Co. 1984.
7) Technical judgment

(C) HACH CO. 199[illegible]

THE INFORMATION CONTAINED HEREIN IS BASED ON DATA CONSIDERED TO BE ACCURATE. HOWEVER, NO WARRANTY IS EXPRESSED OR IMPLIED [illegible] THE RESULTS TO BE OBTAINED FROM THE USE THEREOF.

CAT. NO. 1816

MATERIAL SAFETY DATA SHEET

POR: SASKIA HOFFER
HACH ORDER#: 915748

MSDS DATE: 8/31/94
CHANGE NO.: 14674

For Assistance, Contact:
Regulatory Affairs Dept.
PO Box 907 Ames, IA 50010
(800) 227-4224

HACH COMPANY
PO BOX 907
AMES, IA 50010

Emergency Telephone #
Rocky Mountain Poison Ctr.
(303) 623-5716

I. PRODUCT IDENTIFICATION

PRODUCT NAME: Sulfide 1 Reagent
CAS NO.: NA
CHEMICAL NAME: Not applicable
FORMULA: Not applicable
CHEMICAL FAMILY: Not applicable

II. INGREDIENTS

Sulfuric Acid
PCT: <65
CAS NO.: 7664-93-9
SARA: LISTED
TLV: 1 mg/M3
PEL: 1 mg/M3
IARC: LISTED
HAZARD: Causes severe burns. Harmful if inhaled. Known carcinogen

Other component
PCT: <1
CAS NO.: NA
SARA: NOT LISTED
TLV: Not applicable
PEL: Not applicable
HAZARD: Not applicable

Demineralized Water
PCT: to 100
CAS NO.: 7732-18-5
SARA: NOT LISTED
TLV: Not applicable
PEL: Not applicable
HAZARD: None

Any component of this mixture not specifically listed (eg. "other components") is not considered to present a carcinogen hazard.

III. PHYSICAL DATA

STATE: liquid APPEARANCE: Clear, colorless or light brown ODOR: None
SOLUBILITY IN: WATER: Miscible ACID: Miscible OTHER: Not determined
BOILING POINT: ~100°C MELTING PT.: NA SPEC GRAVITY: 1.500 pH: <0.5
VAPOR PRESSURE: Not determined VAPOR DENSITY (air=1): ND
EVAPORATION RATE: hygro METAL CORROSIVITY - ALUMINUM: Corrosive
STEEL: 0.048 in/yr STABILITY: See Conditions to Avoid
STORAGE PRECAUTIONS: Store in a cool place away from oxidizers and reducers.

IV. FIRE, EXPLOSION HAZARD AND REACTIVITY DATA

FLASH PT.: Not applicable METHOD: NA
FLAMMABILITY LIMITS - LOWER: NA UPPER: NA
SUSCEPTIBILITY TO SPONTANEOUS HEATING: None
SHOCK SENSITIVITY: None AUTOIGNITION PT.: NA
EXTINGUISHING MEDIA: dry chemical. DO NOT USE WATER
FIRE/EXPLOSION HAZARDS: May emit toxic fumes in fire
HAZARDOUS DECOMP. PRODUCTS: May emit toxic fumes of sulfur oxides in fire
OXIDIZER: mild NFPA Codes: Health: 3 Flammability: 0 Reactivity: 2
NFPA Symbol: W
CONDITIONS TO AVOID: Heat, flames, contact with oxidizers or reducers, caustics and caustic fumes, acetic acid, chlorosulfonic acid

V. HEALTH HAZARD DATA

THIS PRODUCT MAY BE: corrosive to eyes, skin and respiratory tract.
ACUTE TOXICITY: Moderately toxic
ROUTES OF EXPOSURE: ingestion, inhalation
TARGET ORGANS: Not determined
CHRONIC TOXICITY: Chronic irritation or inflammation, Teeth erosion
ROUTES OF EXPOSURE: inhalation
TARGET ORGANS: teeth, lungs
CANCER INFORMATION: An ingredient of this mixture is a known carcinogen.
ROUTES OF EXPOSURE: inhalation
TARGET ORGANS: nasal cavity, paranasal sinus, lungs, larynx
OVEREXPOSURE: Severely burns any tissue contacted. Breathing in the mist or vapor may cause mouth soreness, teeth erosion and difficulty in breathing. Inhalation of the mist or vapor of conc. sulfuric acid can cause cancer of the nasal tissue, lungs and larynx.
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: Pre-existing eye, skin and respiratory conditions

VI. PRECAUTIONARY MEASURES

Avoid contact with eyes, skin and clothing
Do not breathe mist or vapor.
Wash thoroughly after handling.
PROTECTIVE EQUIPMENT: adequate ventilation, lab grade goggles, disposable latex gloves, lab coat

VII. FIRST AID

EYE AND SKIN CONTACT: Immediately flush eyes and skin with water for 15 minutes. Remove contaminated clothing. Call physician.
INGESTION: Do NOT induce vomiting. Give 1 - 2 glasses of water. Call a physician immediately. Never give anything by mouth to an unconscious person.
INHALATION: Remove to fresh air. Give artificial respiration if necessar Call physician.

VIII. SPILL AND DISPOSAL PROCEDURES

IN CASE OF SPILL OR RELEASE: Cover the spill with excess soda ash or sodi bicarbonate. Scoop slurry to beaker. Adjust pH to between 6 and 9. Flus to the drain with excess water. Wash site with an alkali solution.
DISPOSE OF IN ACCORDANCE WITH ALL FEDERAL, STATE, AND LOCAL REGULATIONS.

IX. TRANSPORTATION DATA

D.O.T. PROPER SHIPPING NAME: Sulphuric Acid Solution
HAZARD CLASS: 8 ID: UN1830 GROUP: II

I.C.A.O. PROPER SHIPPING NAME: Sulphuric Acid Solution
HAZARD CLASS: 8 ID: UN1830 GROUP: II

I.M.O. PROPER SHIPPING NAME: Sulphuric Acid Solution
HAZARD CLASS: 8 ID: UN1830 GROUP: II

X. REFERENCES

1) TLV's Threshold Limit Values and Biological Exposure Indices for 1988-1989. American Conference of Governmental Industrial Hygienists, 1988.
2) Air Contaminants, Federal Register, Vol. 54, No. 12, Thursday, January 19, 1989. pp. 2332-2983.
3) In-house information
4) Technical judgment
5) IARC Monographs on the Evaluation of Carcinogenic Risk to Humans, Worl Health Organization (Volume 54) 1992, France.

SPECIAL NOTE: The IARC evaluation was based on exposure to the mist or vap of concentrated sulfuric acid generated during chemical processes.

SARA: This product contains a chemical or chemicals subject to the reporti requirements of section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372.

THE INFORMATION CONTAINED HEREIN IS BASED ON DATA CONSIDERED TO BE ACCURATE. HOWEVER, NO WARRANTY IS EXPRESSED OR IMPLIED REGARDING THE ACCURACY OF THESE DATA OR THE RESULTS TO BE OBTAINED FROM THE USE THEREOF.

(C) HACH CO. 1994

CAT. NO. 1817

MATERIAL SAFETY DATA SHEET

POB: SASKIA HOFFER
HACH ORDER#: 915748

MSDS DATE: 5/11/94
CHANGE NO.: 12068

For Assistance, Contact:
Regulatory Affairs Dept.
PO Box 907 Ames, IA 50010
(800) 227-4224

HACH COMPANY
PO BOX 907
AMES, IA 50010

Emergency Telephone #
Rocky Mountain Poison Ctr.
(303) 623-5716

I. PRODUCT IDENTIFICATION

PRODUCT NAME: Sulfide-2 Reagent
CAS NO.: NA
CHEMICAL NAME: Not applicable
FORMULA: Not applicable
CHEMICAL FAMILY: Not applicable

II. INGREDIENTS

Potassium Dichromate
PCT: <1
CAS NO.: 7778-50-9
SARA: LISTED
TLV: 0.05 mg/M3 as Cr
PEL: 0.1 mg/M3 Cr(VI)
IARC: LISTED
NTP: LISTED
HAZARD: Recognized carcinogen; causes severe burns; very toxic

Demineralized Water
PCT: to 100
CAS NO.: 7732-18-5
SARA: NOT LISTED
TLV: Not applicable
PEL: Not applicable
HAZARD: None

III. PHYSICAL DATA

STATE: liquid APPEARANCE: Clear, orange ODOR: None
SOLUBILITY IN: WATER: Miscible ACID: Miscible OTHER: Not determined
BOILING POINT: ~100°C MELTING PT.: NA SPEC GRAVITY: 0.987 pH: 4.2
VAPOR PRESSURE: Not determined VAPOR DENSITY (air=1): ND
EVAPORATION RATE: ND METAL CORROSIVITY - ALUMINUM: ND STEEL: ND
STABILITY: Stable
STORAGE PRECAUTIONS: Store tightly closed in a cool, dry place.

IV. FIRE, EXPLOSION HAZARD AND REACTIVITY DATA

FLASH PT.: Not applicable METHOD: NA
FLAMMABILITY LIMITS - LOWER: NA UPPER: NA
SUSCEPTIBILITY TO SPONTANEOUS HEATING: None
SHOCK SENSITIVITY: None AUTOIGNITION PT.: NA
EXTINGUISHING MEDIA: Not applicable
FIRE/EXPLOSION HAZARDS: None
HAZARDOUS DECOMP. PRODUCTS: None
OXIDIZER: No NFPA Codes: Health: 0 Flammability: 0 Reactivity: 0
CONDITIONS TO AVOID: Extreme temperatures, evaporation

V. HEALTH HAZARD DATA

THIS PRODUCT MAY BE: irritating to eyes and skin, and may cause allergic skin reaction.
ACUTE TOXICITY: Practically non-toxic
ROUTES OF EXPOSURE: Not applicable
TARGET ORGANS: Not applicable
CHRONIC TOXICITY: Not determined
ROUTES OF EXPOSURE: Not determined
TARGET ORGANS: Not determined
CANCER INFORMATION: An ingredient of this mixture is a known carcinogen.
ROUTES OF EXPOSURE: inhalation
TARGET ORGANS: lungs, paranasal sinus, nasal tissue
OVEREXPOSURE: May cause irritation, allergic skin reaction, liver and kidney damage.
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: Allergies or sensitivity to chromic acid or chromates

VI. PRECAUTIONARY MEASURES

Avoid contact with eyes and skin.
Do not breathe mist or vapor.
Wash thoroughly after handling.
PROTECTIVE EQUIPMENT: adequate ventilation, lab grade goggles, disposable latex gloves

VII. FIRST AID

EYE AND SKIN CONTACT: Immediately flush eyes with water for 15 minutes. Call physician. Remove contaminated clothing. Wash skin with soap and plenty of water.
INGESTION: Give large quantities of water or milk. Induce vomiting by sticking finger down throat. Never give anything by mouth to an unconscious person. Call physician.
INHALATION: Not applicable

VIII. SPILL AND DISPOSAL PROCEDURES

IN CASE OF SPILL OR RELEASE: Absorb material on non-reactive material. Scoop up the material and dispose of in an EPA approved hazardous waste facility. Decontaminate site with a soap solution.
DISPOSE OF IN ACCORDANCE WITH ALL FEDERAL, STATE, AND LOCAL REGULATIONS.

IX. TRANSPORTATION DATA

D.O.T. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

I.C.A.O. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

I.M.O. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

X. REFERENCES

1) In-house information
2) Technical judgment
3) IARC Monographs on the Evaluation of the Carcinogenic Risks to Humans, World Health Organization (Volumes 1-42) Supplement 7, 1987, France.
4) Sax, N. Irving. Dangerous Properties of Industrial Materials, 6th Ed. New York: Van Nostrand Reinhold Co. 1984.
5) NIOSH/OSHA Occupational Health Guidelines for Chemical Hazards. Cincinnati: Department of Health and Human Services, 1981.

SARA: This product contains a chemical or chemicals subject to the reporting requirements of section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372.

PER CALIFORNIA PROPOSITION 65: "WARNING - This product contains a chemical known to the State of California to cause cancer."

THE INFORMATION CONTAINED HEREIN IS BASED ON DATA CONSIDERED TO BE ACCURATE. HOWEVER, NO WARRANTY IS EXPRESSED OR IMPLIED REGARDING THE ACCURACY OF THESE DATA OR THE RESULTS TO BE OBTAINED FROM THE USE THEREOF.

(C) HACH CO. 1994

CAT. NO. 2578

MATERIAL SAFETY DATA SHEET

POR: SASKIA HOFFER
HACH ORDER#: 833692

MSDS DATE: 9/12/93
CHANGE NO.: 6745

For Assistance, Contact:
Regulatory Affairs Dept.
PO Box 907 Ames, IA 50010
(800) 227-4224

HACH COMPANY
PO BOX 907
AMES, IA 50010

Emergency Telephone #
Rocky Mountain Poison Ctr.
(303) 623-5716

I. PRODUCT IDENTIFICATION

PRODUCT NAME: Sulfate Standard Solution 50.0 ± 0.5 mg/L as SO4
CAS NO.: NA CHEMICAL NAME: Not applicable
FORMULA: Not applicable CHEMICAL FAMILY: Not applicable

II. INGREDIENTS

Sodium Sulfate, Ultrapure
PCT: <1 CAS NO.: 7757-82-6 SARA: NOT LISTED
TLV: Not established PEL: Not established
HAZARD: May cause irritation

Demineralized Water
PCT: to 100 CAS NO.: 7732-18-5 SARA: NOT LISTED
TLV: Not applicable PEL: Not applicable
HAZARD: None

III. PHYSICAL DATA

STATE: liquid APPEARANCE: Clear, colorless ODOR: None
SOLUBILITY IN: WATER: Miscible ACID: Miscible OTHER: Not determined
BOILING POINT: >100C MELTING PT.: NA SPEC GRAVITY: 0.989 pH: 5.6
VAPOR PRESSURE: Not determined VAPOR DENSITY (air=1): ND
EVAPORATION RATE: 0.63 METAL CORROSIVITY - ALUMINUM: ND STEEL: ND
STABILITY: See Conditions to Avoid
STORAGE PRECAUTIONS: Store tightly closed.

IV. FIRE, EXPLOSION HAZARD AND REACTIVITY DATA

FLASH PT.: Not applicable METHOD: NA
FLAMMABILITY LIMITS - LOWER: NA UPPER: NA
SUSCEPTIBILITY TO SPONTANEOUS HEATING: None
SHOCK SENSITIVITY: None AUTOIGNITION PT.: NA
EXTINGUISHING MEDIA: Not applicable
FIRE/EXPLOSION HAZARDS: None
HAZARDOUS DECOMP. PRODUCTS: None
OXIDIZER: No NFPA Codes: Health: 0 Flammability: 0 Reactivity: 0
CONDITIONS TO AVOID: Heat, evaporation

V. HEALTH HAZARD DATA

ACUTE TOXICITY: Practically non-toxic
ROUTES OF EXPOSURE: Not applicable
TARGET ORGANS: Not applicable
CHRONIC TOXICITY: Practically non-toxic
ROUTES OF EXPOSURE: Not applicable
TARGET ORGANS: Not applicable
CANCER INFORMATION: Not applicable
ROUTES OF EXPOSURE: Not applicable
TARGET ORGANS: Not applicable
OVEREXPOSURE: No effects anticipated
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: None reported

VI. PRECAUTIONARY MEASURES

Wash thoroughly after handling.
PROTECTIVE EQUIPMENT: lab grade goggles

VII. FIRST AID

EYE AND SKIN CONTACT: Flush with plenty of water.
INGESTION: Give large quantities of water. Call physician immediately.
INHALATION: Not applicable

VIII. SPILL AND DISPOSAL PROCEDURES

IN CASE OF SPILL OR RELEASE: Dilute with water. Pour down the drain with excess water.
DISPOSE OF IN ACCORDANCE WITH ALL FEDERAL, STATE, AND LOCAL REGULATIONS.

IX. TRANSPORTATION DATA

D.O.T. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

I.C.A.O. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

I.M.O. PROPER SHIPPING NAME: Not Currently Regulated
HAZARD CLASS: NA ID: NA GROUP: NA

X. REFERENCES

1) TLV's Threshold Limit Values and Biological Exposure Indices for 1988-1989. American Conference of Governmental Industrial Hygienists, 1988.
2) Air Contaminants, Federal Register, Vol. 54, No. 12, Thursday, January 19, 1989. pp. 2332-2983.
3) In-house information
4) Technical judgment

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SODIUM SULFITE
SODIUM SULFITE
SODIUM SULFITE

MATERIAL SAFETY DATA SHEET

FISHER SCIENTIFIC
CHEMICAL DIVISION
1 REAGENT LANE
FAIR LAWN NJ 07410
(201) 796-7100

EMERGENCY NUMBER: (201) 796-7100
CHEMTREC ASSISTANCE: (800) 424-9300

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SUBSTANCE IDENTIFICATION

SUBSTANCE: **SODIUM SULFITE** CAS-NUMBER 7757-83-7

TRADE NAMES/SYNONYMS:
ANHYDROUS SODIUM SULFITE; DISODIUM SULFITE; SODIUM SULPHITE; SODIUM SULFITE, ANHYDROUS; SULFUROUS ACID, SODIUM SALT (1:2); SULFUROUS ACID, DISODIUM SALT; EXSICCATED SODIUM SULFITE; S-430; S-447; BP335; ACC21660

CHEMICAL FAMILY:
Inorganic salt

MOLECULAR FORMULA: NA2-S-O3

MOLECULAR WEIGHT: 126.04

CERCLA RATINGS (SCALE 0-3): HEALTH=3 FIRE=0 REACTIVITY=0 PERSISTENCE=0
NFPA RATINGS (SCALE 0-4): HEALTH=1 FIRE=0 REACTIVITY=0

COMPONENTS AND CONTAMINANTS

COMPONENT: SODIUM SULFITE PERCENT: 100.0
CAS# 7757-83-7

OTHER CONTAMINANTS: NONE.

EXPOSURE LIMITS:
No occupational exposure limits established by OSHA, ACGIH, or NIOSH.

PHYSICAL DATA

DESCRIPTION: Odorless, white to tan crystals or powder with a saline, sulfurous taste. BOILING POINT: 212 F (100 C)

MELTING POINT: decomposes @ red heat SPECIFIC GRAVITY: 2.633 @ 15 C

PH: 9.0 (approx) SOLUBILITY IN WATER: 12.5% @ 0 C

SOLVENT SOLUBILITY: Soluble in glycerol; slightly soluble in alcohol; insoluble in liquid chlorine, ammonia

FIRE AND EXPLOSION DATA

FIRE AND EXPLOSION HAZARD:
Negligible fire hazard when exposed to heat or flame.

FIREFIGHTING MEDIA:
Dry chemical, carbon dioxide, water spray or regular foam (1993 Emergency Response Guidebook, RSPA P 5800.6).

For larger fires, use water spray, fog or regular foam (1993 Emergency Response Guidebook, RSPA P 5800.6).

FIREFIGHTING:
Move container from fire area if you can do it without risk. Do not scatter spilled material with high-pressure water streams. Dike fire-control water for later disposal (1993 Emergency Response Guidebook, RSPA P 5800.6, Guide Page 31).

Use agents suitable for type of surrounding fire. Avoid breathing hazardous vapors, keep upwind.

TOXICITY

SODIUM SULFITE:
TOXICITY DATA:
ANHYDROUS: 7 mg/kg oral-human TDLo (THIDD8); 820 mg/kg oral-mouse LD50; 2825 mg/kg oral-rabbit LDLo; 600 mg/kg subcutaneous-rabbit LDLo; 600 mg/kg subcutaneous-guinea pig LDLo; 1300 mg/kg subcutaneous-dog LDLo; 1300 mg/kg subcutaneous-cat LDLo; 175 mg/kg intravenous-mouse LD50; 400 mg/kg intravenous-cat LDLo; 200 mg/kg intravenous-guinea pig LDLo; 950 mg/kg intraperitoneal-mouse LD50; mutagenic data (RTECS).
HEPTAHYDRATE: 277 mg/kg intraperitoneal-mouse LD50; 743 mg/kg intravenous-man LDLo; reproductive effects data (RTECS).
CARCINOGEN STATUS: None.
ACUTE TOXICITY LEVEL: Moderately toxic by ingestion.
TARGET EFFECTS: Sensitizer- respiratory, oral.
AT INCREASED RISK FROM EXPOSURE: Persons with asthma.

HEALTH EFFECTS AND FIRST AID

INHALATION:
SODIUM SULFITE:
SENSITIZER.
ACUTE EXPOSURE- May cause mucous membrane irritation. Inhalation of this material may cause adverse reactions including bronchospasms in susceptible individuals, especially asthmatics. Symptoms may include flushing, severe wheezing, swelling of the throat, and palatal and generalized itching.
CHRONIC EXPOSURE- Repeated or prolonged exposure may cause sensitization. Rats exposed to aerosol concentrations of 0.1 to 15 mg/m3 for 3 days caused mild pulmonary edema.

FIRST AID- Remove from exposure area to fresh air immediately. Perform artificial respiration if necessary. Keep person warm and at rest. Treat symptomatically and supportively. Get medical attention immediately.

SKIN CONTACT:
SODIUM SULFITE:
ACUTE EXPOSURE- Direct contact may cause irritation and contact dermatitis. May cause itching and burning. Some sulfites may cause sensitization dermatitis in previously exposed individuals.
CHRONIC EXPOSURE- Repeated or prolonged exposure may cause contact dermatitis. Repeated exposure to sulfites may result in sensitization.

FIRST AID- Remove contaminated clothing and shoes immediately. Wash with soap or mild detergent and large amounts of water until no evidence of chemical remains (at least 15-20 minutes). Get medical attention immediately.

EYE CONTACT:
SODIUM SULFITE:
ACUTE EXPOSURE- Direct contact may cause irritation, redness, itching and burning.
CHRONIC EXPOSURE- No data available.

FIRST AID- Wash eyes immediately with large amounts of water or normal saline, occasionally lifting upper and lower lids, until no evidence of chemical remains (at least 15-20 minutes). Get medical attention immediately.

INGESTION:
SODIUM SULFITE:
SENSITIZER.
ACUTE EXPOSURE- May cause gastrointestinal irritation with abdominal pain, nausea, vomiting and diarrhea. In susceptible individuals, particularly asthmatics, sulfites may cause wheezing, shortness of breath, unconsciousness and anaphylaxis. Signs and symptoms may include generalized flushing and itching and respiratory arrest. The estimated human lethal dose is 10 grams. In animals, large doses have caused violent colic and diarrhea, circulatory disturbances, central nervous system depression and death.
CHRONIC EXPOSURE- Repeated ingestion of food containing sulfites may cause sensitization. Reproductive effects have been reported in animals.

FIRST AID- If vomiting occurs, keep head lower than hips to help prevent aspiration. Treat symptomatically and supportively. Get medical attention if needed.

ANTIDOTE:
No specific antidote. Treat symptomatically and supportively.

REACTIVITY

REACTIVITY:
Stable under normal temperatures and pressures.

INCOMPATIBILITIES:
SODIUM SULFITE:
MINERAL ACIDS (STRONG): Reacts to form sulfur dioxide.

POTASSIUM FERRICYANIDE
POTASSIUM FERRICYANIDE
POTASSIUM FERRICYANIDE

MATERIAL SAFETY DATA SHEET

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1 REAGENT LANE
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SUBSTANCE IDENTIFICATION

CAS-NUMBER 13746-66-2

SUBSTANCE: **POTASSIUM FERRICYANIDE**

TRADE NAMES/SYNONYMS:
POTASSIUM FERRICYANATE; TRIPOTASSIUM HEXACYANOFERRATE;
RED PRUSSIATE OF POTASH; RED POTASSIUM PRUSSIATE;
FERRATE(3-), HEXAKIS(CYANO-C)-, TRIPOTASSIUM;
TRIPOTASSIUM FERRIC HEXACYANIDE; TRIPOTASSIUM FERRICYANIDE;
TRIPOTASSIUM IRON HEXACYANIDE; P232; ACC19360

CHEMICAL FAMILY:
Inorganic salt

MOLECULAR FORMULA: K3-FE-C6-N6

MOLECULAR WEIGHT: 329.26

CERCLA RATINGS (SCALE 0-3): HEALTH=2 FIRE=0 REACTIVITY=0 PERSISTENCE=3
NFPA RATINGS (SCALE 0-4): HEALTH=1 FIRE=0 REACTIVITY=0

COMPONENTS AND CONTAMINANTS

COMPONENT: POTASSIUM FERRICYANIDE PERCENT: 100
CAS# 13746-66-2

OTHER CONTAMINANTS: NONE

EXPOSURE LIMITS:
No occupational exposure limits established by OSHA, ACGIH, or NIOSH.

PHYSICAL DATA

DESCRIPTION: Ruby red monoclinic crystals or powder

MELTING POINT: decomposes SPECIFIC GRAVITY: 1.85

SOLUBILITY IN WATER: 33% @ 39 F

SOLVENT SOLUBILITY: Soluble in acetone; slightly soluble in alcohol.

FIRE AND EXPLOSION DATA

FIRE AND EXPLOSION HAZARD:
Negligible fire hazard when exposed to heat or flame.

FIREFIGHTING MEDIA:
Dry chemical, water spray or regular foam
(1993 Emergency Response Guidebook, RSPA P 5800.6).

For larger fires, use water spray, fog or alcohol-resistant foam
(1993 Emergency Response Guidebook, RSPA P 5800.6).

FIREFIGHTING:
Move container from fire area if you can do it without risk. Fight fire from maximum distance. Stay away from ends of tanks. Dike fire-control water for later disposal; do not scatter the material (1993 Emergency Response Guidebook, RSPA P 5800.6, Guide Page 55).

Use agent suitable for type of fire. Do not use water on material. For large fires use water in flooding quantities as fog and spray. Avoid breathing poisonous vapors; keep upwind.

TOXICITY

POTASSIUM FERRICYANIDE:
TOXICITY DATA: 2970 mg/kg oral-mouse LD50; 1600 mg/kg oral-rat LDLo; mutagenic data (RTECS).
CARCINOGEN STATUS: None.
ACUTE TOXICITY LEVEL: Moderately toxic by ingestion.
TARGET EFFECTS: No data available.

HEALTH EFFECTS AND FIRST AID

INHALATION:
POTASSIUM FERRICYANIDE:
ACUTE EXPOSURE- No specific data available. Ferricyanide salts do not readily release cyanide. However, certain industrial processes may release cyanide, which is a chemical asphyxiant.
CHRONIC EXPOSURE- No data available.

FIRST AID- Remove from exposure area to fresh air immediately. Perform artificial respiration if necessary. Maintain airway, blood pressure and respiration. Keep warm and at rest. Treat symptomatically and supportively. Get medical attention immediately. Qualified medical personnel should consider administering oxygen.

SKIN CONTACT:
POTASSIUM FERRICYANIDE:
ACUTE EXPOSURE- No data available, may be irritating.
CHRONIC EXPOSURE- No data available.

FIRST AID- Remove contaminated clothing and shoes immediately. Wash with soap or mild detergent and large amounts of water until no evidence of chemical remains (at least 15-20 minutes). Get medical attention immediately.

EYE CONTACT:
POTASSIUM FERRICYANIDE:
ACUTE EXPOSURE- No data available, may be irritating.
CHRONIC EXPOSURE- No data available.

FIRST AID- Wash eyes immediately with large amounts of water or normal saline, occasionally lifting upper and lower lids, until no evidence of chemical remains (at least 15-20 minutes). Get medical attention immediately.

INGESTION:
POTASSIUM FERRICYANIDE:
ACUTE EXPOSURE- 2970 mg/kg is the lethal dose in mice. Symptoms of poisoning have not been reported. Ingestion of cyanide salts may cause irregular respiration, a sudden loss of consciousness, followed by violent convulsions, paralysis and death from respiratory arrest. There is insufficient data to determine whether cyanide is released from ingestion of ferricyanides.
CHRONIC EXPOSURE- No data available.

FIRST AID- In case of ingestion of large amounts, induce vomiting. Get medical attention. (Deichmann and Gerarde, Toxicology of Drugs and Chemicals)

REACTIVITY

REACTIVITY:
Stable under normal temperatures and pressures in a closed container. Aqueous solutions may decompose on exposure to light.

INCOMPATIBILITIES:
POTASSIUM FERRICYANIDE:
ACIDS: Decomposition with liberation of hydrocyanic acid.
AMMONIA: Possible explosion on contact.
CHROMIUM TRIOXIDE (CHROMIC ANHYDRIDE): Explosion on heating above 196 C.
HYDROCHLORIC ACID: Formation of endothermic complex ferricyanic acid.
SODIUM NITRITE: Formation of explosive compound.

DECOMPOSITION:
Thermal decomposition products may include highly toxic fumes of hydrogen cyanide.

POLYMERIZATION:
Hazardous polymerization has not been reported to occur under normal temperatures and pressures.

STORAGE AND DISPOSAL

Observe all federal, state and local regulations when storing or disposing of this substance.

Storage

Store away from incompatible substances.

POTASSIUM FERROCYANIDE TRIHYDRATE
POTASSIUM FERROCYANIDE TRIHYDRATE
POTASSIUM FERROCYANIDE TRIHYDRATE

MATERIAL SAFETY DATA SHEET

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CHEMICAL DIVISION
1 REAGENT LANE
FAIR LAWN NJ 07410
(201) 796-7100

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SUBSTANCE IDENTIFICATION

CAS-NUMBER 14459-95-1

SUBSTANCE: **POTASSIUM FERROCYANIDE TRIHYDRATE**

TRADE NAMES/SYNONYMS:
YELLOW PRUSSIATE OF POTASH; YELLOW POTASSIUM PRUSSIATE; POTASSIUM HEXACYANOFERRATE II; POTASSIUM HEXACYANOFERRATE(II) TRIHYDRATE; P234; P236; C6H6FeK4N6O3; ACC19389

CHEMICAL FAMILY:
Inorganic salt

MOLECULAR FORMULA: K4-Fe-(CN)6.3H2O

MOLECULAR WEIGHT: 422.39

CERCLA RATINGS (SCALE 0-3): HEALTH=1 FIRE=0 REACTIVITY=0 PERSISTENCE=3
NFPA RATINGS (SCALE 0-4): HEALTH=1 FIRE=0 REACTIVITY=0

COMPONENTS AND CONTAMINANTS

COMPONENT: POTASSIUM FERROCYANIDE TRIHYDRATE PERCENT: 100.0
CAS# 14459-95-1

OTHER CONTAMINANTS: NONE.

EXPOSURE LIMITS:
No occupational exposure limits established by OSHA, ACGIH, or NIOSH.

POTASSIUM FERROCYANIDE:
Subject to SARA Section 313 Annual Toxic Chemical Release Reporting

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PHYSICAL DATA

DESCRIPTION: Lemon yellow, soft, slightly efflorescent crystals, with a mild saline taste. BOILING POINT: decomposes MELTING POINT: 158 F (70 C) -H2O

SPECIFIC GRAVITY: 1.9 SOLUBILITY IN WATER: soluble

SOLVENT SOLUBILITY: Soluble in acetone; insoluble in alcohol, ether, and ammonia.

FIRE AND EXPLOSION DATA

FIRE AND EXPLOSION HAZARD:
Negligible fire hazard when exposed to heat or flame.

FIREFIGHTING MEDIA:
Extinguish using agent suitable for type of surrounding fire.

FIREFIGHTING:
No acute hazard. Move container from fire area if possible. Avoid breathing vapors or dusts; keep upwind.

TOXICITY

POTASSIUM FERROCYANIDE:
TOXICITY DATA:
ANHYDROUS: 6400 mg/kg oral-rat LD50; 5 gm/kg oral-mouse LD50; reproductive effects data (RTECS).
TRIHYDRATE: No data available.
CARCINOGEN STATUS: None.

ACUTE TOXICITY LEVEL: Slightly toxic by ingestion.
TARGET EFFECTS: No data available.

HEALTH EFFECTS AND FIRST AID

INHALATION:
POTASSIUM FERROCYANIDE:
ACUTE EXPOSURE- May cause sore throat and coughing.
CHRONIC EXPOSURE- Reproductive effects have been reported in animals.

FIRST AID- Remove from exposure area to fresh air immediately. Perform artificial respiration if necessary. Keep person warm and at rest. Treat symptomatically and supportively. Get medical attention immediately.

SKIN CONTACT:
POTASSIUM FERROCYANIDE:
ACUTE EXPOSURE- Contact may cause irritation.
CHRONIC EXPOSURE- No data available.

FIRST AID- Remove contaminated clothing and shoes immediately. Wash with soap or mild detergent and large amounts of water until no evidence of chemical remains (at least 15-20 minutes). Get medical attention immediately.

EYE CONTACT:
POTASSIUM FERROCYANIDE:
ACUTE EXPOSURE- Direct contact may cause redness and irritation.
CHRONIC EXPOSURE- No data available.

FIRST AID- Wash eyes immediately with large amounts of water or normal saline, occasionally lifting upper and lower lids, until no evidence of chemical remains (at least 15-20 minutes). Get medical attention immediately.

INGESTION:
POTASSIUM FERROCYANIDE:
ACUTE EXPOSURE- The LD50 in rats was found to be 1600-3200 mg/kg in one study; however, poisoning from oral ingestion seems to have been questionable. The chemical appears to be excreted rapidly without metabolic alteration. The cyanide ion does not appear to be released.
CHRONIC EXPOSURE- No data available.

FIRST AID- If vomiting occurs, keep head lower than hips to help prevent aspiration. Treat symptomatically and supportively. Get medical attention if needed.

ANTIDOTE:
No specific antidote. Treat symptomatically and supportively.

REACTIVITY

REACTIVITY:
Stable under normal temperatures and pressures.

INCOMPATIBILITIES:
POTASSIUM FERROCYANIDE TRIHYDRATE:
ACIDS: Liberates toxic gas.
CHLORATES: Violent explosion.
CUPRIC NITRATE: Fine ground mixture may explode when dried @ 220 C.
NITRATES: Violent explosion.
NITRITES: Violent explosion.
SODIUM NITRITE: Explodes when heated.

DECOMPOSITION:
Thermal decomposition products may include highly toxic fumes of hydrogen cyanide and toxic oxides of carbon and nitrogen.

POLYMERIZATION:
Hazardous polymerization has not been reported to occur under normal temperatures and pressures.

STORAGE AND DISPOSAL

Observe all federal, state and local regulations when storing or disposing of this substance.

Storage

Store at room temperature in a tightly closed container.

Store away from incompatible substances.

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CONDITIONS TO AVOID

No reports found.

POTASSIUM CHLORIDE
POTASSIUM CHLORIDE
POTASSIUM CHLORIDE

MATERIAL SAFETY DATA SHEET

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CHEMICAL DIVISION
1 REAGENT LANE
FAIR LAWN NJ 07410
(201) 796-7100

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SUBSTANCE IDENTIFICATION

CAS-NUMBER 7447-40-7

SUBSTANCE: **POTASSIUM CHLORIDE**

TRADE NAMES/SYNONYMS:
POTASSIUM CHLORIDE (KCL); CHLOROPOTASSURIL; ENSEAL; KALITABS; KAON-CL; KLOTRIX; NEOBAKASAL; POTASSIUM MONOCHLORIDE; POTAVESCENT; REKAWAN; SLOW K; SUPER K; SUPER K (SALT); POTASSIUM MURIATE; KALEORID; PFIKLOR; SPAN-K; P-217; P-330; BP366; CLK; ACC19310

CHEMICAL FAMILY:
Inorganic salt

MOLECULAR FORMULA: K-CL

MOLECULAR WEIGHT: 74.56

CERCLA RATINGS (SCALE 0-3): HEALTH=3 FIRE=0 REACTIVITY=0 PERSISTENCE=0
NFPA RATINGS (SCALE 0-4): HEALTH=1 FIRE=0 REACTIVITY=0

COMPONENTS AND CONTAMINANTS

COMPONENT: POTASSIUM CHLORIDE PERCENT: 100
CAS# 7447-40-7

OTHER CONTAMINANTS: NONE

EXPOSURE LIMITS:
No occupational exposure limits established by OSHA, ACGIH, or NIOSH.

PHYSICAL DATA

DESCRIPTION: Odorless, colorless to white crystals or granular powder with a strong saline taste. BOILING POINT: 2732 F (1500 C) sublimes

MELTING POINT: 1418 F (770 C) SPECIFIC GRAVITY: 1.984

PH: 5.4-8.6 @ 5% soln SOLUBILITY IN WATER: 23.8% @ 20 C

SOLVENT SOLUBILITY: Soluble in glycerol, alkalies, ether; slightly soluble in alcohol; insoluble in acetone.

FIRE AND EXPLOSION DATA

FIRE AND EXPLOSION HAZARD:
Negligible fire hazard when exposed to heat or flame.

FIREFIGHTING MEDIA:
Dry chemical, carbon dioxide, water spray or foam

For larger fires, use water spray, fog or alcohol foam

FIREFIGHTING:
No acute hazard. Move container from fire area if possible. Avoid breathing vapors or dusts; keep upwind.

TOXICITY

POTASSIUM CHLORIDE:
IRRITATION DATA: 500 mg/24 hours eye-rabbit mild.
TOXICITY DATA: 938 mg/kg/2 days oral-infant LDLo; 60 mg/kg/day oral-woman TDLo; 20[illegible] oral-man LDLo; 2800 mg/kg oral-rat LDS0; 1500 mg/kg

oral-mouse LD50; 2500 mg/kg oral-guinea pig LD50; 2550 mg/kg subcutaneous-guinea pig LDLo; 142 mg/kg intravenous-rat LD50; 117 mg/kg intravenous-mouse LD50; 77 mg/kg intravenous-guinea pig LDLo; 660 mg/kg intraperitoneal-rat LD50; 1181 mg/kg intraperitoneal-mouse LD50; 900 mg/kg intraperitoneal-guinea pig LDLo; 130 mg/kg intraarterial-guinea pig LDLo; 40 mg/kg parenteral-guinea pig LDLo; mutagenic data (RTECS).
CARCINOGEN STATUS: None.
ACUTE TOXICITY LEVEL: Moderately toxic by ingestion.
TARGET EFFECTS: Poisoning may affect the potassium level with resultant disturbances in the heart rhythm.
AT INCREASED RISK FROM EXPOSURE: Persons with renal, cardiac, pancreatic and adrenal insufficiencies; persons with esophageal, pyloric or duodenal stenosis.
ADDITIONAL DATA: Interactions with medications have been reported.

HEALTH EFFECTS AND FIRST AID

INHALATION:
POTASSIUM CHLORIDE:
ACUTE EXPOSURE- May cause irritation.
CHRONIC EXPOSURE- Inhalation in potassium mines and plants has been reported to result in lesions of the nasal septum due to potassium chloride.

FIRST AID- Remove from exposure area to fresh air immediately. Perform artificial respiration if necessary. Keep person warm and at rest. Treat symptomatically and supportively. Get medical attention immediately.

SKIN CONTACT:
POTASSIUM CHLORIDE:
ACUTE EXPOSURE- May cause slight irritation.
CHRONIC EXPOSURE- No data available.

FIRST AID- Remove contaminated clothing and shoes immediately. Wash with soap or mild detergent and large amounts of water until no evidence of chemical remains (at least 15-20 minutes). Get medical attention immediately.

EYE CONTACT:
POTASSIUM CHLORIDE:
ACUTE EXPOSURE- May cause irritation. Tested in rabbit eyes, application of 500 mg for 24 hours resulted in mild irritation. Concentrated solutions may cause a stinging sensation.
CHRONIC EXPOSURE- No data available.

FIRST AID- Wash eyes immediately with large amounts of water or normal saline, occasionally lifting upper and lower lids, until no evidence of chemical remains (at least 15-20 minutes). Get medical attention immediately.

INGESTION:
POTASSIUM CHLORIDE:
ACUTE EXPOSURE- May cause gastrointestinal irritation with nausea, vomiting, epigastric distress, abdominal discomfort, and diarrhea. High local concentrations in the gastrointestinal tract may cause esophageal ulceration, if there is dysphagia; gastric ulceration, especially if gastric emptying is delayed; and ulceration, obstruction, hemorrhaging and perforation of the small bowel. Acute intoxications orally are uncommon since large doses usually induce vomiting and normally functioning kidneys excrete potassium rapidly. However, if an overdose results in hyperkalemia there may be paresthesias, anesthesias, generalized weakness, hyporeflexia, flaccid paralysis, listlessness, apprehension, vertigo, mental confusion, hypotension, slow, weak pulse, cardiac arrhythmias, heart block, and possible death. Animals poisoned by potassium salts died from respiratory failure sometimes following convulsions and accompanied by gastroenteritis, dehydration of organs and early renal tubular necrosis. Survivors had anorexia, polydipsia, polyuria, fever, convulsive movements and gastrointestinal disturbances during the first 24 hours, but recovered rapidly.
CHRONIC EXPOSURE- Repeated and prolonged ingestion of excessive amounts may cause symptoms as in acute exposure. Skin rashes have been reported rarely.

FIRST AID- If vomiting occurs, keep head lower than hips to help prevent aspiration. Treat symptomatically and supportively. Get medical attention if needed.

ANTIDOTE:
No specific antidote. Treat symptomatically and supportively.

REACTIVITY

REACTIVITY:
Stable under normal temperatures and pressures.

INCOMPATIBILITIES:
POTASSIUM CHLORIDE:
ACIDS (STRONG): May release toxic chloride gases.
BROMINE TRIFLUORIDE: May react violently.
STEEL: May be corrosive when wet.

CHEMetrics, Inc.
Route 28, Calverton, VA 20138
(800) 356-3072 (540) 788-9026
Fax (540) 788-4856 - Telex 292-861 CHEM UR

24 Hour Emergency Numbers: (703) 590-9204
(540) 439-3860
Creation Date: 05/29/87 (1176-6)
Revision Date: 03/28/95

MATERIAL SAFETY DATA SHEET

I. TRADE NAME: CARBON DIOXIDE ACTIVATOR SOLUTION

CATALOG NO.: A-1900

DESCRIPTION: An accessory solution used in conjunction with reagent ampoules in the determination of carbon dioxide in water. Each bottle contains approximately 5 mL of accessory solution.

NFPA RATINGS: HEALTH: 1 FLAMMABILITY: 3 REACTIVITY: 0

II. COMPONENTS

COMPONENT: Phenolphthalein
CAS NO.: 77-09-8 PERCENT: < 2.0

COMPONENT: Methanol
CAS NO.: 67-56-1 PERCENT: < 3.5

COMPONENT: Deionized Water
CAS NO.: 7732-18-5 PERCENT: <36.0

COMPONENT: Ethyl Alcohol, Denatured
CAS NO.: 64-17-5 PERCENT: 61.0

III. PHYSICAL DATA

STATE: Liquid APPEARANCE: Colorless ODOR: Ethanol-like
SOLUBILITY IN WATER: Miscible
BOILING POINT: 88°C MELTING POINT: -68°C
VAPOR PRESSURE: Not determined SPECIFIC GRAVITY: 0.88
VAPOR DENSITY: Not determined

IV. FIRE AND EXPLOSION DATA

FLASH POINT: 57°F, closed cup (Ethyl Alcohol, Denatured)
AUTOIGNITION POINT: N/A (Ethyl Alcohol, Denatured)
FLAMMABILITY LIMITS (Ethyl Alcohol, Denatured):
UPPER: 19% LOWER: 4.3%
EXTINGUISHING MEDIA: Dry chemical, carbon dioxide, water spray or alcohol foam

V. REACTIVITY DATA

HAZARDOUS DECOMPOSITION PRODUCTS: Combustion may release toxic oxides of carbon.

VI. HEALTH HAZARD DATA

OSHA & ACGIH THRESHOLD LIMIT VALUE: 1000 ppm Ethyl Alcohol, Denatured
ACUTE TOXICITY: Central nervous system depressant
CHRONIC TOXICITY: Eye and respiratory tract irritant; sensitization dermatitis.
CARCINOGEN STATUS: None
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: May cause irritation to eyes, skin and mucous membranes. May cause dermatitis, conjunctivitis, headache, nausea and dizziness.

VII. FIRST AID

EYE AND SKIN CONTACT: Immediately flush eyes and skin with water for 15 minutes.

INGESTION: Seek medical attention.

INHALATION: Remove individual to fresh air.

VIII. PRECAUTIONS

If this product is used as directed, the user will not come in contact with or be exposed to any of its chemical components.
Wash thoroughly after handling.
Avoid contact with eyes.
PROTECTIVE EQUIPMENT: Safety glasses

IX. SPILL AND DISPOSAL PROCEDURES

Take up with absorbent material. Place in small containers for disposal. Dispose of in accordance with all Federal, State and Local Regulations.

X. STORAGE CONDITIONS

Product should be stored in the dark and at room temperature; however, temperatures up to 120°F or even below freezing will not normally affect reagent performance.

THE ABOVE INFORMATION IS BELIEVED TO BE ACCURATE AND REPRESENTS THE BEST INFORMATION CURRENTLY AVAILABLE TO US. ALL PRODUCTS ARE OFFERED IN ACCORDANCE WITH THE MANUFACTURER'S CURRENT PRODUCTION SPECIFICATIONS AND ARE INTENDED SOLELY FOR USE IN ANALYTICAL TESTING. THE MANUFACTURER SHALL IN NO EVENT BE LIABLE FOR ANY INJURY, LOSS OR DAMAGE RESULTING FROM THE HANDLING, USE OR MISUSE OF THESE PRODUCTS.

CHEMetrics, Inc.
Route 28, Calverton, VA 20138
(800) 356-3072 (540) 788-9026
Fax (540) 788-4856 - Telex 292-861 CHEM UR

24 Hour Emergency Numbers: (703) 590-9204
(540) 439-3860
Creation Date: 03/10/87 (1181-6)
Revision Date: 03/28/95

MATERIAL SAFETY DATA SHEET

I. TRADE NAME: CARBON DIOXIDE NEUTRALIZER SOLUTION

CATALOG NOS.: A-1905, A-1910 and A-1925

DESCRIPTION: An accessory solution used in conjunction with reagent ampoules in the determination of carbon dioxide in water. Each bottle contains approximately 10 mL of accessory solution.

NFPA RATINGS: HEALTH: 3 FLAMMABILITY: 0 REACTIVITY: 0

II. COMPONENTS

COMPONENT: Hydrochloric Acid
CAS NO.: 7647-01-0 PERCENT: < 3.0

COMPONENT: Deionized Water
CAS NO.: 7732-18-5 PERCENT: >97.0

III. PHYSICAL DATA

STATE: Liquid APPEARANCE: Colorless ODOR: None
SOLUBILITY IN WATER: Complete pH: 2.2
BOILING POINT: 100°C MELTING POINT: 0°C
VAPOR PRESSURE: 14 mm Hg @ 20°C (H_2O) SPECIFIC GRAVITY: 1.2
VAPOR DENSITY: 0.7 (H_2O)

IV. FIRE AND EXPLOSION DATA

FLASH POINT: N/A AUTOIGNITION POINT: N/A
FLAMMABILITY LIMITS: UPPER: N/A LOWER: N/A
EXTINGUISHING MEDIA: Dry chemical, carbon dioxide, water spray or regular foam

V. REACTIVITY DATA

HAZARDOUS DECOMPOSITION PRODUCTS: Heating may release corrosive hydrogen chloride.

VI. HEALTH HAZARD DATA

OSHA & ACGIH THRESHOLD LIMIT VALUE: None established
ACUTE TOXICITY: Irritation
CHRONIC TOXICITY: Irritation and sensitization dermatitis
CARCINOGEN STATUS: None
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: May cause irritation to eyes, skin and mucous membranes. May cause dermatitis, conjunctivitis, burns and teeth erosion.

VII. FIRST AID

EYE AND SKIN CONTACT: Immediately flush eyes and skin with water for 15 minutes.

INGESTION: Seek medical attention.

INHALATION: Remove individual to fresh air.

VIII. PRECAUTIONS

If this product is used as directed, the user will not come in contact with or be exposed to any of its chemical components.
Wash thoroughly after handling.
Avoid contact with eyes.
PROTECTIVE EQUIPMENT: Safety glasses

IX. SPILL AND DISPOSAL PROCEDURES

Take up with absorbent material. Place in small containers for disposal. Dispose of in accordance with all Federal, State and Local Regulations.

X. STORAGE CONDITIONS

Product should be stored in the dark and at room temperature; however, temperatures up to 120°F or even below freezing will not normally affect reagent performance.

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(800) 356-3072 (540) 788-9026
(540) 788-4856 - Telex 292-861 CHEM UR

24 Hour Emergency Numbers: (703) 590-9204
(540) 439-3860

Creation Date: 03/03/89 (1134-6)
Revision Date: 03/27/95

MATERIAL SAFETY DATA SHEET

I. TRADE NAME: CARBOND DIOXIDE Titrets®

CATALOG NOS.: K-1910, K-1920, K-1925, R-1910, R-1920 and R-1925

DESCRIPTION: Reagent ampoules for the titrimetric determination of carbon dioxide in water. Each ampoule contains approximately 1 mL of liquid reagent sealed under vacuum.

NFPA RATINGS: HEALTH: 1 FLAMMABILITY: 0 REACTIVITY: 0

II. COMPONENTS

COMPONENT: Sodium Hydroxide
CAS NO.: 1310-73-2 PERCENT: < 1.0

COMPONENT: Deionized Water
CAS NO.: 7732-18-5 PERCENT: >99.0

III. PHYSICAL DATA

STATE: Liquid APPEARANCE: colorless ODOR: None
SOLUBILITY IN WATER: Complete pH: 11 - 12
BOILING POINT: 100°C MELTING POINT: 0°C
VAPOR PRESSURE: N/A SPECIFIC GRAVITY: 1.0
VAPOR DENSITY: N/A

IV. FIRE AND EXPLOSION DATA

FLASH POINT: N/A AUTOIGNITION POINT: N/A
FLAMMABILITY LIMITS: UPPER: N/A LOWER: N/A
EXTINGUISHING MEDIA: Water, dry chemical, foam or carbon dioxide

V. REACTIVITY DATA

HAZARDOUS DECOMPOSITION PRODUCTS: None

VI. HEALTH HAZARD DATA

OSHA & ACGIH THRESHOLD LIMIT VALUE: None established
ACUTE TOXICITY: None known
CHRONIC TOXICITY: None known
CARCINOGEN STATUS: None
MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: May cause eye, skin and mucous membrane irritation.

VII. FIRST AID

EYE AND SKIN CONTACT: Immediately flush eyes and skin with water for 15 minutes.

INGESTION: Seek medical attention.

INHALATION: Remove individual to fresh air.

VIII. PRECAUTIONS

If this product is used as directed, the user will not come in contact with or be exposed to any of its chemical components.
Wash thoroughly after handling.
Avoid contact with eyes.
FRAGILE: Liquid in glass. Handle with care.
PROTECTIVE EQUIPMENT: Safety glasses

IX. SPILL AND DISPOSAL PROCEDURES

Take up with absorbent material. Place in small containers for disposal. Dispose of in accordance with all Federal, State and Local Regulations.

X. STORAGE CONDITIONS

Product should be stored in the dark and at room temperature; however, temperatures up to 120°F or even below freezing will not normally affect reagent performance.

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APPENDIX F

MCCLELLAN AFB QAPP APPLICABILITY CHECKLIST AND APPLICABILITY STATEMENT

QUALITY ASSURANCE PROJECT PLAN
APPLICABILITY STATEMENT

The McClellan AFB Quality Assurance Project Plan (QAPP) Revision 3, dated April 97 (Revision Date) is sufficient for project quality control during performance of the work specified in the attached field sampling plan, which is:

Titled: Final Work Implementation Plan for a Demonstration of Intrinsic Remediation at ICs 17/19/21

Dated: October 1997

The attached QAPP Applicability Checklist designates the applicable sections and SOPs of the QAPP.

Michael B. Phelps — Supplier Program Manager

Fred Stanin — Supplier Quality Assurance Officer

9/30/97 — Date

APPLICABILITY CHECKLIST

		Applicable	NA
1.0	INTRODUCTION	☒	☐
1.1	QAPP Objectives and Use	☒	☐
1.2	Administrative Procedures	☒	☐
2.0	SITE DESCRIPTION AND HISTORY	☒	☐
2.1	Site History	☒	☐
2.2	Types of Contaminants Reported	☒	☐
3.0	PROGRAM ORGANIZATION AND RESPONSIBILITIES	☒	☐
3.1	Air Force, U.S. EPA, and Cal/EPA	☒	☐
3.2	Supplier Project Organization	☒	☐
4.0	DATA QUALITY OBJECTIVES AND QUALITY ASSURANCE OBJECTIVES	☒	☐
4.1	DQOs and Data Use Planning	☒	☐
4.2	Quality Assurance Objectives	☒	☐
4.3	Geologic Data Quality Assurance Objectives	☒	☐
4.4	Hydrologic Data Quality Assurance Objectives	☒	☐
5.0	FIELD PROCEDURES	☒	☐
5.1	Site Selection	☒	☐
5.2	General Field and Sampling Requirements	☒	☐
5.3	Geophysical Procedures	☐	☒
5.4	Drilling	☒	☐
5.5	Well Installation	☒	☐
5.6	Aquifer and Air Permeability Test Methods	☐	☒
5.7	Cone Penetrometer Procedures	☐	☒
5.8	Groundwater Sampling	☒	☐
5.9	Surface Water Sampling	☐	☒
5.10	Sediment Sampling	☐	☒
5.11	Soil Sampling	☐	☒
5.12	Soil Gas Sampling	☐	☒
5.13	Emission Flux Measurements	☐	☒
5.14	Trenching	☐	☒

6.0	SAMPLE CUSTODY		☒	☐
	6.1	Documentation and Custody Procedures	☒	☐
	6.2	Chain-of-Custody Forms and Master Log	☒	☐
	6.3	Sample Shipment and Handling	☒	☐
	6.4	Laboratory Custody Procedures	☒	☐
7.0	FIELD INSTRUMENT CALIBRATION PROCEDURES		☒	☐
	7.1	Water Sampling Instrument Calibration	☒	☐
	7.2	Real-Time Organic Vapor Monitoring Instrument Calibration	☒	☐
	7.3	Radiation Meter Calibration	☐	☒
	7.4	Canister Flow Controller Calibration	☐	☒
	7.5	Flowmeter Calibration	☐	☒
8.0	ANALYTICAL PROCEDURES AND CALIBRATION		☒	☐
	8.1	Detection and Quantitation Limits	☒	☐
	8.2	Laboratory Standards and Reagents	☒	☐
	8.3	Sample Preparation Procedures	☒	☐
	8.4	Inorganic and Radiochemical Analytical Methods	☒	☐
	8.5	Organic Analytical Methods	☒	☐
	8.6	Air/Soil Gas Analytical Methods	☐	☒
	8.7	Field Methods	☒	☐
9.0	DATA REDUCTION, VALIDATION, AND REPORTING		☒	☐
	9.1	Laboratory Data Reduction and Verification	☒	☐
	9.2	Project Data Flow, Transfer, and Verification	☒	☐
	9.3	Project Data Review and Validation	☒	☐
	9.4	Reporting	☒	☐
10.0	INTERNAL QUALITY CONTROL		☒	☐
	10.1	Off-Site Analytical Laboratory QC Samples	☒	☐
	10.2	On-Site Analytical laboratory QC Samples	☒	☐
	10.3	Field QC Samples	☒	☐
11.0	AUDITS AND DATA VALIDATION		☐	☐
	11.1	Technical Systems Audits	☒	☐
	11.2	Performance Audits	☐	☒
	11.3	Data Validation	☐	☒
	11.4	Recommended Audit Frequency	☒	☐

12.0	PREVENTIVE MAINTENANCE	☒	☐
13.0	DATA ASSESSMENT PROCEDURES	☒	☐
	13.1 Blank Data Assessment	☒	☐
	13.2 Accuracy	☒	☐
	13.3 Precision	☒	☐
	13.4 Completeness	☒	☐
	13.5 Interlaboratory Data Comparison	☐	☒
	13.6 Field and Off-Site Laboratory Data Comparison	☐	☒
14.0	CORRECTIVE ACTION	☒	☐
15.0	QUALITY ASSURANCE REPORTS	☒	☐
16.0	SITE MANAGEMENT	☒	☐

STANDARD OPERATING PROCEDURES

McAFB-001	SOP Format and Content	☒	☐
McAFB-042	General Field Operations	☒	☐
McAFB-002	Conducting Magnetic and Electromagnetic Surveys (Surface)	☐	☒
McAFB-003	Downhole Geophysical Surveys	☐	☒
McAFB-004	Drilling Operations, Well Installation, Well Completion, Well Development, and Borehole Abandonment Procedures	☒	☐
McAFB-041	Well Maintenance Procedures	☒	☐
McAFB-005	Cone Penetrometer Testing	☐	☒
McAFB-006	Installation of Soil Vapor Extraction Wells and Piezometer Nests	☐	☒
McAFB-007	Sampling of Perched Water and Installation of Conductor Casing HSA Borings in Perched Water Conditions	☐	☒
McAFB-008	Identifying and Taking Action for Non-Aqueous Phase Liquids During Subsurface Drilling	☒	☐
McAFB-009	Use of the Soil Moisture Quickdraw Tensiometer	☐	☒
McAFB-010	Aquifer Testing - Pumping and Slug Tests	☐	☒
McAFB-043	Step-Drawdown Test	☐	☒
McAFB-011	Air Permeability Testing	☐	☒
McAFB-012	Trenching	☐	☒
McAFB-013	Sampling Groundwater from Monitoring and Extraction Wells	☒	☐
McAFB-014	Sampling Groundwater with HydroPunch® I and II Samplers	☐	☒

McAFB-015	Collection of Sediment Samples in Ponds, Surface Impoundments, and Streambeds	☐	☒
McAFB-032	Surface Water Sampling	☐	☒
McAFB-016	Collection of Surface and Subsurface Soil Samples	☒	☐
McAFB-017	Soil Gas Sampling	☐	☒
McAFB-018	Surface Emission Flux Sampling	☐	☒
McAFB-019	Downhole Emission Flux Sampling	☐	☒
McAFB-034	Surface and Subsurface Field Screening for Low Level Radioactive Contamination	☐	☒
McAFB-020	Field Instrument: Photoionization Detector (PID) Calibration and Operation	☒	☐
McAFB-021	Field Instrument: Flame Ionization Detector (FID) Calibration and Operation	☐	☒
McAFB-023	Ensys Inc. Immunoassay Test Kit Procedures for PCBs and Petroleum Fuels	☐	☒
McAFB-024	Field Instrument: Calibration and Operation of Water Sampling Field Instruments	☒	☐
McAFB-033	Air Sampling Flow Controller Calibration	☐	☒
McAFB-038	Radiation Detection Instrument General Operation and Performance Check	☐	☒
McAFB-025	MTI Microchip GC	☐	☒
McAFB-026	Methanol Preservation Procedures for VOCs in Soil	☐	☒
McAFB-027	Field Soil Gas Analysis Using GC with PID and ECD	☐	☒
McAFB-028	Data Review Procedures	☒	☐
McAFB-029	Data Validation Standard Operating Procedure	☐	☒
McAFB-030	Data Exchange Protocol	☒	☐
McAFB-031	Prefractionator Method for Vinyl Chloride Analysis	☐	☒
McAFB-035	Sample Preparation and Analysis for Radium-228 Activity in Aqueous Samples	☐	☒
McAFB-036	Sample Preparation and Analysis for Tritium in Aqueous Solutions	☐	☒
McAFB-037	Sample Preparation and Analysis for Radioactive Strontium in Aqueous Samples	☐	☒
McAFB-039	Total Digestion of Soil, Sludges, Ashed Vegetation, and Air Filters for Radiochemical Analysis	☐	☒
McAFB-040	Actinide Sample Preparation, Nuclide Separation and Analysis	☐	☒
McAFB-044	Sample Preparation and Analysis for Gamma Activity in Solids	☐	☒

APPENDIX G

RESPONSE TO DRAFT WIP COMMENTS

DRAFT WORK IMPLEMENTATION PLAN
COMMENT/RESPONSE TABLE

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
General			RWQCB /1	In general, we agree that IC 19 is a good candidate at McClellan AFB for the study of biodegradation of VOCs. The site conditions and wastes disposed at IC 19 provide conditions which support biodegradation of VOCs in both the vadose zone and groundwater.	No response required.
General			RWQCB /2	We do not believe that it is appropriate to call this proposal as looking at "natural" biodegradation. The conditions that allow for the biodegradation processes to occur have been largely determined by the manmade conditions at the site. If the wastes containing VOCs had not been co-disposed with readily biodegradable wastes such as fuels and municipal wastes, then it is likely that the reductive dehalogenation of the VOCs would not be taking place to the degree observed at IC 19. One need only look at other sites at McClellan at which co-disposal has or has not occurred and see that parent compounds such as TCE, PCE, and 1,1,1-TCA have or have not been changed to their daughter compounds. I would not define the processes that are occurring to be the "natural" biodegradation of the VOCs.	Section 1 and Section 3 were modified to include a definition of "natural" biodegradation and the word "natural" was eliminated as a modifier for biodegradation.
General			RWQCB /3	This proposal is attempting to determine if there is sufficient biodegradation of VOCs in the groundwater so that no additional remediation will be needed. It is not clear at this time if the reductive dehalogenation and cometabolic degradation is occurring primarily in the vadose zone or the groundwater. This study may want to make some evaluation of the degradation that is occurring in the vadose zone and if enhancements of the degradation are warranted. For example, the daughter products can potentially be cometabolically degraded in an aerobic zone in the presence of methane. Once some of the VOCs have migrated from the anaerobic zone to the aerobic zone, the cometabolic process could proceed if sufficient oxygen is present	Additional discussion of this topic was added to Sec. 4.4.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
General			RWQCB /4	We do not agree with calling this process a "technology," especially if there will be no modifications to the existing system. Nothing is being applied in this case. The term technology is used many times throughout the document (See page 3-7, Section 3.2, which refers to "intrinsic remediation is a technology ...").	Section 3 now defines the use of the word "technology" as it applies to this demonstration study and preference for the use of the words "strategy" and "approach" were given in the document.
3.3.1	3-9	5	RWQCB /5	Groundwater is a considered a receptor, not just a potential receptor.	Text was revised accordingly.
3.3.1	3-9	5 and 6	RWQCB /6	The authors of the document do not present an accurate picture of State Water Resources Control Board Resolution No. 68-16, Statement of Policy with Respect to Maintaining High Quality of Waters in California. It is recommended that the discussion be eliminated since it does not add any benefit to the proposal.	The subject discussion was deleted.
4.2	4-1	4	RWQCB /7	Objective 2. In situ biodegradation of wastes in place has been allowed for many years on a site-specific basis. The authors tend to paint a poor description of the regulatory community. The regulatory community receiving this document has already determined that the processes being studied are viable. Therefore, our approval of the WIP does not increase regulatory acceptance as we have approved similar proposals in the past.	Objective 2 was eliminated.
4.2	4-2	1	RWQCB /8	The way this paragraph is written, it appears that the authors are prejudging the results by assuming that they will show intrinsic remediation is sufficient at this site. As stated, success is achieved only if the studied processes are shown to work at IC 19. This study should be to determine if intrinsic remediation is viable at IC 19, and if not, why it is not. Success of the demonstration is whether sufficient information is developed to make that determination one way or the other.	Text was revised to address comment

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
4.4.1			RWQCB / 9	The models to be used should be specifically stated. In addition, the VAPOURT model does not allow for any vadose zone biodegradation of the VOC concentrations. Mass loadings for individual VOCs at IC 19 may vary from the modeled amounts. This section should also provide a table for the necessary data needed for the models to be used and a listing of where that data will be obtained.	Section 4 has been extensively revised to address this comment. A table of model input parameters was been added to Section 4.
4.4.3			RWQCB /10	This section discusses the development of long-term monitoring and compliance plan. However, the schedule does not include this development and submittal.	Discussion was added to Section 4 stating that the plan would be submitted as a section of the results report.
7.0	7-1	1	RWQCB /11	Sampling Plan. This SAP refers to two non-site specific protocols and SOPs which the readers do not have. Following the requirements of the QAPP for McClellan AFB is required. If there are other protocols that will be followed that are not found in the McClellan QAPP, then they should be provided.	The WIP was revised to thoroughly reference appropriate protocols from the Basewide QAPP. Protocols not contained in the Basewide QAPP were added in an Appendix.
7.2	7-2	3	RWQCB /12	Sampling Parameters. We recommend including sampling and analysis for BOD and COD, dissolved organic carbon, volatile fatty acids (acetic and propionic acid), total phosphorus, and biomass (by [phospholipid] fatty acid analysis).	These analytes were added to the sampling protocol and are included in Table 7-1.
7	7-3	Table 7.1	RWQCB /13	This table contains both a site-specific method detection limit and a groundwater reporting limit. First, what is a "groundwater reporting limit"? Second, the quantitation limit should be at or below any regulatory limit for a given VOC. As an example, the MCL for vinyl chloride is 0.5 µg/L and the table has a reporting limit of 1.1 µg/L. Past quantitation levels at McClellan have been below 0.5 for most VOCs.	Table 7-1 was revised to reflect the Basewide QAPP quantitation limits.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
8.0			RWQCB /14	QAPP. Any sections that are utilized from the Program Sampling and Analysis Plan for Risk-Based Remediation Demonstrations (ES, 1996) should be provided in this document as an appendix.	The WIP was revised to reference appropriate protocols from the Basewide QAPP. Protocols not contained in the Basewide QAPP are included in an Appendix.
1.1	1-1	1	Base /1	Here and throughout the document, please refer to the area of concern as the Northern OU C Hot Spot or as IC 17/19/21. While this distinction is made in the text, it could potentially be confusing to the reader. This will also require the document title to be revised.	The document has been retitled and the study area is referred to as ICs 17/19/21.
1.1	1-1	1	Base /2	Delete "state of the art."	Phrase was deleted.
1.1	1-1	2	Base /3	Reword this sentence. Long-term monitoring is required to demonstrate that the process is still working. Exposure controls are needed to keep people from extracting water from the plume for use.	Text was revised accordingly
1.1	1-1	3	Base /4	Delete first sentence; does not add to the discussion.	This sentence was deleted.
1.2	1-2	3	Base /5	The first sentence should be revised to state that the IROD requires that McClellan AFB continue to investigate and evaluate potential remedial solutions. This will allow a better flow between ideas in this paragraph. Also the reference to future IRODs should be deleted.	Text was revised accordingly.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
1.2	1-2	3	Base /6	If this document is going to refer to the natural attenuation process as a technology, then it would be helpful to specify why it is a "technology" i.e., a manner of accomplishing a task especially using technical processes, methods, or knowledge (Webster Dictionary).	The word "technology" is now defined and an explanation of why the word "technology" is used has been added.
2.1.1	2-1	2	Base /7	Reword. McClellan AFB is on the BRAC closure list. It is appropriate to speak of the historic mission, recent mission, and future of the program	Text was revised accordingly
2.1.1	2-3	1	Base /8	Information is incorrect. There are 6 groundwater extraction systems on base with 5 treatment systems. The GWTP is only one of these systems	Paragraph was revised accordingly.
2.1.1	2-3	2	Base /9	McClellan uses more than CS and PRL to designate sites	A more complete description of IRP descriptors was added to text.
2.1.2	2-3	3	Base /10	You should note that although the source of contamination is in IC 17/19/21 that this demonstration is being conducted in the GWOU	Text was revised accordingly.
2.2	2-4	Figure 2.2	Base /11	Figure 2.2 should show the location of the study area	Study area was included on Figure 2-2.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
2.1.2 through 2.1.4		Figures 2.3 through 2.14	Base /12-16	A better quality reproduction of Figure 2.3 is needed. Also, data from a more recent source would be appropriate (e.g., Phase 2 RICS). Suggest using either a color map or quality gray scale map. Figure 2.4 should be more specific to the area of the study. The figure needs to be of better quality. Note that the cross section provided is of OU B and OU C. The information provided in the Working Copy of the Phase 2 RICS for the study area was not incorporated into this document. The site specific information should be updated accordingly. Figures 2.5, 2.6, 2.7. The quality of these figures is poor. Either a high-quality gray scale reproduction of the color original or a color original should be included. Also, the revised conceptual models presented in the more recent RICS document should be used. Figures 2.9-2.14. The information presented in these figures is dated. More recent information should be used. It would be helpful to use higher quality originals to improve the photocopy.	Better quality reproductions have been included. Text and figures reflect 1997 Phase 2 RICS. Figure 2-4 was revised to indicate that the cross section includes both OU B and OU C.
	2-22	Table 2.1	Base /17	Table 2.1 should contain references to the type of sample, and date sample was taken	The information was added to the table.
General			Base /18	All pages should be numbered.	All pages, including figure and table pages, have been numbered.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
General			Base /19	Throughout the document the intrinsic remediation process is not consistently referred to. In places it's a management strategy in others it's a technology. Please be consistent.	See response to RWQCB comment 4.
3.3.1	3-8		Base /20 - 23	Bullet 1 - This advantage is based upon the biodegradation going to "completion"; since this is not always the case consider qualifying this statement. Bullet 2 - This statement is misleading. Reword. There are other technologies besides pump and treat. These technologies are effective at removing contaminants from the aquifer. etc. Bullet 3 - reword second statement. I believe our intent is to say that this process does not interfere with above ground operations. Bullet 4 - this statement, while true, is misleading. the opposite is also true in that engineered solutions are more protective of human health as they can ensure long-term source reduction.	Sect. 3.3 was revised accordingly.
3.3.1	3-8	4	Base /20 - 23	Delete this paragraph. The remaining discussion needs to be revised. This should provide a clear and succinct discussion on the benefits of the technology in general. The reader should be allowed to conclude as to how they can benefit from the technology. Limitations discussion needs to be succinct The technical limitations discussion needs to be expanded. Regulatory issues should be discussed secondary to the technical limitations where appropriate. Regulatory acceptance and the requirements for assuring compliance, while important, should be listed following technical limitations.	The text has been revised accordingly.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
3.4	3-10	2	Base /24	In the developmental status section, references should be added to site specific information. The discussion should be limited to sites with chlorinated compounds present. If a claim of "no further action" is made, reference the appropriate ROD or report	The site references have been limited to those with CAHs and a table has been added to Section 3 which includes appropriate sites and references.
4.2	4-1		Base /25-27	Section 4 Objectives: Objective 3 should be listed as the primary objective for this demonstration. The other two objectives should remain in the same relative order. The success criteria for objectives 1 and 2 are inappropriate. Acceptance of the final report and LTM plan along with the final AFCEE guidance seems more appropriate to fulfill objectives 1 and 2.	Sect. 4.2 was revised to incorporate these comments.
4.2	4-2	1	Base /25-27	Reword. See comment above.	
4.3	4-2		Base /28	The test plan, at a minimum, needs to present a summary of the actions needed to accomplish the stated objectives. It is appropriate to reference the reader to appropriate sections of the document where further details are presented	Sect. 4.3 was revised accordingly.
4.4	4-2		Base /29	This section should contain information on the types of statistical analyses to be performed on the data as well as the interpretation of the data for use to meet the objectives.	Section 4.4 was extensively revised to include a discussion of data needs, data sources, and sensitivity and uncertainty analyses.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
4.4	4-2		Base /30 & 31	Fate & Transport Modeling. The current discussion on modeling is only sufficient as a lead in to actual choice of groundwater model(s) to be used. It is necessary to either choose the model that will be used or to narrow the potential model to 1-2 choices and provide specific and detailed instructions for the choice of the final model to be used. Once the model is chosen a discussion on the data needs to support this model should be discussed. Also, a generic discussion on how you plan to do model calibration and validation would be helpful. You should also mention that modeling will be done accounting for biodegradation and w/o biodegradation. The work plan should also address the known upcoming source removal action (SVE) that will occur at IC 19. This will have implications on modeling, and long term compliance sampling.	Section 4.4 was extensively revised to clearly define the models to be used and the modeling approach.
1.2	1-2	3	Base /32	Section 4.3.2 does not address how you will account for second order degradation within the conceptual model. In that will you apply an analytical transport model that allows for second order degradation or use another approach	Additional discussion of the use of second order biodegradation rates was to Section 4.4
4.4.3	4-5	4	Base /33	More details on the content of the plan would be beneficial. Also a discussion that this plan will be part of the overall initial technical report. The exact locations of sampling points will be proposed by your company to McClellan AFB. McClellan AFB will coordinate with its stakeholders to get approval for the entire process including well locations.	Additional details of the long-term monitoring and compliance plan were added to Section 4.4.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
5		Figure 5.1	Base /34	Section 5 is incomplete. This section should include generic discussions on field activities for sampling. Details listing the wells and locations should also be provided. The technical basis for the location of the new monitoring wells should also be presented to allow for concurrence by the base, regulatory agencies, and stakeholders. The quality of Figure 5.1 should be improved. Also the original source of the map should be referenced. The residual management section should at a minimum referenced responsibilities of the various players for handling the purge water. The demobilization section should include a minimal discussion on what activities will be required.	Section 5 was extensively revised and reorganized to include all field activities, rationale for sampling locations, and residuals management responsibilities.
6.2			Base /35	Regulatory compliance. This section needs to note the various regulations that apply to the work to be conducted and how compliance is assured	Section 6 was revised extensively to include specific regulations and how compliance with the regulations will be met.
7			Base /36	The SAP does not meet the minimum requirements or expectations for work under CERCLA or at McClellan AFB. This work plan must include any sampling procedures and methodologies that are not issued as part of the basewide RI/FS QAPP. They should be included as an appendix to this document.	Section 7 was extensively revised to include all field and sampling activities. Protocols not contained in the Basewide QAPP are included in an Appendix.
7.2	7-1	3	Base /37	There are no data gaps remaining following the completion of the RI. The working copy report provided to you should contain sufficient information on the locations of source in the vadose zone. This paragraph should be revised to indicate the currently available information	Text was revised to reflect current information.
7.2	7-2	1	Base /38	It would be more appropriate to say that you will provide information from your sampling to the base who will forward it to the appropriate GSAP contractor to include in the overall program.	The sentence was revised accordingly.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
7.2.2	7-2	6	Base /39	Because the technical protocol document is in draft form it would be beneficial to include the appropriate table as an appendix to this document.	Appropriate sections from the technical protocol are included in Appendix D.
7	7-4	Figure 7.1	Base /40	The quality of Figure 7.1 needs to be improved. It should only show the wells that are to be sampled.	This figure was replaced by Figure 5-1 and the quality was improved.
7			Base /41	This work plan should contain a summary table showing what measurements will be taken at each sampling location. I assume that water level measurements will be taken as part of sampling. If so this needs to be added to the SAP	A table was added which shows all methods for each location. Water level measurement was added to the SAP.
7			Base /42	Where field procedures are modified, the modified version of the procedure should be attached to the work plan. Procedures that are not included in the RI QAPP must be attached to the WIP. These procedures must provide the detail needed by the sampler to complete the work. A list of analytical equipment to be used in the field should also be included. Each specific section should indicate the type of container or specific instrument required to perform the analysis. Calibration procedures for the appropriate instrumentation to be used in the field should be referenced in the SAP or QAPP.	The WIP was revised to thoroughly reference appropriate protocols and calibration procedures from the Basewide QAPP. Protocols not contained in the Basewide QAPP are included in an Appendix. Field analytical equipment, sampling containers, and calibration requirements have been specified.
7.2.4	7-9		Base /43	The QC sampling section should show the total number of QA/QC samples per method. This section or the QAPP should specifically discuss or reference an existing portion of the McClellan RI/FS QAPP that has the appropriate detailed discussion of the topics	A table was added which includes the number of samples by method and the Basewide QAPP has been referenced.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
8			Base /44	The QAPP section does not meet the minimum requirement, or expectations for work under CERCLA or at McClellan AFB. The document does not present detail or rationale to direct personnel or program activities. The continued references to a Program SAP are not appropriate. Discussions not presented in a McClellan AFB approved document must be presented in this document for the review and approval of the base, regulators, and stakeholders.	Section 8 was revised extensively and reference to appropriate protocols from the Basewide QAPP have been added. Protocols not contained in the Basewide QAPP are included in an Appendix. References to the Program SAP have been deleted.
9			Base /45	The H&SP section does not meet the minimum requirements or expectations for work under CERCLA or at McClellan AFB. The H&SP should at a minimum provide a generic discussion of all health and safety issues. What external reviews and approvals have been given to the "program" document referenced? Discussions on the hazards, if any, of solutions used in field sampling are not provided. A map to the base clinic is not provided and the off-site hospital route map is inadequate. McClellan staff should be added to the notification list, e.g., duty officer, Contracting Officer, EM representatives. Biological hazards are not addressed.	Program HASP which provides a generic discussion of all H&S issues including biological hazards has been included as an Appendix. A map of the base clinic has been included and the off-site hospital route revised. Appropriate McClellan AFB staff have been added to emergency contacts list.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
General			EPA(Healy) A	With the study described in the subject document, McAFB essentially appears to be conducting a treatability study capable of supporting the selection of a biodegradation remedy (i.e., intrinsic remediation). To maximize the usefulness of the proposed study, I suggest that McAFB consult the August 1993 EPA "Guide for Conducting Treatability Studies Under CERCLA: Biodegradation Remedy Selection" produced by the SITE Program (EPA Report No. EPA/540/R-93/519a). By anticipating the needs of an FS and RD (e.g., detailed cost comparison of various alternatives including any contingency plans), McAFB should clearly present how they will eventually address the biodegradation criteria recommended in the above guidance and what types of costs they will compare for the likely cleanup alternatives. This level of planning seems appropriate for the subject document, especially since one of the stated objectives is to increase regulatory acceptance of intrinsic remediation.	The EPA reference and how the demonstration study complies with the EPA reference guidelines has been added to Section 8.4. A discussion of coasts has also been added.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
General			EPA(Healy) /B	Is there any information relevant to the subject document that might be contained in the December 1995 Groundwater OU Natural Attenuation WIP produced for McAFB by CH2M Hill?	The subject reference was reviewed during preparation of the draft WIP and specifically referenced in Section 3.2 in a discussion of sulfate concentrations. However, unlike the subject reference, which focuses on uncontained plume sections (UPS), this demonstration takes a site-specific (or source-specific) approach to the evaluation of natural attenuation, with an emphasis on biodegradation processes. In addition, the AFCEE technical protocol document, upon which the draft WIP approach is based, provides a more complete treatment of the subject.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
4.2	4-1	2	EPA(Healy) /1	Would it be more accurate to add that McAFB is evaluating the potential for intrinsic remediation at sites where groundwater is contaminated with CAHs and electron donors?	A potential mechanism for the biodegradation of low-molecular-weight CAHs (e.g., vinyl chloride) is their use as an electron donor rather than as an electron acceptor (as discussed in Section 3.1.2 of the draft WIP). In addition, if sufficient quantities of native organic carbon or natural reducing conditions are present (not expected to be the case at McClellan AFB sites), the electron donor is not necessarily a contaminant. Since the draft WIP provides a general approach to evaluate these conditions as well as groundwater contaminated with highly-chlorinated compounds, the additional wording is unnecessarily restrictive.
4.2	4-1		EPA(Healy) /2	Will McAFB use study results to model the relative movements of the CAH plume and the electron donor plume through their effective life times? In other words, will sufficient levels of electron donor always be present and available for the degradation of CAHs down to their desired remediation levels? If not, what type of contingency plan will be in place to capture portions of the CAH plume which might escape the necessary conditions? Similarly, will McAFB model the behavior of vinyl chloride and its ability to migrate to oxygenated areas of the subsurface where it would be expected to degrade to harmless by-products? These questions would certainly need to be addressed prior to making cost estimates for a companion pump and treat system for the IC19 plume.	Additional discussions have been added to Section 4 to address this comment and define the modeling approach which will be used.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
4.2	4-2	1	EPA(Healy) /3	I am confused as to the eventual goal of using intrinsic remediation at IC19. This paragraph refers to containment, although my understanding is that McAFB is considering groundwater cleanup in a planned VOC ROD	The project objectives have been clarified.
7	7-1	1	EPA(Healy) /4	First two bullets: These documents should have been provided as appendices, since most reviewers probably did not have immediate access to them	Relevant sections of technical protocol document are included as Appendix D.
7	7-1	1	EPA(Healy) /5	Third bullet: Can this reference be replaced by the 1997 Basewide QAPP?	Reference was replaced as specified.
7.2.1	7-2	5	EPA(Healy) /6	First bullet: What is the likelihood that NAPL is present at this site and how might its presence affect the overall study objectives? This might better be discussed in the site description section	Additional discussion of NAPL was added to Section 2.
7		Figure 7.1	EPA(Healy) /7	Is this figure identical to Figure 5.1? Perhaps all the sampling locations can be identified directly on the map	Comment is addressed in Figures 5.1 and 5.2 which replace Figure 7.1.
General			EPA (Levine) /1	I have a few comments which should be clarified. Of particular concern with the intrinsic remediation work plan is the lack of consistency with following the Air Force protocol. The first action specified in the protocol is to apply a screening tool to determine the relative merit of applying natural attenuation at a given site. The Air Force claims that they have done this, but do not present the resultant table and score.	The screening score and a discussion have been added to Section 3.2.
2			EPA (Levine)/2	In addition, there are considerable site contaminant data in electronic format, which should be presented in a time series. This is simple to perform and should be part of this document.	Time series graphs have been added as Appendix B.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
3.3.1			EPA (Levine)/3	The section on limitations should include disadvantages such as cost for long-term monitoring, impacts of plume migration, potential for initiating a contingency plan, and public acceptance.	Addressed in response the Base comments 20 through 23.
4.3			EPA (Levine)/4	The test plan is vague and does not support that "A sufficient number of samples ....will be collected." These should be specified in Section 7.2.	Addressed in response the Base comment 26.
4.4.1			EPA (Levine)/5	The discussion is extremely weak by not specifying what model(s) might be used and how it will be used. All input parameters should be specified now to ensure data quality. The Air Force should define "appropriate" as used in the last paragraph on estimating biodegradation rates.	Addressed in response the Base comments 30 and 31.
4.4.3			EPA (Levine)/6-7	The long-term monitoring and compliance plan will need to demonstrate that mass reduction is occurring at the estimated rates. There should be compliance triggers specified in the monitoring plan. These can be considered to be detects in clean downgradient wells, or half MCLs. When a compliance trigger is detected the plan should specify an action, such as increased frequency of monitoring, and an evaluation of whether the plume(s) is stable. A contingency plan should be developed in case natural attenuation does not meet remedial action objectives in a reasonable time frame or if the plume(s) is not stable.	Addressed in response to EPA (Healy) comment 2.
5.1			EPA (Levine) /8	The field activities characterization section claims that sufficient data has been collected previously to support a fate and transport model without identifying which model or how it will be used. This should be presented here.	Addressed in response the Base comments 30 and 31.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
7			EPA (Levine)/9	Section 7 should present any SOP not previously reviewed by EPA as a McClellan submittal. Since the historical data are not presented in Section 2.4 nor is the groundwater flow velocity presented in Section 2.3.2 there is no rationale presented for the locations of monitoring wells nor for sampling. Figure 7.1 suggests that bailers may be used. EPA recommends not using bailer.	Addressed in responses to Base comments 34 and 36. The estimated groundwater flow velocity and direction will be included in the discussion of the rationale for the new MW locations. A bailer will not be used for purging MWs; however, a bailer will be used to collect samples from MWs without dedicated pumps following SOP McAFB - 013 (Sampling Groundwater from Monitoring and Extraction Wells) from the McClellan QAPP.
8			EPA (Levine)/10	Section 8 should present all SOPs not previously submitted by the Air Force for McClellan AFB. The DQOs should be presented here as well. A number of concerns have been noted during the review of the SAP and the QAPP. In particular the SAP does not provide sufficient information for a sampling team to adequately perform sampling procedures; the use of references is not sufficient. Also, the SAP and QAPP extensively reference the McClellan AFB Basewide RI/FS APP (McClellan AFB, 1994) and the Program Sampling and Analysis Plan (SAP) (Parsons ES, 1995). This is acceptable, however, it is recommended that this site-specific SAP and QAPP be used as companion documents with the Basewide QAPP and the Program SAP and be distributed together. The SAP and QAPP can not be approved by the Quality Assurance (QA) Office until the following concerns are addressed.	Addressed in response the Base comment 44. DQOs have been added to Section 8.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
7			EPA (QAMS)/ Major Concerns 1A, 1B and 2A	A number of required elements for a field sampling plan are not included in Section 7 or elsewhere in the WIP. It is recommended that information on the following items be included in the SAP section of the WIP: • Sampling schedule and frequency (Section 10 provides an overall project schedule, but not a sampling schedule for the three week sampling period; • Equipment decontamination; • Instrument calibration and criteria (reference to the Program SAP is not sufficient); • Preventive maintenance; • Disposal of contaminated materials; • Sample holding times; • Sample container; • Sample volume; • Sample preservation; • Sample packaging and shipment; • Sample documentation; and • Documentation and deliverables. The site-specific QAPP should include all internal QC checks (for example, information on second column confirmation, required control limits for each QC check and corrective actions required when control limits are exceeded). In addition, the QAPP should also indicate, preferably in table format, the method precision and accuracy acceptance criteria for all cited methods.	Addressed in responses to Base comments 34,35, and 44.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
7.2			EPA (QAMS)/ Major Concerns 1A, 1B and 2A	Section 7.2 states that a "sufficient number" of samples will be collected from uncontaminated and contaminated areas. The SAP must clearly indicate where samples will be collected and the total number of samples to be collected for this site-specific project. Sample number information on samples to be collected for groundwater contaminants of concern and geochemical parameters must be included.	The SAP has been revised to show the criteria for locations, sample number information, and rationale for each location.
7			EPA (QAMS)/ Major Concern 2B	In addition, the SAP should discuss how the number of samples to be collected was estimated. Wiedemeier et al., in a paper titled "Technical Protocol for Evaluating the Natural Attenuation of Chlorinated Ethenes in Groundwater," indicates that chemical and geochemical data is required for a minimum of 6 samples that are representative of both background conditions and conditions within the contaminant plume. The SAP should indicate the number of samples and discuss what statistical means were used to establish the number of samples to be collected in order to provide sufficient quality data for model input. The SAP should also indicate what wells will be sampled for background conditions versus conditions within the contaminant plume.	The SAP has been revised to show the criteria for locations, sample number information, and rationale for each location.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
8			EPA (QAMS)/ Major Concern 3	Section 8 provides the project specific QAPP elements for the project, and indicates that it is a part of the larger Basewide QAPP (1994). It is appropriate for this section to reference the Basewide QAPP; however, Section 8 does not include in either text or by reference, a number of elements required by the Region and QA/R-5 guidance. Even though these elements may be included in the Basewide QAPP, they should at least be referenced in this project specific QAPP. The specific elements missing from the project specific QAPP include the following: Information on double-blind performance evaluation samples for laboratory accuracy evaluation; identification of the number, frequency, and type of technical system audits; instrument/equipment testing and inspections and	Addressed in response to Base comment 44. All of the requested information is now provided in Section 8.
8.1	8-1		EPA (QAMS)/ Major Concern 4	Section 8.1 references the Program SAP for a discussion of data quality objectives (DQOs). Because this is a unique demonstration, it is suggested that project-specific DQOs be described in this section, including the project's level of acceptable error in the results.	Project specific DQOs have been added.
8.3	8-2		EPA (QAMS)/ Major Concern 5A	Section 8.3 provides the names of personnel who will be involved in the project. It is suggested that in addition to their names and titles, their affiliation also be included. It is suggested that a project-specific organizational chart be included in Section 8, depicting [Parsons ES], the analytical laboratory, any subcontractors, and McClellan AFB, indicating all lines of communication. The organizational chart should clearly depict the independence of the Air Force and Parsons [ES] Quality Assurance Officers (QAOs).	An organizational chart has been added to Section 8.
General			EPA (QAMS)/ Major Concern 5B	No approval sheet has been included for the WIP. This should include the names, titles, and signatures of the approving personnel (e.g., [Parsons ES] QAO and Project Manager (PM); the McClellan AFB QAO and PM; and the EPA PM).	Based on direction from McClellan AFB, no response to this comment is necessary.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
8.6	8-2		EPA (QAMS)/ Major Concern 6	Section 8.6 provides references for how data validation will be conducted. It is suggested that the site-specific QAPP indicate if it will use the EPA National Functional Guidelines for validation of at least 20 percent of data. It is also suggested that the QAPP indicate that a final data validation will be performed by a party independent of the data generation.	Data validation will not be performed as discussed in Section 8, based on Basewide QAPP guidelines.
5.1			EPA (QAMS)/ Concern 1A	Section 5.1 indicates that four new monitoring wells will be installed for the project. The section indicates that no additional techniques to those discussed in the Basewide QAPP (McClellan AFB, 1994) will be used. Regional (9QA-06-93, 1993) guidance requires that field specific information be included in each site-specific project. Therefore the WIP should include the referenced material including construction details and also well specifications such as well depths, screen lengths, and casing materials.	Based on direction from McClellan AFB, no response is necessary. However, some of the requested information will be provided as detailed in responses to Base comments 34 and 36.
7.2.3	7-5		EPA (QAMS)/ Concern 1B and 2	Section 7.2.3 references a number of sampling procedures from the McClellan Basewide QAPP (e.g., General Field and Sampling Requirements; Groundwater Sampling; Sample Custody and Documentation; Field Instrument Calibration Procedures; and Equipment Decontamination). Section 7.2. also references standard operating procedures (SOPs) for "Sampling of Groundwater from Monitoring and Extraction Wells," "Photoionization, Calibration and Operation" and "Equipment Decontamination." Regional guidance requires that each site-specific project field sampling plan should sequentially describe each sampling procedure such that it may be clearly followed by a sampling crew. Also, a copy of all SOPs should be attached to the SAP.	Addressed in response to Base comment 36.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
7.2.3.1, 7.2.3.2, 7.2.3.3, 7.2.3.4, 7.2.3.5, 7.2.3.6, and 7.2.3.7			EPA (QAMS)/ Concern 1B and 2	Section 7.2.3.1 states that additional procedures for taking dissolved oxygen measurements are included in another document. Once again all procedures for site-specific projects must be included in this document either in the body of the document or as an attachment). Similarly a step-by-step procedure for oxidation-reduction potential (ORP) should be included in Section 7.2.3.2. Section 7.2.3.3 should describe all measurement procedures for ferrous iron measurements, and not just state "after appropriate preparation." Similarly, sulfide measurements procedures should be included in Section 7.2.3.5. In addition, Sections 7.2.3.4, 7.2.3.6 and 7.2.3.7 indicate that measurements will be made after appropriate sample preparation; all sample preparation and measurement methods should be described in the plan.	Addressed in response to Base comment 40. SOPs have been added in an Appendix.
	7-4	Figure 7-1	EPA (QAMS)/ Concern 3	Figure 7-1 clearly identifies the four proposed new monitoring wells for the project. However, the other 21 monitoring wells are difficult to locate (Section 5.4 indicates 25 wells will be monitored). It is suggested a legend identifying all proposed sampling wells be included in the figure.	Table 5.1 and 5.2 now clearly indicate the wells to be sampled.
7.2		Table 7.1 and Table 7.s	EPA (QAMS)/ Concern 4A	Section 7.2 outlines the measurements and analyses that will be performed for the project, and Table 7.1 indicates the analytical methods for the parameters listed. Manganese and sulfide are indicated as field parameters to be measured in Section 7.2, but have been omitted from Table 7.1. Also, it is indicated in Section 7.2 that total alkalinity will be analyzed in the laboratory, again this is not indicated in Table 7.1. It is suggested, therefore, that discrepancies between the table and text be corrected.	The discrepancies have been resolved.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
7	7-10	Table 7.2	EPA (QAMS)/ Concern 4B	Table 7.2 does not include the QC samples or specific acceptance criteria for a number of methods identified in Table 7.1, including EPA methods 350.1, 353.1, 300.0, SW9060, SW3550 and SW8015AM. Specific QC acceptance criteria and QC samples for the methods used to analyze methane, ethane, and ethene should be included in Table 7.2. In addition, QC samples and acceptance criteria for the Hach methods identified in Table 7.1 should be described in Table 7.2. (Note: the footnote to Table 7.1 should identify what the "AM" in method SW8015AM denotes).	Tables have been added to include the requested QC information.
8.2	8-1		EPA (QAMS)/ Concern 5	Section 8.2 incorrectly states that "site-specific sampling requirements are discussed in Section 7.2.4 of this WIP." Site-specific requirements are not discussed in Section 7.2.4, rather Section 7.2.4 references the Program SAP (Parsons ES, 1996) and Section 8.0 of this WIP. Specific information should be included and circular references clarified.	The circular reference has been omitted and Section 7 and 8 have been extensively revised and now include specific sampling requirements.
8	8-3	Figure 8.1	EPA (QAMS)/ Concern 6	The chain of custody form should allow for the identification of a laboratory QC sample, to ensure the analytical laboratory does not use a blank sample as a laboratory QC sample.	The form was revised accordingly.
7			EPA (QAMS)/ Comment 1	The SAP should also indicate that 2-3 times the normal volume of water should be collected for the laboratory QC sample	A table has been added which identifies QC sample locations and indicates that twice the volume must be collected.
7.2.2	7-2		EPA (QAMS)/ Comment 2A	In general the WIP provides sufficient rationale for the sampling to be performed during the project. However, Section 7.2.2 indicates that the rationale for each method to be used is included in the technical protocol document. This is not available for review, therefore, it is suggested that the rationale be included in the SAP.	This information has been included in Section 7 and Appendix D.

Section	Page	Paragraph	Reviewer / Comment #	Comment	Response
7.2.2	7-5		EPA (QAMS)/ Comment 2B	Section 7.2.2 includes a list of the monitoring wells for the project. However, this includes only 21 wells, rather than 25 indicated in Section 5.4. Presumably the four new wells are not indicated.	All MWs are now included, including the designation for the 5 new MWs.