FINAL

Engineering Evaluation/Cost Analysis for the Risk-Based Remediation of Pumphouse #2



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Malmstrom Air Force Base
Montana

Prepared For

Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas

and

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Malmstrom Air Force Base
Montana



January 1997

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FINAL

ENGINEERING EVALUATION/COST ANALYSIS FOR THE RISK-BASED REMEDIATION OF PUMPHOUSE #2

MALMSTROM AIR FORCE BASE

MONTANA

Prepared for

Air Force Center for Environmental Excellence
Brooks Air Force Base
San Antonio, Texas

and

Malmstrom Air Force Base
Montana

January 1997

TABLE OF CONTENTS

Page

LIST OF ACRONYMS AND ABBREVIATIONS viii

SECTION 1 - EXECUTIVE SUMMARY 1-1

1.1 Purpose and Scope 1-1
1.2 Site Background 1-3
1.2.1 Operational History 1-3
1.2.2 Previous Remedial Investigations 1-7
1.3 Summary of Proposed Type of Cleanup 1-7
1.4 Report Organization 1-10

SECTION 2 - SITE CHARACTERIZATION ACTIVITIES 2-1

2.1 Scope of Data Collection Activities 2-1
2.2 Soil Gas and Soil Flux Measurements 2-5
2.2.1 Soil Gas Sampling 2-5
2.2.2 Soil Gas Flux Sampling 2-5
2.3 Subsurface Soil Sampling 2-10
2.4 Groundwater Sampling 2-14
2.5 Sediment Sampling 2-17
2.6 Surface Water Sampling 2-17
2.7 Aquifer Testing 2-17
2.8 Source Reduction Treatability Testing 2-17

SECTION 3 - PHYSICAL CHARACTERISTICS OF THE STUDY AREA 3-1

3.1 Regional Topography and Surface Water Hydrology 3-1
3.2 Regional Geology and Hydrogeology 3-1
3.2.1 Geology 3-1
3.2.2 Hydrogeology 3-2
3.3 Site Topography and Surface Water Hydrology 3-3
3.4 Site Geology and Hydrogeology 3-3
3.4.1 Site Lithology and Stratigraphic Relationships 3-3
3.4.2 Site Hydrogeology 3-4
3.5 Climatological Characteristics 3-9
3.6 Land Use 3-9
3.6.1 Site Access 3-9
3.6.2 Current Land Use 3-9

TABLE OF CONTENTS (Continued)

Page

3.6.3 Proposed Land Use 3-12
3.6.4 Groundwater Use 3-12

SECTION 4 - NATURE AND EXTENT OF CONTAMINATION 4-1

4.1 Overview 4-1
4.2 Sources of Contamination 4-1
4.3 Chemicals of Potential Concern 4-2
4.3.1 Contaminant Screening Criteria 4-2
4.3.2 Identifying Screening Criteria Exceedances 4-5
4.4 Soil/Sediment Chemistry 4-5
4.4.1 BTEX Soil/Sediment Contamination 4-7
4.4.2 Soil Gas Sampling Results 4-11
4.4.3 Soil Flux Sampling Results 4-12
4.5 Groundwater Chemistry 4-13
4.5.1 Groundwater Benzene and Ethylbenzene Contamination 4-13
4.6 Surface Water Chemistry 4-20
4.7 Summary 4-20

SECTION 5 - PROPOSED DEGREE OF CLEANUP REQUIREMENTS 5-1

5.1 Exposure Pathways Analysis 5-1
5.1.1 Conceptual Site Model 5-2
5.1.1.1 Source and Release Mechanisms 5-4
5.1.1.2 Contaminant Environmental Transport 5-5
5.1.1.3 Potentially Exposed Populations 5-7
5.1.2 Summary of Potentially Completed Exposure Pathways 5-9
5.2 Proposed Type of Cleanup 5-10
5.2.1 Site-Specific Target Levels for Contaminated Soils and Groundwater 5-10
5.2.2 Promulgated Remedial Standards for Contaminated Soils and Groundwater 5-12
5.3 Remediation Requirements 5-13

SECTION 6 - EVALUATION OF NATURAL CHEMICAL ATTENUATION 6-1

6.1 Introduction 6-1
6.2 Operative Mechanisms of Contaminant Attenuation 6-1
6.2.1 Nondestructive Attenuation Mechanisms 6-2
6.2.1.1 Solubility 6-2
6.2.1.2 Sorption 6-3
6.2.1.3 Volatility 6-3

TABLE OF CONTENTS (Continued)

Page

6.2.1.4 Advection and Dispersion 6-4
6.2.1.5 Summary of Nondestructive Attenuation 6-5
6.2.2 Biodegradation of BTEX Compounds in Soil and Groundwater 6-5
6.3 Evidence of Field-Scale Contaminant Mass Loss 6-6
6.3.1 Qualitative Changes in COC Concentrations in Soils 6-6
6.3.2 Observed Changes in COC Concentrations in Groundwater 6-7
6.3.3 Determination of Attenuation Rates 6-7
6.4 Evidence of Contaminant Biodegradation via Microbially Catalyzed Redox Reactions 6-9
6.4.1 Redox Couples in Biodegradation 6-9
6.4.2 Dissolved Oxygen Concentrations 6-12
6.4.3 Dissolved Nitrate and Nitrite Concentrations 6-12
6.4.4 Dissolved Manganese Concentration 6-14
6.4.5 Ferrous Iron Concentrations 6-14
6.4.6 Sulfate and Sulfide Concentrations 6-16
6.4.7 Methane and Carbon Dioxide Concentrations 6-17
6.5 Theoretical Assimilative Capacity Estimates 6-17
6.6 Predicting Chemical Fate Over Time 6-18
6.6.1 Leaching Effects 6-20
6.6.2 Advective Effects 6-20
6.6.3 Biodegradation Effects 6-20
6.7 Conclusions 6-20

SECTION 7 - PILOT TESTING OF SOURCE REDUCTION TECHNOLOGIES 7-1

7.1 *In Situ* Bioventing Pilot Testing 7-1
7.1.1 Bioventing Well and Vapor Monitoring Point Installation 7-1
7.1.2 Respiration Testing 7-4
7.1.3 Air Permeability Testing 7-4
7.1.4 Pilot-Test Results 7-6
7.2 Biosparging Test 7-6
7.2.1 Biosparging Well Installation 7-8
7.2.2 Biosparging Test Procedures 7-8
7.2.3 Biosparging Test Results 7-8
7.2.3.1 Radius of DO and Water Level Influence 7-8
7.2.3.2 Potential Air Emissions 7-10
7.2.3.3 Technology Assessment 7-10

TABLE OF CONTENTS (Continued)

Page

SECTION 8 - COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES 8-1

8.1 Summary of Candidate Remedial Alternatives 8-1
8.1.1 Alternative 1- Natural Chemical Attenuation, Long-Term Monitoring, Land and Groundwater Use Controls, Public Education, and Limited Sediment Excavation and *Ex Situ* Treatment 8-2
8.1.2 Alternative 2: Natural Chemical Attenuation, Long-Term Monitoring, Land and Groundwater Use Controls, Public Education, Bioventing in Source Area, and Limited Sediment Excavation and *Ex Situ* Treatment 8-5
8.2 Review of Screening and Evaluation Criteria 8-5
8.2.1 Effectiveness 8-6
8.2.2 Implementability 8-6
8.2.3 Cost 8-6
8.3 Detailed Evaluation of Remedial Alternatives 8-7
8.3.1 Alternative 1- Natural Chemical Attenuation, Long-Term Monitoring, Land and Groundwater Use Controls, Public Education, and Limited Sediment Excavation and *Ex Situ* Treatment 8-7
8.3.1.1 Effectiveness 8-7
8.3.1.2 Technical and Administrative Implementability 8-10
8.3.1.3 Cost 8-11
8.3.2 Alternative 2 - Natural Chemical Attenuation, Long-Term Monitoring, Land and Groundwater Use Controls, Public Education, Bioventing in Source Area, and Limited Sediment Excavation and *Ex Situ* Treatment 8-12
8.3.2.1 Effectiveness 8-12
8.3.2.2 Technical and Administrative Implementability 8-12
8.3.2.3 Cost 8-14
8.4 Consideration of Active Groundwater Treatment 8-15
8.5 Recommended Alternative 8-15

SECTION 9 - IMPLEMENTATION OF RECOMMENDED REMEDIAL ACTION 9-1

9.1 Scope of Remedial Activities 9-1
9.1.1 Review and Approval of Engineering Evaluation/Cost Analysis 9-1
9.1.2 Implementation of Long-Term Groundwater Monitoring 9-1
9.1.3 Sediment Excavation and *Ex Situ* Treatment 9-2

TABLE OF CONTENTS (Continued)

Page

9.1.4 Verification of Current and Future Land and Groundwater Use Controls 9-3
9.2 Implementation Schedule 9-3
9.3 Contingency Plan 9-5
9.4 Cost of Implementation 9-6

SECTION 10 - LONG-TERM MONITORING PLAN 10-1

10.1 Overview 10-1
10.2 Groundwater Monitoring Networks 10-1
10.2.1 Upgradient and Plume Wells 10-3
10.2.2 Sentry Well 10-3
10.2.3 Point-of-Action Wells 10-3
10.2.4 Point-of-Compliance Wells 10-8
10.3 Groundwater Sampling 10-8
10.3.1 Implementation Requirements 10-8
10.3.2 Sampling Frequency 10-8
10.4 Subsurface Soil Sampling 10-9
10.5 Land Use Controls Verification 10-9

REFERENCES R-1

APPENDIX A - SAMPLE ANALYTICAL RESULTS

APPENDIX B - BORING LOGS, WELL CONSTRUCTION DIAGRAMS, AND WELL DEVELOPMENT REPORTS

APPENDIX C - AQUIFER TEST DATA

APPENDIX D - DEVELOPMENT OF SSTLS

APPENDIX E - NATURAL CHEMICAL ATTENUATION CALCULATIONS

APPENDIX F - SOURCE-REDUCTION TEST DATA

APPENDIX G - SCREENING AND DEVELOPMENT OF REMEDIAL ALTERNATIVES

APPENDIX H - SAMPLING AND ANALYSIS PLAN

APPENDIX I - QUALITY ASSURANCE PROJECT PLAN

TABLE OF CONTENTS (Continued)

LIST OF TABLES

No.	Title	Page
2.1	Analytical Methods and Reporting Limits	2-3
2.2	Analytical Analysis and Field Measurements by Sampling Location	2-6
4.1	Identification of Soil and Groundwater Contaminant Screening Criteria Exceedances	4-4
4.2	List of Chemicals of Potential Concern	4-6
4.3	Summary of Other Soil Sampling Results	4-8
4.4	Summary of 1993 RFI Groundwater Sampling Results	4-14
4.5	1994 Groundwater Samples in Exceedance of Screening Criteria	4-15
4.6	1996 Groundwater Samples in Exceedance of Screening Criteria	4-17
5.1	Summary of Chemical-Specific SSTLs	5-11
5.2	Comparison of COPC Concentrations to Chemical-Specific SSTLs	5-14
6.1	Comparison of RFI and Risk-Based Groundwater Data	6-8
6.2	Estimate of Assimilative Capacity of Saturated Soil and Groundwater	6-19
7.1	Oxygen Utilization Rates During Initial Bioventing Pilot Tests	7-5
7.2	Oxygen Influence in Subsurface During Initial Bioventing Pilot Testing	7-5
7.3	Initial and 1-Year Soil and Soil Gas Analytical Results	7-7
7.4	Biosparging Pilot-Test Results	7-9
8.1	Cost Estimate for Alternative 1	8-11
8.2	Cost Estimate for Alternative 2	8-14
8.3	Summary of Remedial Alternative Evaluation	8-16
9.1	Estimated Cost by Fiscal Year	9-6
10.1	Groundwater Monitoring Analytical Protocol for Upgradient and Plume Wells	10-4
10.2	Groundwater Monitoring Analytical Protocol for Point-of-Action and Sentry Wells	10-6

LIST OF FIGURES

No.	Title	Page
1.1	Risk-Based Remediation Decision Diagram	1-2
1.2	Regional Location of Malmstrom AFB	1-4
1.3	Location of Pumphouse #2	1-5
1.4	Site Layout	1-6
1.5	Proposed LTM Well Network, POA, and Soil Excavations	1-9

TABLE OF CONTENTS (Continued)

LIST OF FIGURES (CONTINUED)

No.	Title	Page
2.1	Soil Gas and Soil Flux Sampling Locations	2-9
2.2	Subsurface Soil Sampling Locations	2-11
2.3	Previous Soil Sampling Locations	2-12
2.4	1995 Soil Sampling Locations	2-13
2.5	1994 Groundwater Sampling Locations	2-15
2.6	1996 Groundwater Sampling Locations	2-16
2.7	1994 Subsurface Water and Sediment Sampling Locations	2-18
2.8	Slug Test Locations	2-19
2.9	Bioventing Pilot Test Locations	2-21
3.1	North-South Hydrogeologic Cross Section A-A'	3-5
3.2	East West Hydrogeologic Cross Section B-B'	3-6
3.3	Groundwater Surface Elevations (December 5, 1995)	3-7
3.4	Ground Surface Elevations (October 12, 1996)	3-8
3.5	Current On-Base Land Uses	3-10
3.6	Current Off-Base Land Uses	3-11
3.7	Future On-Base Land Uses	3-13
4.1	Extent of Total BTEX Contamination in Soils	4-10
4.2	1993 Extent of Total BTEX Contamination in Groundwater	4-18
4.3	1994-1996 Extent of Total BTEX Contamination in Groundwater	4-19
5.1	Final Conceptual Site Model	5-3
6.1	Sequence of Microbially Mediated Redox Processes	6-11
6.2	Isopleth Maps for BTEX and Oxidized Electron Acceptors in Groundwater	6-13
6.3	Isopleth Maps for BTEX and Byproducts of Electron Acceptor Reduction in Groundwater	6-15
7.1	Biosparging and Bioventing Pilot Test Locations	7-2
7.2	Hydrogeologic Cross-Section Adjacent to Bioventing and Biosparging Pilot Test Areas	7-3
8.1	Bioventing Vent Well Locations	8-4
9.1	Implementation of Proposed Actions Long-Term Monitoring Plan	9-4
10.1	Proposed LTM Monitoring Well Network	10-2

LIST OF ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
ARM	Administrative Rules of South Dakota
AST	Aboveground storage tank
bgs	Below ground surface
BH	Borehole
BTEX	Benzene, toluene, ethylbenzene, and total xylenes
°C	Degrees Celsius
cm/sec	Centimeters per second
COC	Chemicals of concern
COPC	Chemicals of potential concern
CSM	Conceptual site model
DO	Dissolved oxygen
EE/CA	Engineering evaluation/cost analysis
EPA	Environmental Protection Agency
ES	Engineering-Science, Inc.
°F	Degrees Fahrenheit
ft/day	Feet per day
ft/ft	Foot per foot
f_{oc}	Fractional organic carbon content
FY	Fiscal year
GAC	Granular activated carbon
gpm	Gallons per minute
HEAST	Health Effects Assessment Summary Tables
HHSM	Hydrocarbon Spill Screening Model
HSA	Hollow-stem auger
IRIS	Integrated Risk Information System
IRP	Installation Restoration Program
K_D	Distribution partition coefficient
kg	Kilogram
LNAPL	Light nonaqueous-phase liquid

LTM	Long-term monitoring
LTMP	Long-term monitoring plan
MAFB	Malmstrom Air Force Base
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal
MDEQ	Montana Department of Environmental Quality
MDL	Method detection limit
µg/kg	Microgram per kilogram
µg/L	Microgram per liter
$\mu g/m^2$-min	Microgram per square meter per minute
mg	Milligram
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
mg/m^3	Milligrams per cubic meter
mm Hg	Millimeter of mercury
MP	Monitoring point
MPA	Monitoring point A
MPB	Monitoring point B
MPC	Monitoring point C
mph	Miles per hour
msl	Mean sea level
MW	Monitoring well
NCP	National Contingency Plan
NRMRL	National Risk Management Research Laboratory
NOAA	National Oceanographic and Atmospheric Administration
O&M	Operations and maintenance
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PAH	Polycyclic aromatic hydrocarbon
Parsons ES	Parsons Engineering Science, Inc.
PEL	Permissible exposure limit
POA	Point-of-action
POL	Petroleum, oil, and lubricant
ppm	Parts per million

ppmv	Parts per million per volume
PQL	Practical quantitation limit
psi	Pounds per square foot
PVC	Polyvinyl chloride
QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
RAP	Remedial action plan
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
SAP	Sampling and analysis plan
scfm	Standard cubic feet per minute
SDWA	Safe Drinking Water Act
SESOIL	Seasonal Soil Compartment Model
SSTL	Site-specific target level
TEH	Total extractable hydrocarbons
TOC	Total organic carbon
TPH	Total petroleum hydrocarbons
TVH	Total volatile hydrocarbons
TWA	Time-weighted-average
U	Undetected
US	United States
USACE	US Army Corps of Engineers
USGS	US Geological Survey
UST	Underground storage tank
VOCs	Volatile organic compounds
VW	Vent well

SECTION 1

EXECUTIVE SUMMARY

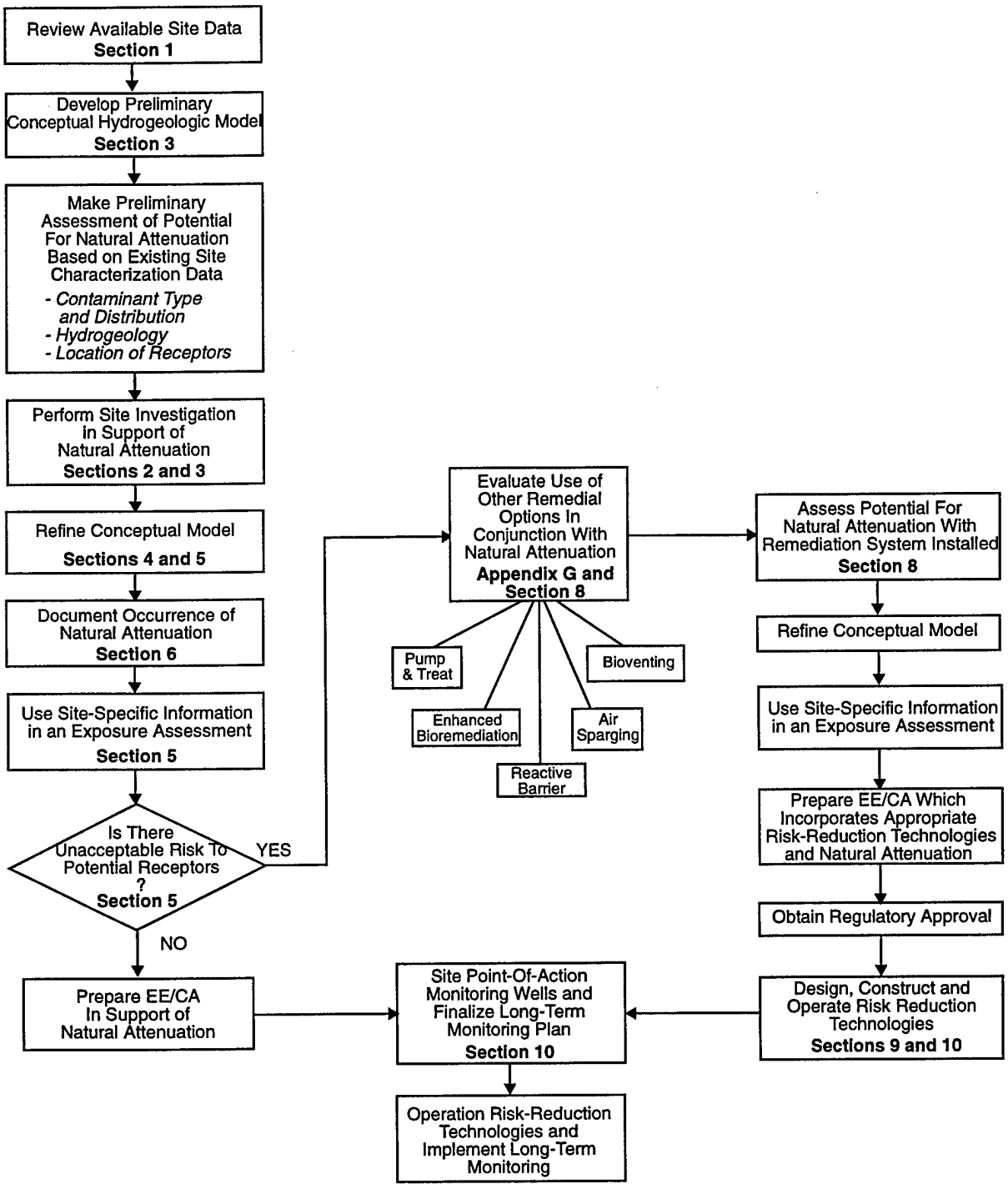
1.1 PURPOSE AND SCOPE

Parsons Engineering Science, Inc. (Parsons ES), formerly Engineering-Science, Inc. (ES), was retained by the United States (US) Air Force Center for Environmental Excellence (AFCEE) to prepare an engineering evaluation/cost analysis (EE/CA) in support of a risk-based remediation decision for soil and groundwater contaminated with fuel hydrocarbons at Pumphouse #2, a former fuel storage and pumping facility at Malmstrom Air Force Base (AFB), in Great Falls, Montana (the Base). Risk-based remediation is designed to combine natural physical, chemical, and biological processes with low-cost source removal technologies such as *in situ* bioventing, as necessary, to economically reduce potential risks posed by subsurface petroleum fuel spills. A decision diagram for the risk-based process is shown in Figure 1.1.

This EE/CA is prepared as part of a multi-site initiative sponsored by AFCEE to develop a handbook on how quantitative fate and transport calculations and risk information based on site-specific data can be integrated to quickly determine the type and magnitude of remedial action required at fuel-contaminated sites to minimize contaminant migration and potential receptor risks. Pumphouse #2 is one of eight sites nationwide that will be used as a case study in the development of the handbook. This handbook is being developed for AFCEE by Parsons ES.

The purpose of this EE/CA is to develop and describe a recommended corrective action, to be implemented at Pumphouse #2, that meets the requirements of the Montana Department of Environmental Quality (MDEQ, 1994) (formerly the Montana Department of Health and Environmental Sciences) regulations for underground storage tank (UST) closure. The remedy proposed in this EE/CA would ensure that contaminant concentrations at Pumphouse #2 meet MDEQ soil and groundwater standards at a point-of-action (POA) downgradient from the site. The remedy proposed herein provides for the removal of fuel contamination from the soil and groundwater as a result of naturally occurring biological, chemical, and physical processes documented to be occurring at the site.

Several remedial approaches that rely both on natural contaminant attenuation processes and on engineered solutions were evaluated for the site. The remedy proposed in this EE/CA would ensure that no fuel contamination would migrate beyond the area that can be placed under reliable exposure controls [i.e., beyond the proposed point-of-action (POA)] at concentrations that may pose a risk to human health and/or the environment.



Note: **Bold text indicates the section in this EE/CA which contains detailed information.**

FIGURE 1.1

RISK-BASED REMEDIATION DECISION DIAGRAM

EE/CA

Risk-Based Approach to Remediation

Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

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The activities conducted pursuant to the preparation of this EE/CA included focused site investigation activities and data analysis to characterize:

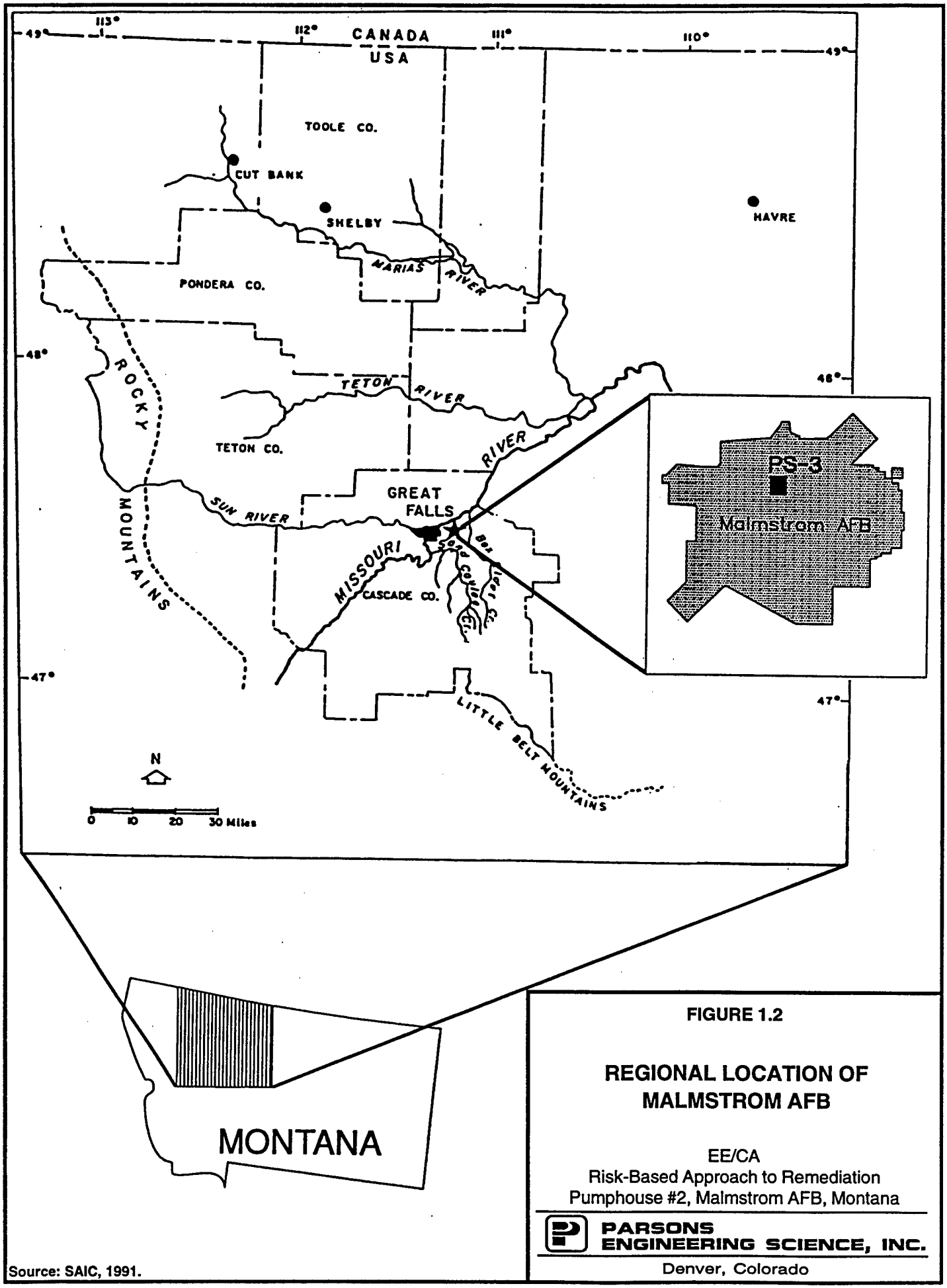
- The nature and extent of fuel hydrocarbon contamination at the site;
- The local geology, hydrogeology, and hydrology that may affect contaminant transport;
- The current and potential future uses of groundwater and exposure of receptors to other potentially impacted environmental media;
- The proximity of the site to drinking water aquifers, surface water, and other sensitive environmental resources;
- The expected persistence, mobility, chemical form, and fate of hazardous substances in the soil and groundwater under the influence of natural physical, chemical, and biological processes; and
- The treatability of residual and dissolved fuel contamination using low-cost source removal technologies such as bioventing and biosparging.

1.2 SITE BACKGROUND

Malmstrom AFB is located in north-central Montana at the eastern edge of the City of Great Falls (Figure 1.2). Pumphouse #2, the former location of a fuel storage and pumping facility, is located in the northern portion of the Base, just off the flightline. Pumphouse #2, along with another pumphouse, Pumphouse #3, and the hydrant refueling system under the aircraft apron comprise the US Air Force's Installation Restoration Program (IRP) Site PS-3 at Malmstrom AFB. The majority of previous site investigations have encompassed the entire Site PS-3 area. However, this risk-based demonstration focused only on Pumphouse #2. Figure 1.3 shows the location of the site on Malmstrom AFB. All tanks, piping, and physical structures were removed from the site in May and June 1995. Prior to demolition activities, the site consisted of a pumphouse (Building 245), an electrical control building (Building 246), and one 2,000-gallon and six 50,000-gallon USTs (Figure 1.4).

1.2.1 Operational History

The 2,000-gallon UST was used to store off-specification fuel and water collected in the fuel filters within Building 245. This UST was inactive for approximately 3 years prior to its removal in 1995. Four of the larger USTs, which were used to store diesel fuel, also were inactive for several years prior to removal. The remaining two USTs contained unleaded MOGAS (automotive gasoline) and a deicing glycol solution until site demolition activities commenced in the spring of 1995. The five inactive tanks at the site were removed from service in 1992 after failing tank integrity tests. The amount of fuel released from the USTs and associated pipelines is unknown.



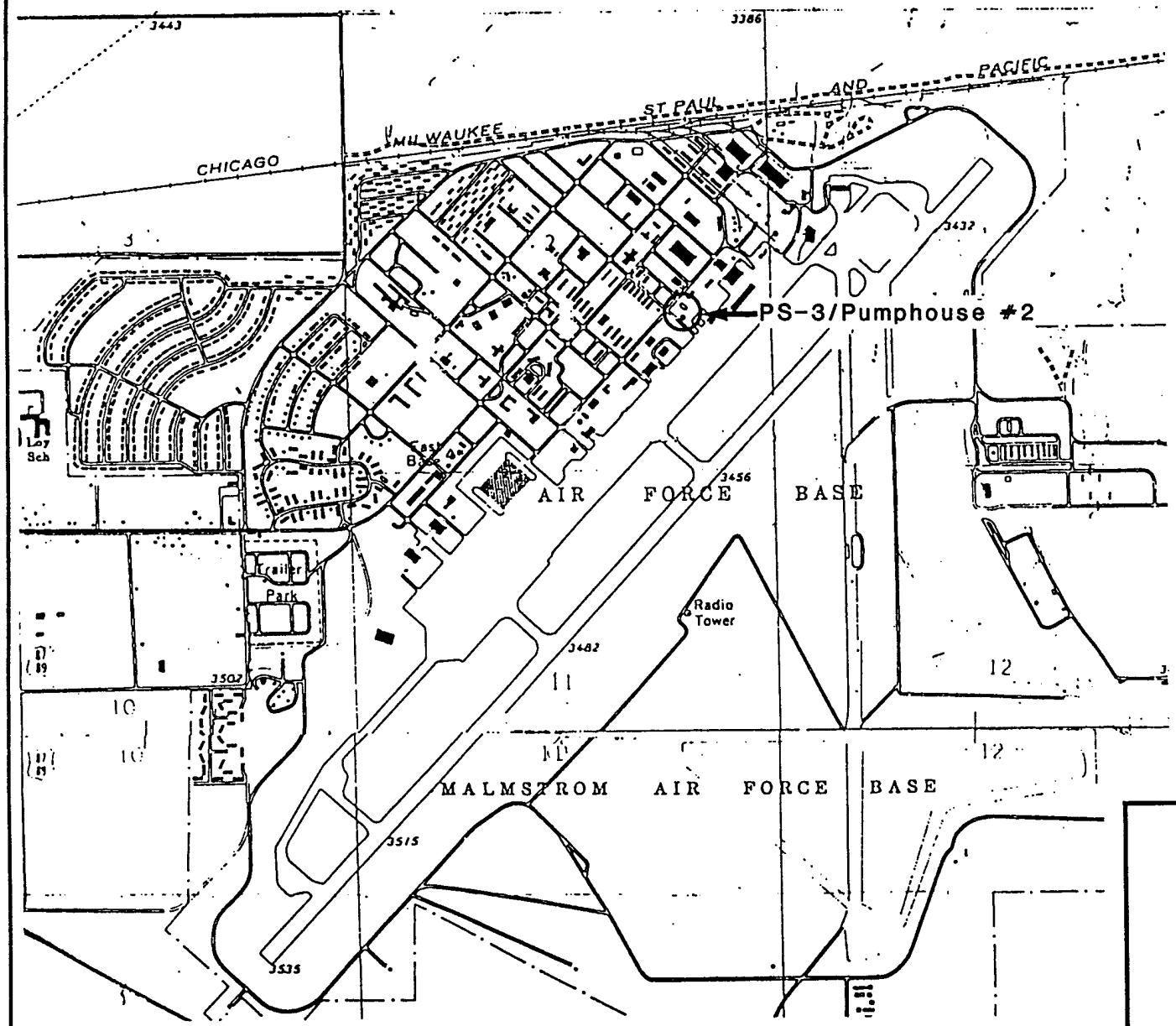
Source: SAIC, 1991.

FIGURE 1.2

REGIONAL LOCATION OF MALMSTROM AFB

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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Denver, Colorado



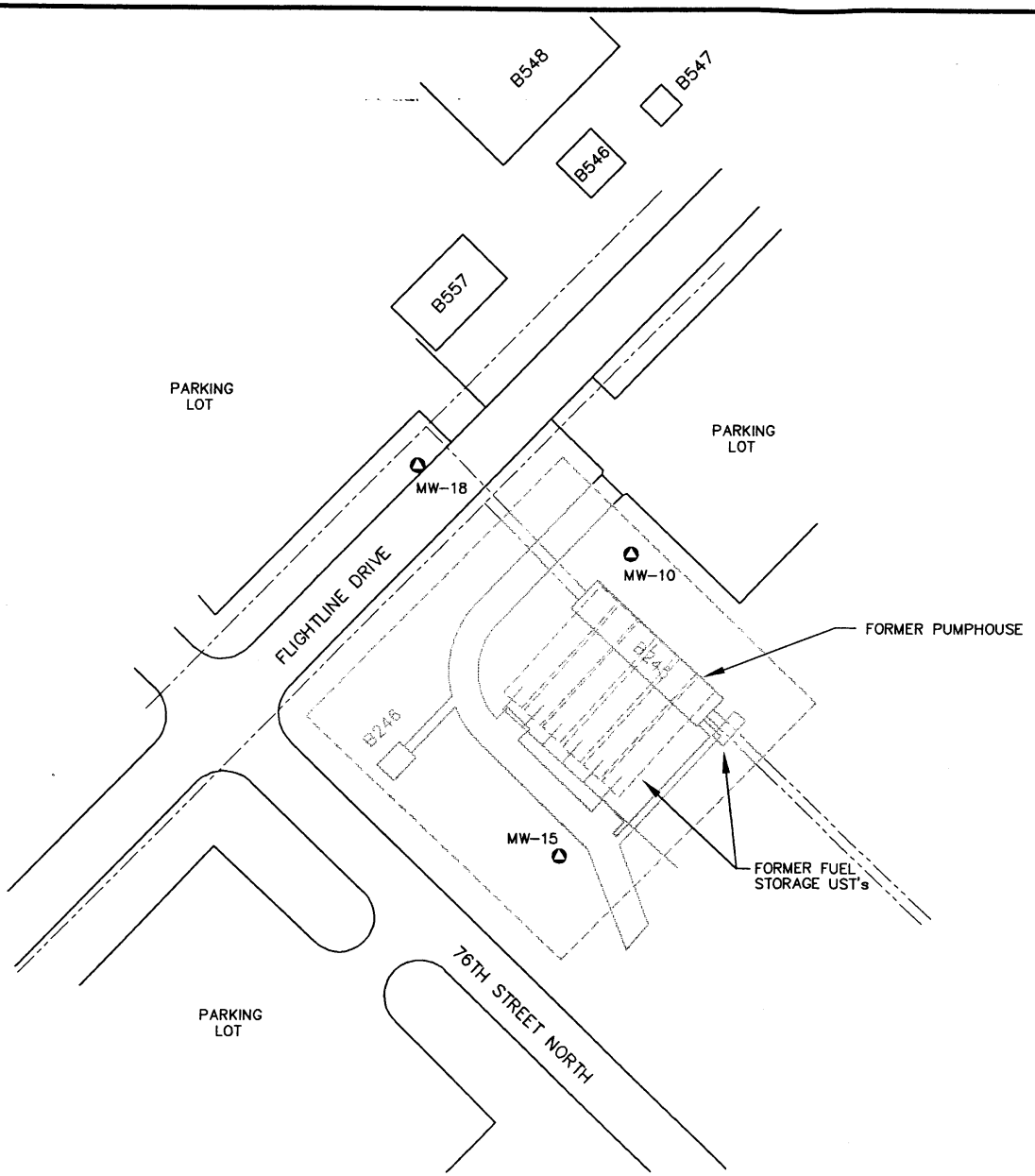
Source: USGS, 1965.

FIGURE 1.3

LOCATION OF PUMPHOUSE #2

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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Denver, Colorado



LEGEND

- RFI GROUNDWATER MONITORING WELL (1993)
- B546 — BUILDING
- FENCE LINE
- UNDERGROUND FUEL PIPELINE
- B246 — LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF THE DEMOLITION EFFORTS CONDUCTED IN MAY/JUNE 1995

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FIGURE 1.4

SITE LAYOUT

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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1.2.2 Previous Remedial Investigations

Pumphouse #2 has been characterized as a portion of IRP Site PS-3 under the US Air Force IRP (JRB Associates, 1985; Battelle, 1988; SAIC, 1991), a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) (Woodward-Clyde, 1992; HDR, 1994), and as part of the Air Force bioventing pilot test program sponsored by AFCEE (ES, 1993). The results of these investigations indicate soil and groundwater fuel hydrocarbon contamination at and surrounding Pumphouse #2. One potential source of contamination at Pumphouse #2 was a leaking fuel transfer pipeline northwest of Building 245. Soil and groundwater samples collected adjacent to the pipeline during previous investigations had the highest concentrations of benzene, toluene, ethylbenzene, and total xylene (BTEX) of all samples collected at Pumphouse #2. Analysis of samples obtained during the IRP Phase II, Stage 1 (Battelle, 1988) and Stage 2 investigations (SAIC, 1991) were interpreted by SAIC (1991) to indicate that the primary contaminant type at the site was diesel fuel. The source of this diesel fuel was thought to be USTs at Pumphouse #2. However, it is probable that there were multiple slow leaks that contributed to contamination at the site. Diesel fuel may be present in the immediate vicinity of the former pumphouse; however, the presence of high concentrations of volatile organic compounds (VOCs) across Flightline Drive indicates that jet fuel (e.g., JP-4) also may be a source of contaminants at Pumphouse #2.

Benzene, ethylbenzene, total xylenes, and naphthalene were detected in soil and groundwater at Pumphouse #2 during previous investigations. The greatest concentrations of contaminants were detected during the 1993 field investigation for the RFI. During the RFI field investigation, benzene and ethylbenzene were the only VOCs detected in groundwater at concentrations above the federal maximum contaminant levels (MCLs) of 5 micrograms per liter (µg/L) for benzene and 700 µg/L for ethylbenzene. Benzene exceeded its MCL at two wells, MW-15 and MW-18, at concentrations of 37 and 890 µg/L, respectively. Ethylbenzene exceeded its MCL at well MW-18 at a concentration of 870 µg/L (HDR, 1994). No light nonaqueous-phase liquid (LNAPL) was found in any of the three existing groundwater monitoring wells at Pumphouse #2 during the RFI investigation. Further details on the physical characteristics of Pumphouse #2 and the probable nature and extent of subsurface fuel hydrocarbon contamination are presented in Sections 3 and 4, respectively, of this EE/CA.

1.3 SUMMARY OF PROPOSED TYPE OF CLEANUP

The Air Force intends to implement a risk-based remedial action at Pumphouse #2 that is sufficient to minimize contaminant migration and eliminate potential risks to human health and the environment. The site characterization data presented in this EE/CA show that existing hazardous substance concentrations in soil and groundwater exceed the concentrations required by MDEQ (1994) UST closure rules. However, the contaminant pathway analysis performed for the site concluded that all pathways could be readily eliminated by instituting proper site management. By eliminating contaminant pathways, human health risk can be reduced to an acceptable level. No ecological receptors were found at this industrial site, and thus no risk to ecological

receptors is posed by site contaminants. Benzene concentrations currently in groundwater at the site may pose an unacceptable carcinogenic risk based on a dermal contact exposure scenario. Benzene is the only compound currently in groundwater that presents a human health risk on the basis of site-specific exposure assumptions. Groundwater use restrictions will be implemented to eliminate this potential contaminant pathway. The risk analysis also shows that existing concentrations of BTEX in shallow soil and sediment at Pumphouse #2 will result in further degradation of groundwater quality. Groundwater contaminated by contact with contaminated soil may pose an unacceptable human health risk. Thus, although contaminated soils at the site do not pose a direct risk to human health, they should be remediated to prevent the contamination of groundwater which could, in turn, pose an unacceptable risk. Contaminated shallow soils and sediments will be removed from the site and treated to eliminate this potential contaminant pathway.

Exposure controls, limited soil excavation, and natural attenuation with long-term monitoring are proposed to eliminate potential risks to onsite workers. Contaminants at the site do not and will not pose a risk to offsite receptors. Only minimal contaminant migration is anticipated due to natural physical, chemical, and biological processes that are effectively attenuating contaminants. An assessment of the effects of natural processes operating at the site suggests that, without engineered activities, these processes will be sufficient to prevent contaminants from migrating to and beyond the proposed POA at concentrations above MDEQ (1994) groundwater quality standards. This proposed POA is approximately 0.5 mile upgradient of the nearest Base boundary. No residential areas are located between Pumphouse #2 and the closest downgradient Base boundary, and future on-Base industrial land uses are not expected to change in the foreseeable future.

Supplementing natural processes with excavation and landfarming of shallow contaminated soils is an option that was evaluated in this study and is discussed in Section 8. The remedial alternative evaluation presented in this EE/CA indicates that the impact to the dissolved contaminant plume in groundwater could be reduced if source removal actions are implemented. On the basis of this evaluation, approximately 24 cubic yards (cy) of contaminated sediments and shallow soil were recommended for removal from the site. Sections 7 and 9 discuss *in situ* bioventing as an alternative and less intrusive method of reducing the BTEX concentration of this small volume of soil. Once the source of the contaminant plume at Pumphouse #2 has been removed, the plume will begin to contract due to the effects of natural attenuation processes. Long-term compliance monitoring is proposed to provide supporting evidence of plume stability and eventual contaminant attenuation, and confirmation that the predicted degree of remediation is being attained. Figure 1.5 shows the locations of the proposed long-term monitoring well network, POA, and recommended area of soil/sediment excavation (or possible bioventing).

It will cost an estimated $176,180 to implement the recommended remedial alternative for the Pumphouse #2 site. This cost estimate includes funds for 5 years of annual groundwater monitoring. It is anticipated that a risk-based closure can be obtained at the site within 3 to 5 years. MDEQ (1994) groundwater quality standards would be met at every point within the site in approximately 12 years. Up until this

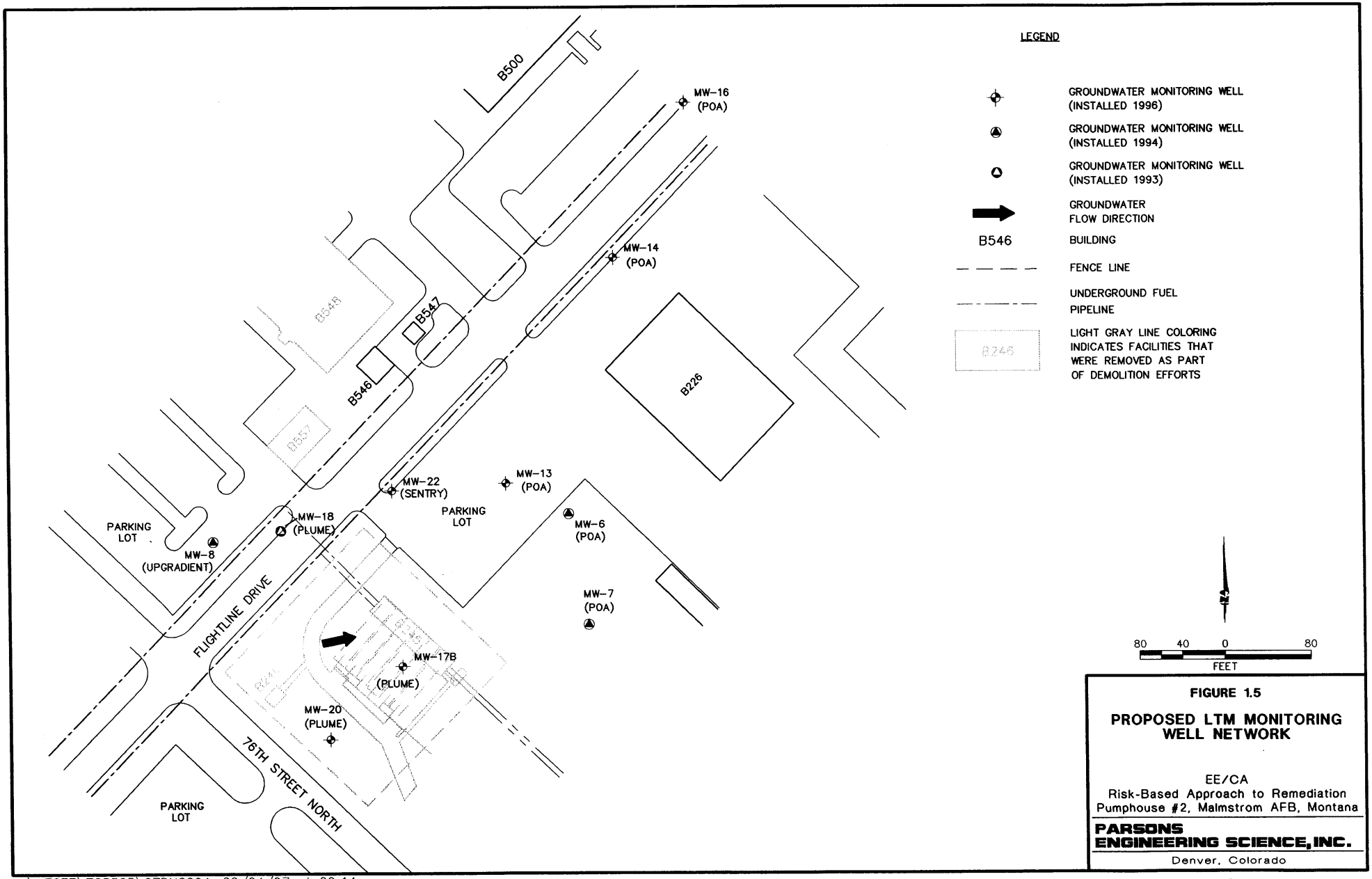


FIGURE 1.5

PROPOSED LTM MONITORING WELL NETWORK

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

K:\AFCEE\725525\97DN0094, 02/04/97 at 09:14

time, institutional controls will be used to prevent ingestion of or contact with contaminated groundwater by onsite workers.

1.3 REPORT ORGANIZATION

This EE/CA consists of 10 sections, including this introduction, and 9 appendices. Section 2 summarizes the site characterization activities performed by Parsons ES. Physical characteristics of Pumphouse #2 and the nature and extent of soil and groundwater contamination are described in Sections 3 and 4, respectively. Section 5 presents the proposed soil and groundwater cleanup objectives and requirements for the site. Section 6 documents the effects of naturally occurring physical, chemical, and biological processes on site-related contaminants, and summarizes how these processes will affect soil and groundwater contamination over time. Section 7 presents contaminant treatability pilot test results and evaluates source removal technologies. A comparative analysis of two candidate remedial alternatives is presented in Section 8. Section 9 provides a detailed implementation plan for the recommended remedial alternative, and a site-specific long-term monitoring plan is presented in Section 10.

Appendix A presents soil, groundwater, surface water, soil gas flux test, and soil gas analytical results and validation results for data collected during the 1993 RFI and the 1994/1995 field investigations. Appendix B contains the boring logs, well construction diagrams, and well development data for sampling activities completed in 1994/1995. Aquifer test data and analyses are presented in Appendix C. Appendix D presents the development of site-specific target concentrations for soil and groundwater contaminants that will be protective of human health and the environment. Appendix E contains quantitative calculations relevant to documenting the effectiveness of naturally occurring physical, chemical, and biological processes on reducing the mass, mobility, and toxicity of site-related contaminants. Appendix F contains source removal treatability testing data and calculations. Appendix G summarizes the screening and development of remedial alternatives considered in detail in Section 8 of this EE/CA. Appendix H presents a site-specific sampling and analysis plan (SAP) for use during long-term monitoring at the site. The quality assurance project plan (QAPP) for long-term sampling is presented in Appendix I.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

Field investigations were conducted by Parsons ES at Pumphouse #2 during October and November 1994, March 1995, and October 1996 to further characterize the nature and extent of contamination at and downgradient from Pumphouse #2, and to collect site-specific data documenting the effects of naturally occurring contaminant attenuation processes and the feasibility of low-cost source removal technologies. Sufficient data were collected to conduct a quantitative source and release analysis, perform an exposure pathway analysis, and evaluate the potential treatability of contaminated media using low-cost remedial technologies. Emphasis was placed on filling data gaps identified during previous remedial investigations and on collecting data relevant to documenting the biodegradation of fuel hydrocarbons in soil and groundwater.

2.1 SCOPE OF DATA COLLECTION ACTIVITIES

The field investigation focused on collecting data on the specific chemical constituents that may drive potential risks and impact the final remedial design for Pumphouse #2. The chemicals of potential concern (COPCs) for Pumphouse #2 were initially identified based on the chemical composition of the primary suspected source, jet fuel 4 (JP-4). JP-4 is a turbine fuel, used exclusively by the US Air Force, and composed of the hydrocarbon fraction that distills in the 140-degrees-Celsius (°C) to 270°C range. The fuel is predominantly a mixture of C_4 through C_{14} hydrocarbons. The major component categories (and their represented percentages by weight) in JP-4 are n-alkanes (32 percent), branched alkanes (31 percent), cycloalkanes (16 percent), benzenes and alkylbenzenes (18 percent), and naphthalenes (3 percent) (Little, 1987; Martel, 1987).

On the basis of the environmental behavior of each group of specific hydrocarbons and the results of previous site investigation activities at Pumphouse #2, the COPCs identified and addressed as part of this demonstration included the BTEX compounds and the polycyclic aromatic hydrocarbon (PAH) compound naphthalene. Soil, surface water, and groundwater analytical data collected on these COPCs were obtained using fixed-base analytical methods performed by Evergreen Analytical, Inc., of Wheat Ridge, Colorado. Soil gas analytical data were obtained by using fixed-base analytical methods performed by Air Toxics, Inc., of Folsom, California. Field and other fixed-base analytical data relevant to documenting biodegradation and assessing the effectiveness of low-cost source removal technologies also were collected.

The investigation activities completed at Pumphouse #2 during the risk-based remediation project were conducted using the approach and methodologies presented in

the *Draft Work Plan for an Engineering Evaluation/Cost Analysis in Support of the Risk-Based Approach to Remediation at Pumphouse #2* (ES, 1994a) (hereafter referred to as the work plan). The following sampling and testing activities were performed by Parsons ES at Pumphouse #2 as part of this project:

- One-year follow-up groundwater sampling and monitoring well replacements (1996);
- Collection and analysis of soil samples at 4 drainage ditch locations (1996);
- One-year sampling and evaluation of the pilot-scale *in situ* bioventing remediation system;
- Collection and analysis of soil gas samples at 5 locations;
- Collection and analysis of soil gas flux samples at 5 locations;
- Drilling and installation of 7 additional groundwater monitoring and 4 bioventing air injection wells and 1 biosparging point;
- Collection of 17 discrete subsurface soil samples from 14 soil boreholes for field screening and fixed-base analytical evaluation;
- Field screening and sampling for chemical parameters relevant to documenting fuel hydrocarbon biodegradation in 10 groundwater monitoring wells;
- Collection and analysis of 20 analytical groundwater samples from 14 groundwater monitoring wells and four other temporary sampling locations (SB-1, SB-2, GW-2, and GW-6);
- Collection and analysis of 8 analytical sediment samples from drainage ditches adjacent to the site (1996);
- Collection and analysis of 3 analytical surface water samples from standing water in drainage ditches adjacent to the site; and
- Aquifer slug testing at 4 groundwater monitoring wells.

A descriptive summary of all of the field and fixed-base analytical methods used at Pumphouse #2 is presented in Table 2.1, per MDEQ (1994) UST closure regulations. The program-specific method detection limits (MDLs) for all analytical methods used to measure COPCs also are presented in Table 2.1. The MDL is the lowest concentration at which a chemical can be measured and distinguished with 99-percent confidence from the normal "noise" of an analytical instrument or method. Table 2.1 also lists the reporting limit for each analytical method by analyte and environmental medium. In most cases, the reporting limit is equal to the practical quantitation limit (PQL) which is the lowest level at which a chemical can be accurately and reproducibly quantitated.

TABLE 2.1
ANALYTICAL METHODS AND REPORTING LIMITS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Analyte	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	Soil Reporting Limit [a/]	Soil Units	Site-Specific Water MDL	Water Reporting Limit [a/]	Water Units
Benzene	TO3	Fixed-Base	0.006	mg/L						
Toluene	TO3	Fixed-Base	0.008	mg/L						
Ethylbenzene	TO3	Fixed-Base	0.009	mg/L						
Xylene (Total)	TO3	Fixed-Base	0.009	mg/L						
Petroleum Hydrocarbons	TO3	Fixed-Base	0.130	mg/L						
Total Extractable Hydrocarbons (TEH)	M8015	Fixed-Base						0.522	5.000	µg/L
Total Volatile Hydrocarbons (TVH)	M8015	Fixed-Base			5.840	110.000	µg/kg	0.089	1.000	µg/L
Benzene	SW8020	Fixed-Base			0.400		µg/kg	0.283	0.400	µg/L
Toluene	SW8020	Fixed-Base			0.400		µg/kg	0.257	4.000	µg/L
Ethylbenzene	SW8020	Fixed-Base			0.400		µg/kg	0.283	4.000	µg/L
Xylene (Total)	SW8020	Fixed-Base			0.400		µg/kg	0.247	4.000	µg/L
1,2,3-Trimethylbenzene	SW8020	Fixed-Base			0.400		µg/kg	0.153	4.000	µg/L
1,2,4-Trimethylbenzene	SW8020	Fixed-Base			0.400		µg/kg	0.168	4.000	µg/L
1,3,5-Trimethylbenzene	SW8020	Fixed-Base			0.400		µg/kg	0.168	4.000	µg/L
Naphthalene	SW8270	Fixed-Base						0.380	10.000	µg/L
pH	SW9045	Fixed-Base				0.010	pH Units			
Total Organic Carbon	SW9060	Fixed-Base			0.015	0.050	Percent			
Moisture, Percent	E160.3	Fixed-Base				0.100	Percent			
Phosphorus, Total Orthophosphate (as P)	E300.0	Fixed-Base			0.510	2.500	mg/kg			
Alkalinity, Total (as $CaCO_3$)	E310.1	Fixed-Base				25.000	mg/kg			
Nitrogen, Total Kjeldahl	E351.3	Fixed-Base			5.000	5.000	mg/kg			
Iron	SW6010	Fixed-Base			0.032	1.600	mg/kg			
Benzene	SW8240	Fixed-Base						0.330	0.400	µg/L
Toluene	SW8240	Fixed-Base						0.380	5.000	µg/L
Ethylbenzene	SW8240	Fixed-Base						0.450	5.000	µg/L
Xylene (Total)	SW8240	Fixed-Base						0.220	5.000	µg/L
1,2,3-Trimethylbenzene	SW8240	Fixed-Base						0.200	5.000	µg/L
1,2,4-Trimethylbenzene	SW8240	Fixed-Base						0.200	5.000	µg/L
1,3,5-Trimethylbenzene	SW8240	Fixed-Base						0.200	5.000	µg/L
Electrical Conductivity	FCOND	Field							0.020	µmhos/cm
Dissolved Oxygen	FDO	Field							0.500	mg/L
pH	FPH	Field							0.000	pH Units
Redox Potential	FREDOX	Field							0.000	pE Units
Temperature	FTEMP	Field							1.000	°C

TABLE 2.1 (Concluded)
ANALYTICAL METHODS AND REPORTING LIMITS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Analyte	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	Soil Reporting Limit [a]	Soil Units	Site-Specific Water MDL	Water Reporting Limit [a]	Water Units
Iron	H8008	Field						0.010	0.024	mg/L
Nitrate	H8039	Field						0.010	0.066	mg/L
Nitrite	H8040	Field						0.005	0.010	mg/L
Sulfate	H8051	Field						0.010	0.010	mg/L
Hydrogen Sulfide	H8131	Field						0.010	0.024	mg/L
Iron, Ferrous	H8146	Field						0.010	0.024	mg/L
Alkalinity, Total (as $CaCO_3$)	H8221	Field							20.000	mg/L
Carbon Dioxide	H8223	Field						0.010	1.250	mg/L
Manganese	HMANG	Field						0.010	0.050	mg/L
Carbon Dioxide	COU-02	Fixed-Base						4.000	5.000	mg/L
Methane	RSK175	Fixed-Base						0.004	0.004	mg/L

[a] Most reporting limits are equal to the practical quantitation limit (PQL); in some cases, the reporting limit is equal to the reliable detection limit (RDL).

Table 2.2 summarizes the field and fixed-base analytical methods used at each sampling location. Field sampling and testing activities are summarized briefly in the following sections.

2.2 SOIL GAS AND SOIL FLUX MEASUREMENTS

Soil gas sampling was performed to estimate the extent of subsurface soil contamination and to determine the potential for lateral and upward diffusion of contaminated soil gas at the site. The purpose of surface flux sampling was to measure the actual upward diffusion of the volatile COPCs from the soil into the atmosphere and potentially into buildings if they were ever constructed on the site. These data are used to determine if the vapor inhalation pathway is complete.

2.2.1 Soil Gas Sampling

Soil gas samples were collected by Parsons ES in October 1994 from the five locations shown on Figure 2.1. Sampling locations were determined based on an evaluation of data from a soil gas survey performed as part of the IRP Phase II, Stage 2 investigation at the site (SAIC, 1991). Sampling activities focused on an area of hydrocarbon contamination adjacent to the fuel transfer line on the northwestern side of Flightline Drive. All soil gas samples were screened for fuel hydrocarbons, oxygen, and carbon dioxide using the test equipment and methods specified for field soil gas surveys in the AFCEE protocol documents *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing* (Hinchee *et al.*, 1992) and *Addendum One to Test Plan and Technical Protocol for a Field Treatability Test for Bioventing: Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential* (Downey and Hall, 1994).

Soil gas samples were collected and analyzed using the fixed-base EPA analytical Method TO-3 for specific volatile COPCs (i.e., the BTEX compounds) and total volatile hydrocarbons (TVH). Table 2.2 identifies the types of field and fixed-base analytical data collected at each soil gas sampling location. All sample handling and field quality assurance (QA)/quality control (QC) procedures for soil gas are specified in Appendix A of the work plan (ES, 1994a). Analytical results for soil gas samples are summarized in Section 4 and presented in tabular form in Appendix A of this EE/CA.

2.2.2 Soil Gas Flux Sampling

Five soil gas flux tests were performed at Pumphouse #2 by Parsons ES in November 1994 at the locations shown on Figure 2.1. Tests were performed at Pumphouse #2 to determine if soil contamination could potentially release VOCs into the atmosphere or nearby buildings and impact ambient air quality. Sampling points were located so that one sample (FLUX-1) was collected from a background area (i.e., an area upgradient from and presumably unaffected by site-related contamination), three from suspected source areas (FLUX-2, -3, and -5), and one (FLUX-4) from a downgradient area.

TABLE 2.2
ANALYTICAL ANALYSIS AND FIELD MEASUREMENTS BY SAMPLING LOCATION
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

SAMPLING LOCATION	NORTHING	EASTING	SAMPLE MATRIX	SAMPLING DATE	SAMPLE DEPTH (ft. bgs)	SCREENED ANALYTES AND FIELD PARAMETERS								
						BTEX	NAPH	TVH/ TEH	ELECTRON ACCEPTORS	CO_2	CH_4	MOISTURE	pH	TOC
MW-1	1195259.21	1554196.35	SOIL	4-Nov-94	6.5-7.5'	1[a]								
MW-2	1195442.71	1554338.51	SOIL	4-Nov-94	5.5-6.5'	1		X						
MW-3	1195543.01	1554339.59	SOIL	4-Nov-94	5.5-6.5'	1								
MW-3	1195543.01	1554339.59	SOIL	4-Nov-94	8.5-9.5'	1								
MW-4	1195675.65	1554102.02	SOIL	5-Nov-94	3.5-4.5'	1								
MW-5	1195735.94	1554170.77	SOIL	5-Nov-94	4.5-5.5'	1								
MW-6	1195615.69	1554417.67	SOIL	5-Nov-94	3.5-4.5'	1								
MW-7	1195513.22	1554435.41	SOIL	5-Nov-94	4.5-5.5'	1		X						
MW-8	1195590.56	1554087.97	SOIL	9-Nov-94	4.5-5.5'	1								
MW-9	1195622.16	1554118.95	SOIL	9-Nov-94	2.5-3.5'							X		
MW-9	1195622.16	1554118.95	SOIL	9-Nov-94	4.5-5.5'	1		X						
MW-9	1195622.16	1554118.95	SOIL	9-Nov-94	5.5-6.5'								X	X
MW-11	1195657.94	1554154.25	SOIL	9-Nov-94	3-4'	1								
MW-11	1195657.94	1554154.25	SOIL	9-Nov-94	4.5-5.5'							X	X	X
MW-12	1195566.9	1554201.81	SOIL	10-Nov-94	9-10'	1								
MW-12	1195566.9	1554201.81	SOIL	10-Nov-94	1.5-2.5'							X		
MW-12	1195566.9	1554201.81	SOIL	10-Nov-94	4.5-5.5'			X					X	X
MW-12	1195566.9	1554201.81	SOIL	10-Nov-94	6-7'	1								
SB-1	1554181.39	1195668.58	SOIL	22-Oct-94	4.5-5.5'	1								
SB-2	1554134.83	1195500.42	SOIL	23-Oct-94	1.5-2.5'	1								
SB-2	1554134.83	1195500.42	SOIL	23-Oct-94	3.5-4.5'	1								
BS	1554195.88	1195559.78	SOIL	10-Nov-94	4.5-5.5'	1								
SB-23	1195572.75	1554186.83	SOIL	24-Oct-96	0-0.25'	1		X[b]						
SB-23	1195572.75	1554186.83	SOIL	24-Oct-96	2-2.25'	1		X[b]						
SB-24	1195604.19	1554149.4	SOIL	24-Oct-96	0-0.25'	1		X[b]						
SB-24	1195604.19	1554149.4	SOIL	24-Oct-96	2-2.25'	1		X[b]						
SB-25	1195771.29	1554304.68	SOIL	24-Oct-96	0-0.25'	1		X[b]						
SB-25	1195771.29	1554304.68	SOIL	24-Oct-96	2-2.25'	1		X[b]						
SB-26	1195742.43	1554347.44	SOIL	24-Oct-96	0-0.25'	1		X[b]						
SB-26	1195742.43	1554347.44	SOIL	24-Oct-96	2-2.25'	1		X[b]						
SG-1	1554134.83	1195500.42	SOIL GAS	21-Oct-94	3-3.5'	2[c]								
SG-2	1554201.81	1195566.9	SOIL GAS	21-Oct-94	3-3.5'	2								

TABLE 2.2
ANALYTICAL ANALYSIS AND FIELD MEASUREMENTS BY SAMPLING LOCATION
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

SAMPLING LOCATION	NORTHING	EASTING	SAMPLE MATRIX	SAMPLING DATE	SAMPLE DEPTH (ft. bgs)	SCREENED ANALYTES AND FIELD PARAMETERS								
						BTEX	NAPH	TVH/ TEH	ELECTRON ACCEPTORS	CO_2	CH_4	MOISTURE	pH	TOC
SG-3	1554197.22	1195641.8	SOIL GAS	21-Oct-94	3-3.5'	2								
SG-4	1554155.59	1195598.23	SOIL GAS	21-Oct-94	3-3.5'	2								
SG-5	1554139.52	1195580.78	SOIL GAS	21-Oct-94	3-3.5'	2								
FLUX-1	1554220	1195266	FLUX GAS	16-Nov-94	NA	2								
FLUX-2	1554216	1195385	FLUX GAS	16-Nov-94	NA	2								
FLUX-3	1554213	1195584	FLUX GAS	16-Nov-94	NA	2								
FLUX-4	1554186	1195656	FLUX GAS	16-Nov-94	NA	2								
FLUX-5	1554158	1195610	FLUX GAS	16-Nov-94	NA	2								
MW-2	1195442.71	1554338.51	GROUND WATER	12-Nov-94	NA	1			X				X	
MW-3	1195543.01	1554339.59	GROUND WATER	17-Mar-95	NA	1								
MW-4	1195675.65	1554102.02	GROUND WATER	11-Nov-94	NA	1	X	X	X				X	
MW-5	1195735.94	1554170.77	GROUND WATER	14-Nov-94	NA	1							X	
MW-6	1195615.69	1554417.67	GROUND WATER	12-Nov-94	NA	1	X		X				X	
MW-6	1195615.69	1554417.67	GROUND WATER	16-Oct-96	NA	1		X	X	X				
MW-7	1195513.22	1554435.41	GROUND WATER	11-Nov-94	NA	1			X				X	
MW-7	1195513.22	1554435.41	GROUND WATER	17-Oct-96	NA	1		X	X	X			X	
MW-8	1195590.56	1554087.97	GROUND WATER	17-Mar-95	NA	1								
MW-8	1195590.56	1554087.97	GROUND WATER	16-Oct-96	NA	1		X	X	X				
MW-9	1195622.16	1554118.95	GROUND WATER	15-Nov-94	NA	1			X				X	
MW-9	1195622.16	1554118.95	GROUND WATER	17-Mar-95	NA	1								
MW-10	1195554.02	1554261.18	GROUND WATER	13-Nov-94	NA				X					
MW-10	1195554.02	1554261.18	GROUND WATER	14-Nov-94	NA	1		X	X				X	X
MW-11	1195657.94	1554154.25	GROUND WATER	17-Mar-95	NA	1								
MW-12	1195566.9	1554201.81	GROUND WATER	13-Nov-94	NA	1	X	X	X	X	X		X	X
MW-12	1195566.9	1554201.81	GROUND WATER	17-Mar-95	NA	1								
MW-13	1195649.38	1554361.4	GROUND WATER	13-Oct-96	NA	1		X	X	X			X	
MW-14	1195857.58	1554462.83	GROUND WATER	14-Oct-96	NA	1		X	X	X				
MW-15	1195400.17	1554231.71	GROUND WATER	13-Nov-94	NA				X					
MW-15	1195400.17	1554231.71	GROUND WATER	14-Nov-94	NA	1	X		X				X	
MW-16	1196000.49	1554529.99	GROUND WATER	14-Oct-96	NA	1		X	X	X				
MW-17A	1195484.44	1554252.99	GROUND WATER	12-Oct-96	NA	1		X	X	X			X	
MW-17B	1195478.54	1554258.74	GROUND WATER	12-Oct-96	NA	1		X	X	X			X	

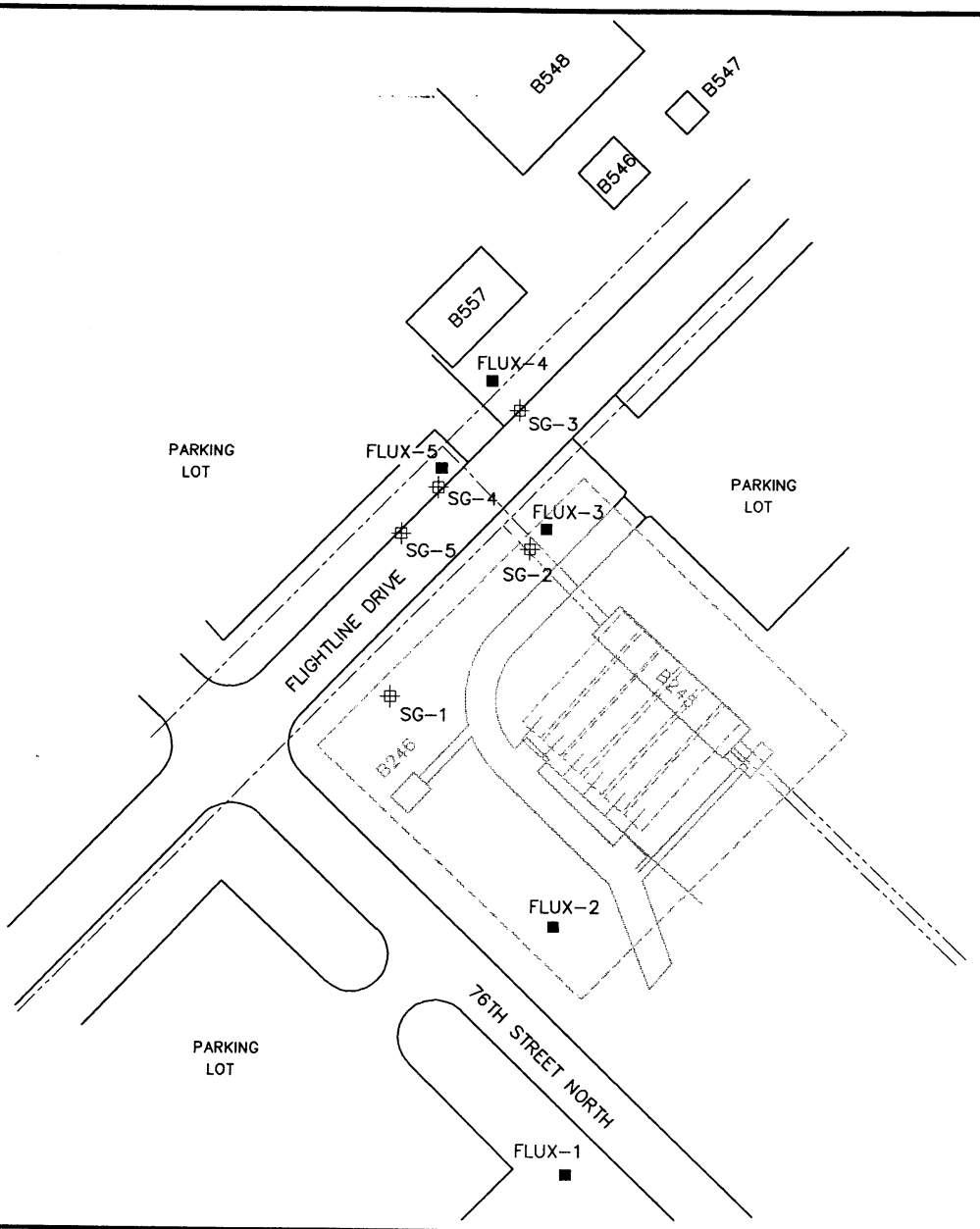
TABLE 2.2
ANALYTICAL ANALYSIS AND FIELD MEASUREMENTS BY SAMPLING LOCATION
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

SAMPLING LOCATION	NORTHING	EASTING	SAMPLE MATRIX	SAMPLING DATE	SAMPLE DEPTH (ft. bgs)	SCREENED ANALYTES AND FIELD PARAMETERS								
						BTEX	NAPH	TVH/ TEH	ELECTRON ACCEPTORS	CO_2	CH_4	MOISTURE	pH	TOC
MW-18	1195597.38	1554152.77	GROUND WATER	13-Nov-94	NA				X					
MW-18	1195597.38	1554152.77	GROUND WATER	15-Nov-94	NA	1		X	X	X	X		X	X
MW-18	1195597.38	1554152.77	GROUND WATER	16-Oct-96	NA	1		X	X	X				
MW-19	1195561.49	1554273.79	GROUND WATER	10/14/96, 12/23/96	NA	1		X	X	X			X	
MW-20	1195418.82	1554227.81	GROUND WATER	14-Oct-96	NA	1		X	X	X			X	
MW-21	1195591.68	1554229.66	GROUND WATER	13-Oct-96	NA	1		X	X	X			X	
MW-22	1195651.53	1554268.66	GROUND WATER	14-Oct-96	NA	1		X	X	X				
GW-2	1554317.25	1195506.95	GROUND WATER	5-Nov-94	NA	1								
GW-6	1554179.48	1195564.38	GROUND WATER	10-Nov-94	NA	1								
SB-1	1554181.39	1195668.58	GROUND WATER	22-Oct-94	7-7.5'	1								
SB-2	1554134.83	1195500.42	GROUND WATER	23-Oct-94	6-6.5'	1								
VW	1195533.83	1554170.97	GROUND WATER	13-Nov-94	NA	1	X		X				X	
SW-2	1554258.76	1195648.11	SURFACE WATER	22-Oct-94	NA	1							X	
SW-3	1554070.27	1195520.04	SURFACE WATER	22-Oct-94	NA	1							X	
SW-4	1554156.47	1195618	SURFACE WATER	22-Oct-94	NA	1	X						X	X
SED-1	1554116.01	1195494.46	SEDIMENT	22-Oct-94	0-0.25'	1								
SED-2	1554258.76	1195648.11	SEDIMENT	10-Nov-94	0-0.25'	1								
SED-5	1554149.57	1195531.36	SEDIMENT	10-Nov-94	0-0.25'	1								
SED-6	1554179.48	1195564.38	SEDIMENT	10-Nov-94	0-0.25'	1								
SED-7	1554211.88	1195599.23	SEDIMENT	10-Nov-94	0-0.25'	1								
SED-8	1554112.75	1195566.73	SEDIMENT	10-Nov-94	0-0.25'	1								
SED-9	1554148.61	1195604.86	SEDIMENT	10-Nov-94	0-0.25'	1								
SED-10	1554222.36	1195685.45	SEDIMENT	10-Nov-94	0-0.25'	1								

[a] 1 = SW8020: Purgeable Aromatics.

[b] X = TEH not analyzed for.

[c] 2 = TO3: Determination of Volatile Organic Compounds in Air.



LEGEND

- SOIL GAS SAMPLING LOCATION
- SOIL FLUX SAMPLING LOCATION
- B546 BUILDING
- FENCE LINE
- UNDERGROUND FUEL PIPELINE
- B546 LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF THE DEMOLITION EFFORTS CONDUCTED IN MAY/JUNE 1995

60 30 0 60
FEET

FIGURE 2.1

SOIL GAS AND SOIL FLUX SAMPLING LOCATIONS

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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Flux samples were collected at Pumphouse #2 using the equipment and procedures outlined in the EPA (1986) guidance document, *Measurement of Gaseous Emissions Rates from Land Surfaces Using a Emission Isolation Flux Chamber.* Samples were collected in a flux chamber and transferred to 1-liter SUMMA® canisters for laboratory BTEX and TVH analyses using EPA Method TO-3. If significant COPC emissions are measured, data from the flux chamber can then be combined with a simple dispersion model to identify potential ambient air quality impacts, as described in the work plan (ES, 1994a). All sample handling and field QA/QC procedures for soil gas are specified in Appendix A of the work plan (ES, 1994a). Analytical results for soil gas flux samples are summarized in Section 4 and presented in tabular form in Appendix A of this EE/CA.

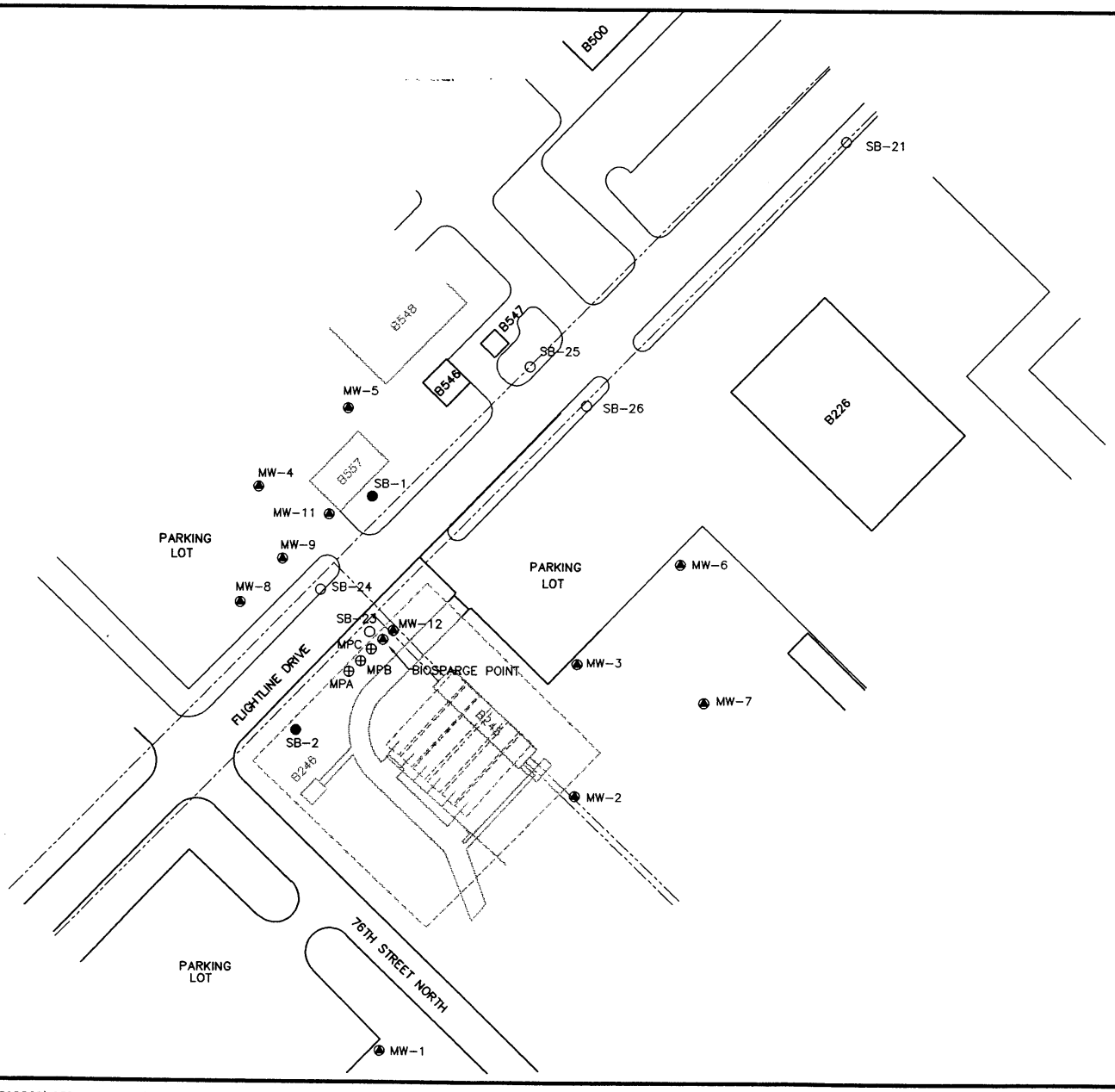
2.3 SUBSURFACE SOIL SAMPLING

Subsurface soil samples were collected at Pumphouse #2 to further delineate the nature and extent of saturated and unsaturated soil contamination at the site. New soil boreholes were drilled with the goal of expanding the existing groundwater monitoring well network and collecting additional soil quality data. During the course of the 1994 field investigation at Pumphouse #2, 17 soil samples were collected from 14 borings. Seven of the borings were completed as 2-inch-diameter groundwater monitoring wells, four were completed as 4-inch-diameter bioventing air injection wells, one was completed as a biosparging point, and two boreholes were abandoned after sample collection.

During the 1996 field investigation 8 soil samples were collected from 4 borings within the drainage ditch. No soil samples were collected from the 9 groundwater monitoring wells installed in 1996. Figure 2.2 shows the locations of all 1994 and 1996 subsurface soil sampling locations. Figure 2.3 shows the locations of all soil locations previously sampled at Pumphouse #2 as part of the IRP and RFI programs. Additional soil samples also were collected from the bottom of the excavation when the USTs were removed from the site in May and June 1995 (MCS, 1995). Figure 2.4 shows the locations of the tank closure soil samples.

All drilling and subsurface soil sampling performed as part of the risk-based site investigation took place in November 1994 and October 1996, and was accomplished using a hollow-stem auger (HSA) or hand auger, and the procedures described in the work plan (ES, 1994a). These procedures are in accordance with the general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (EPA, 1987). Samples were collected and handled as described in Appendix A of the work plan. QA/QC samples also were collected and analyzed in accordance with the work plan (ES, 1994a).

Table 2.2 presents the State of Montana state plane coordinates and sample depth interval for each of the subsurface soil sampling locations sampled as part of this EE/CA at Pumphouse #2. This table also lists the field and fixed-base analytical methods used to evaluate each of the soil samples. Analytical results for soil are included in tabular form in Appendix A. Borehole logs, well completion diagrams, well development records, and survey data are included in Appendix B. Geological



LEGEND

- GROUNDWATER MONITORING WELL (INSTALLED 1994)
- SOIL BORING (1996)
- SOIL BORING (1994)
- BIOVENTING BORINGS (1993 AND 1994)
- B546 BUILDING
- FENCE LINE
- UNDERGROUND FUEL PIPELINE
- B246 LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF DEMOLITION EFFORTS

NOTE:

NO SOIL SAMPLES WERE COLLECTED FROM SOIL BORING SB-21.

N

80 40 0 80

FEET

FIGURE 2.2

SUBSURFACE SOIL SAMPLING LOCATIONS

EE/CA

Risk-Based Approach to Remediation

Pumphouse #2, Malmstrom AFB, Montana

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Denver, Colorado

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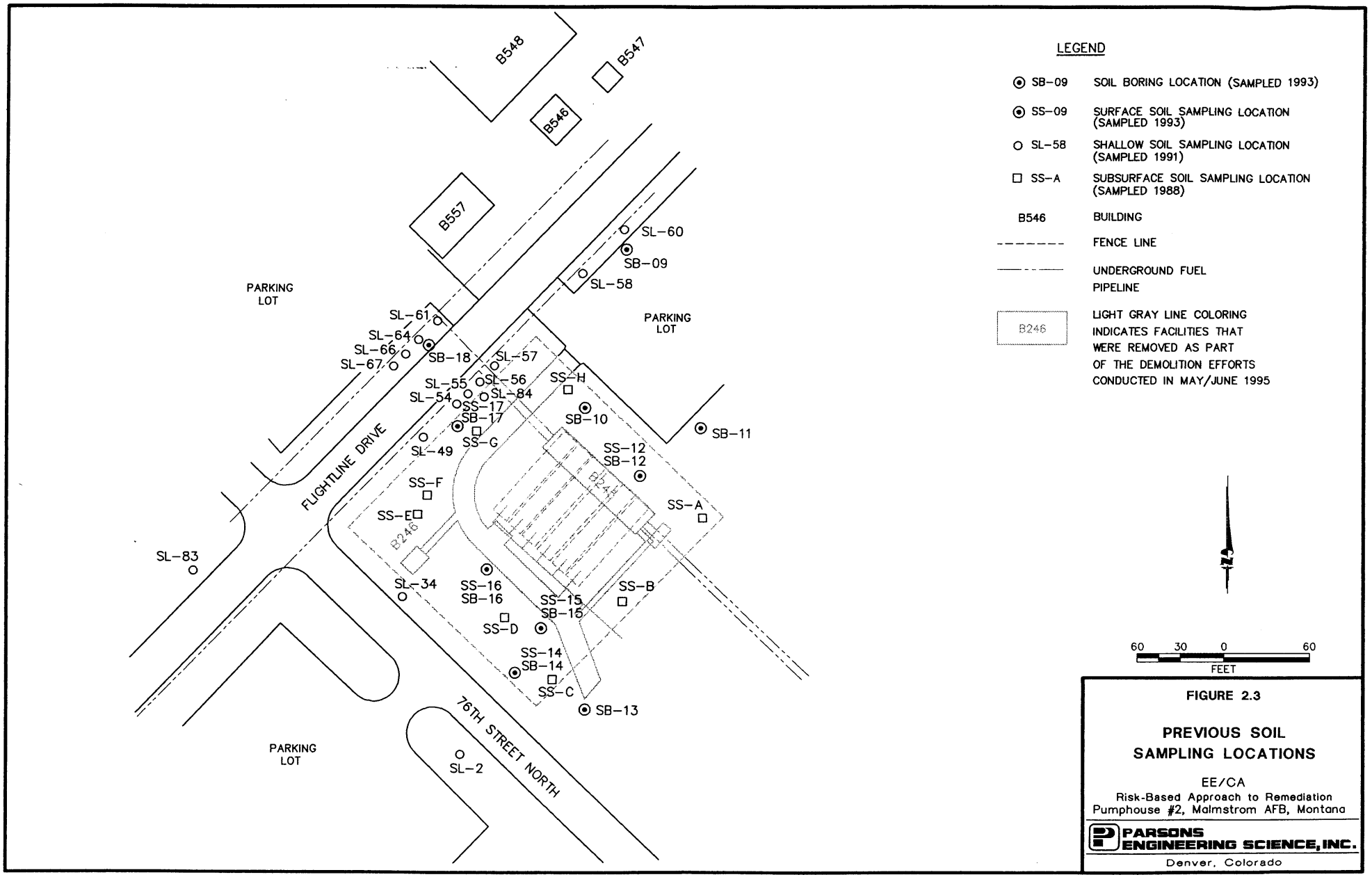


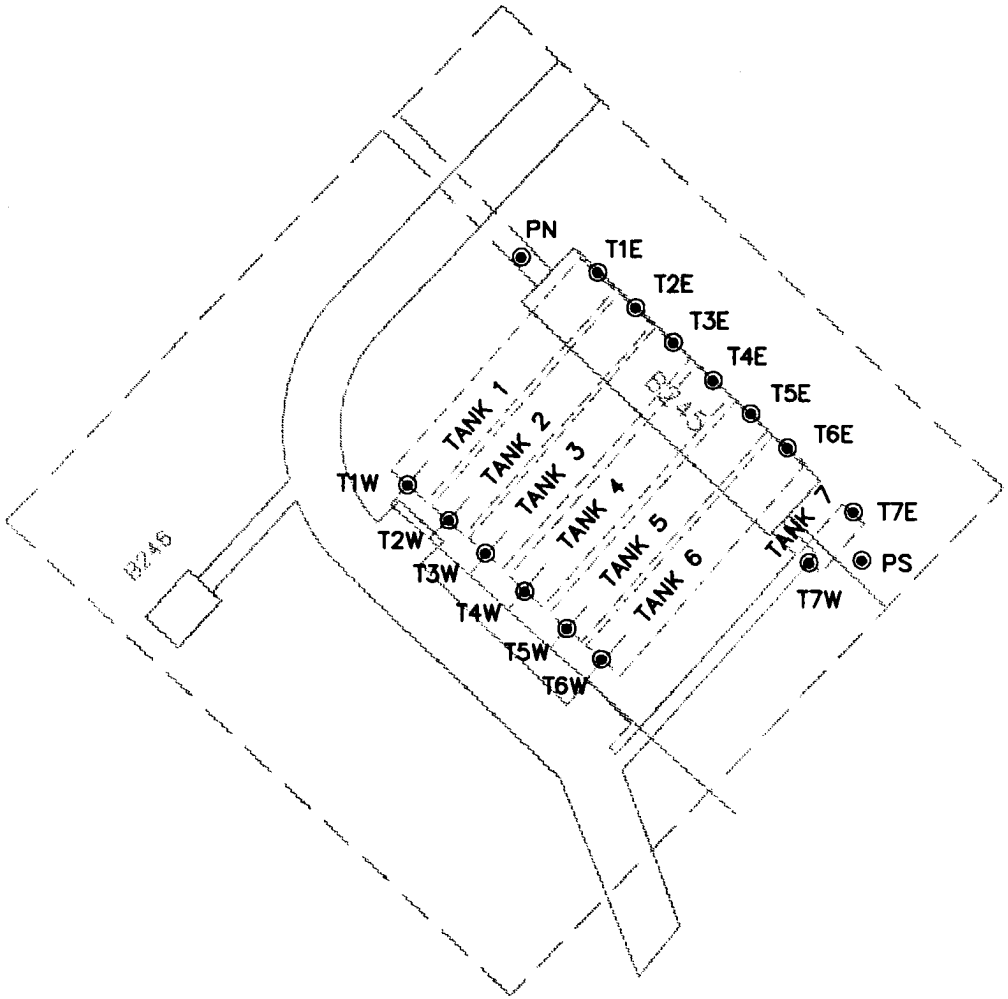
FIGURE 2.3

PREVIOUS SOIL SAMPLING LOCATIONS

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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LEGEND

T1E — TANK CLOSURE LOCATION SOIL SAMPLE (1995)

B546 — LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF THE DEMOLITION EFFORTS CONDUCTED IN MAY/JUNE 1995

50 25 0 50
FEET

FIGURE 2.4

1995 SOIL SAMPLE LOCATIONS (TANK CLOSURE SAMPLING)

EE/CA
Risk–Based Approach to Remediation
Pumphouse #2, Malstrom AFB, Montana

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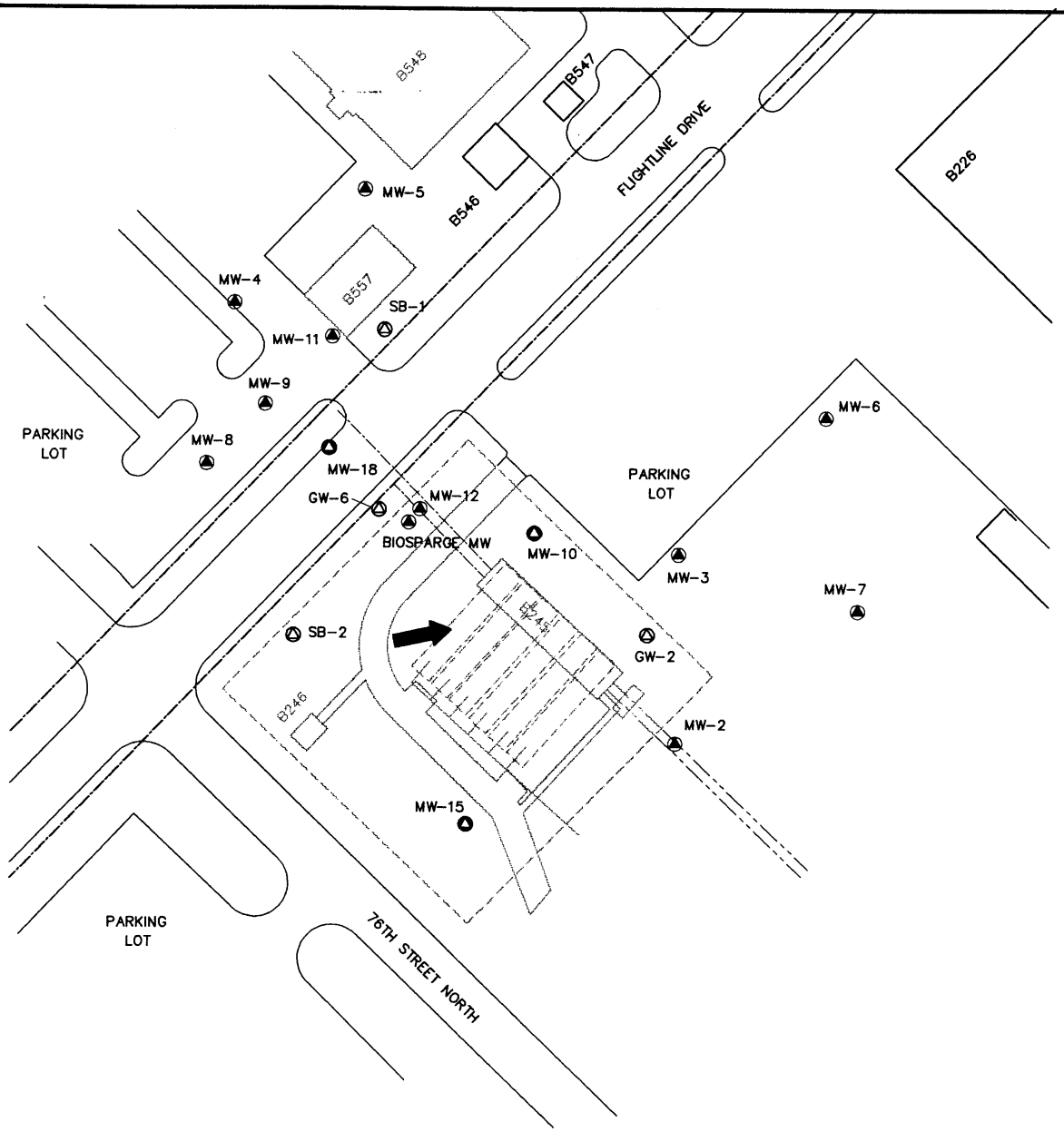
data are presented in Section 3 to characterize the physical setting of the site. Analytical results for soil are used in Section 4 to characterize the nature and extent of soil contamination at Pumphouse #2.

2.4 GROUNDWATER SAMPLING

During the November 1994 field investigation groundwater samples were collected from 10 newly constructed and 3 existing groundwater monitoring wells at Pumphouse #2 to further delineate the nature and extent of dissolved petroleum hydrocarbon contamination. Geochemical data relevant to documenting the potential for biodegradation of dissolved COPCs and quantitatively investigating chemical fate and transport also were collected. During the October 1996 field investigation groundwater samples were collected from 9 newly constructed and 4 existing groundwater monitoring wells. Groundwater samples were collected using the procedures described in the work plan (ES, 1994a). These procedures are in accordance with the general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (EPA, 1987). Investigation activities included well development or purging, sampling, water level measurements, and field and fixed-base analytical measurements.

Groundwater samples were collected in November 1994 and March 1995 from the 18 different sampling locations listed in Table 2.2 and shown on Figure 2.5. It should be noted that MW-1, a background monitoring well, was not sampled due to insufficient groundwater volume in the well casing. Both field and fixed-base analytical data were collected at 10 of the groundwater sampling locations. Fixed-base analytical sampling was performed at the remaining eight locations where insufficient groundwater volume prevented the collection of field data.

Groundwater samples were collected in October 1996 from the 13 different sampling locations listed in Table 2.2 and shown on Figure 2.6. Both field and fixed-base analytical data were collected at each of the 13 groundwater sampling locations. During each sampling event QA/QC samples were collected and analyzed in accordance with Appendix A of the work plan (ES, 1994a). All groundwater samples, including QA/QC samples, were analyzed for the BTEX compounds using EPA Method SW8020. EPA Method SW8270 was used to quantify the target PAH compound (specifically naphthalene). The complete list of fixed-base analytical and field methods used to evaluate groundwater samples by sampling location is presented in Table 2.2. Field and laboratory analytical data were collected to evaluate natural attenuation processes in accordance with the draft AFCEE document *Technical Protocol for Implementing the Intrinsic Remediation (Natural Attenuation) with Long-Term Monitoring Option for Dissolved Fuel Contamination in Groundwater* (Wiedemeier *et al.*, 1995), prepared by Parsons ES and the EPA's Subsurface Protection and Remediation Division. Hydrogeological data are presented in Section 3 to characterize the physical setting of the site. Analytical data are used in Section 4 to characterize the nature and extent of groundwater contamination at the site. All groundwater sampling results are presented in tabular form in Appendix A.



LEGEND

- GROUNDWATER MONITORING WELL (INSTALLED 1994)
- GROUNDWATER MONITORING WELL (INSTALLED 1993)
- TEMPORARY GROUNDWATER MONITORING WELL (INSTALLED 1994)
- GROUNDWATER FLOW DIRECTION
- B546 BUILDING
- FENCE LINE
- UNDERGROUND FUEL PIPELINE
- B246 LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF THE DEMOLITION EFFORTS CONDUCTED IN MAY/JUNE 1995

N

60 30 0 60
FEET

FIGURE 2.5

1994 GROUNDWATER SAMPLING LOCATIONS

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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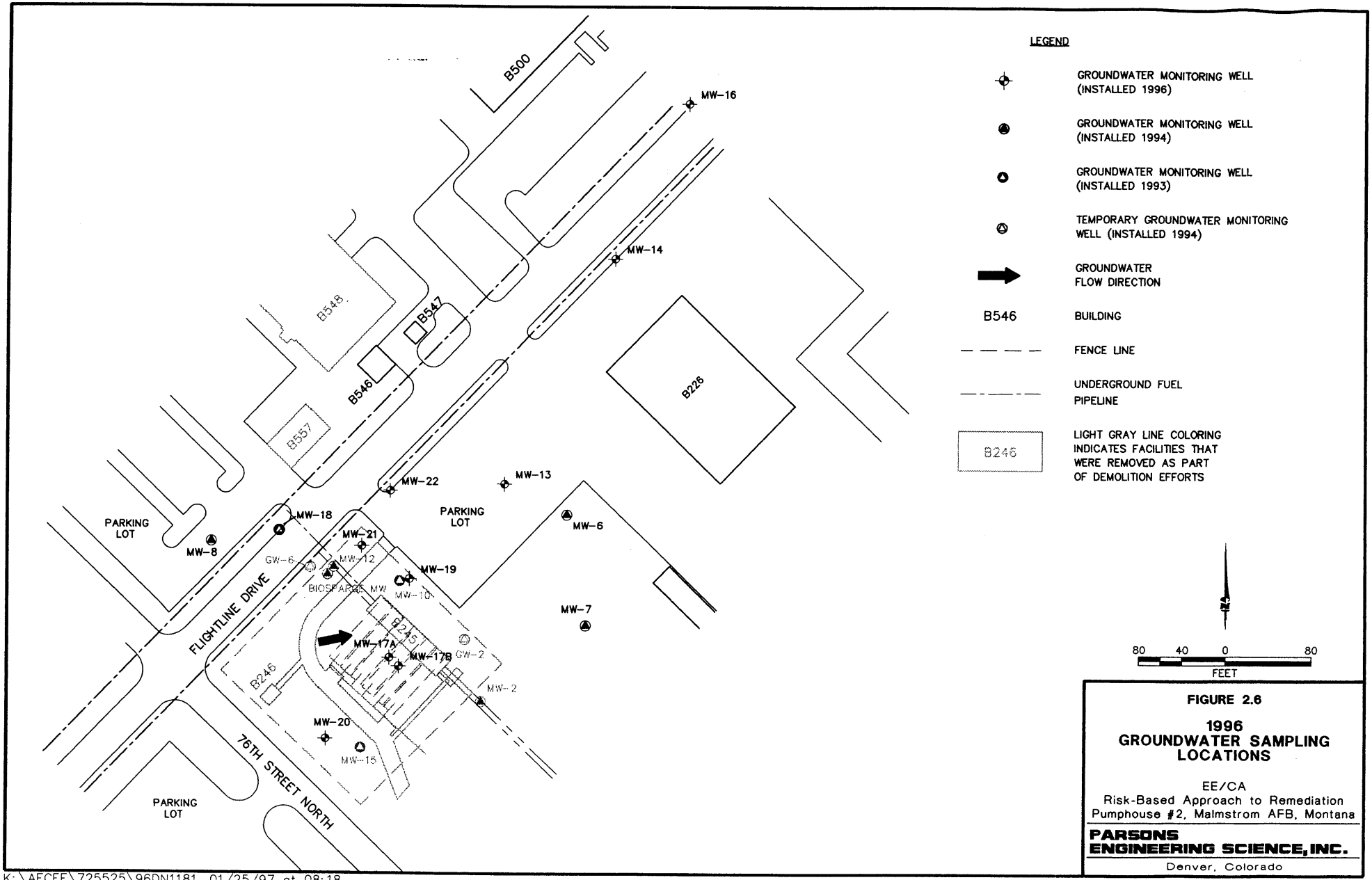


FIGURE 2.6

1996 GROUNDWATER SAMPLING LOCATIONS

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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2.5 SEDIMENT SAMPLING

Sediment samples were collected from the bottom of two large drainage ditches that run parallel to Flightline Drive along the northwestern edge of the site (Figure 2.7). These ditches drain to the northeast. Samples were collected to determine if shallow soil or groundwater contamination related to potential leaking fuel transfer lines in the area could have adversely impact surface water quality. Eight samples were collected from the locations shown on Figure 2.7. All sediment samples were collected in accordance with Appendix A of the work plan (ES, 1994a), and were analyzed for the BTEX compounds using EPA Method SW8020. Table 2.2 presents the State of Montana state plane coordinates and sample depth interval of each of the sediment soil sampling locations sampled as part of this field effort at Pumphouse #2. Analytical results for sediments are included in tabular form in Appendix A.

2.6 SURFACE WATER SAMPLING

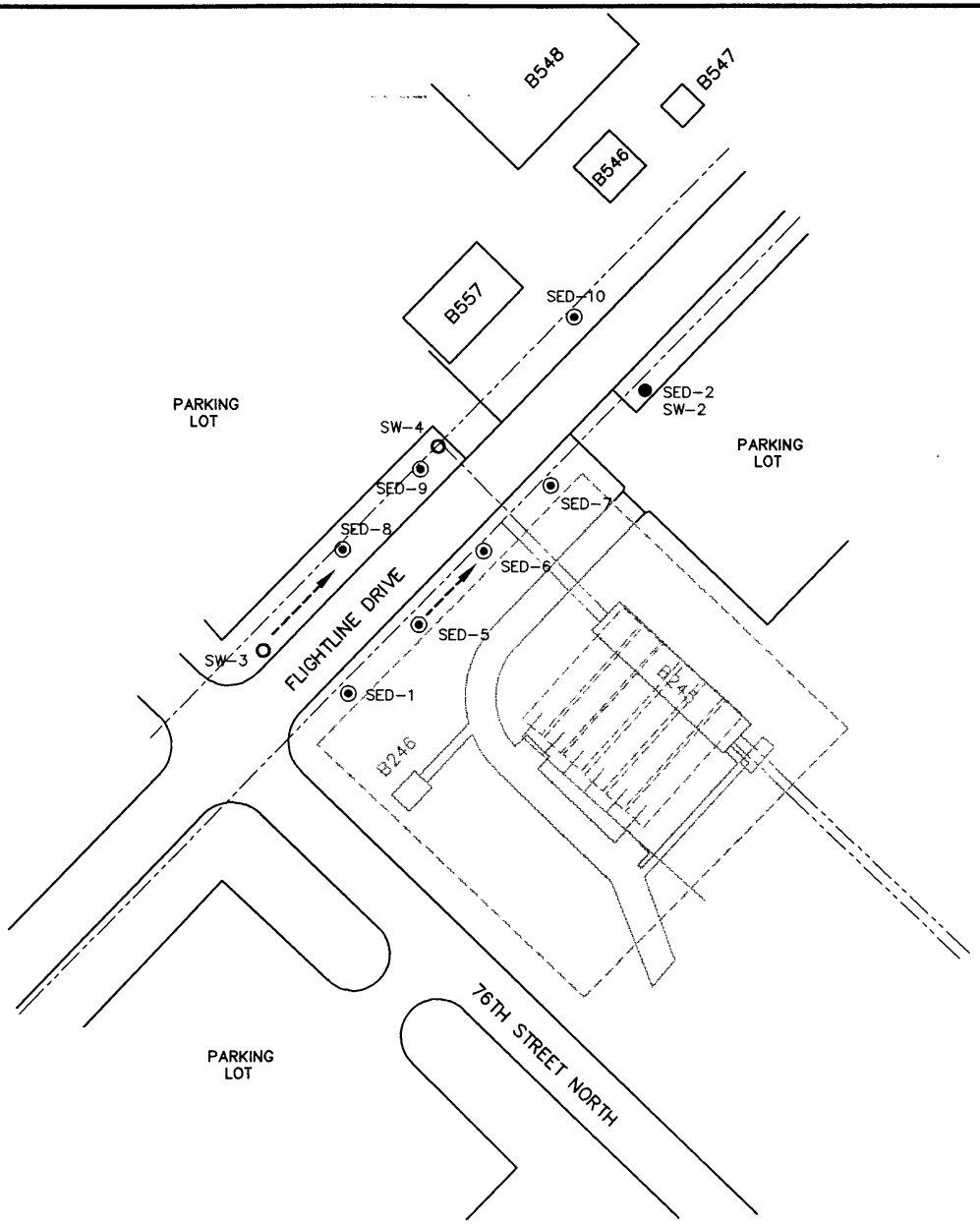
Surface water sampling was also performed at three locations in the two drainage ditches immediately northwest of Pumphouse #2 along Flightline Drive (Figure 2.7). Sampling was performed to determine if contaminated shallow soils or groundwater at Pumphouse #2 currently are adversely impacting surface water quality in the vicinity of the site. All samples were collected and analyzed in accordance with Appendix A of the work plan (ES, 1994a). Three grab samples were collected from areas of standing water in October 1994 and analyzed for the BTEX compounds using EPA Method SW8020. One sample, SW-4, also was analyzed using Method SW8270 to quantify target PAH compounds. Table 2.2 presents the State of Montana state plane coordinates of each of the surface water sampling locations sampled as part of this field effort at Pumphouse #2. This table also lists the fixed-base analytical methods used to evaluate each of the surface water samples. Analytical results for surface water samples are included in tabular form in Appendix A.

2.7 AQUIFER TESTING

Aquifer slug tests were performed at four wells in and around Pumphouse #2 to estimate the hydraulic conductivity of the shallow saturated zone. Testing was performed by Parsons ES personnel in November 1994 at the locations shown on Figure 2.8. Rising and falling head tests were performed at each testing well. Water levels during testing were recorded on a Hermit Environmental Data Logger® (Model SE1000B). Tests were conducted in accordance with the work plan (ES, 1994a). Aquifer test results are described in Section 3, and test data and analyses are presented in Appendix C.

2.8 SOURCE REDUCTION TREATABILITY TESTING

Bioventing is an innovative technology that uses low rates of air injection to supply oxygen to soil bacteria employed in the biodegradation of fuel hydrocarbons. An extended bioventing pilot test was performed at Pumphouse #2 during 1993 and 1994 to assess whether this low-cost source reduction technology could be used to remediate contaminated soil, if necessary to protect human health and the environment. This



LEGEND

- SED-9 — SEDIMENT SAMPLING LOCATION
- SW-4 — SURFACE WATER SAMPLING LOCATION
- SED-2 / SW-2 — SEDIMENT AND SURFACE WATER SAMPLING LOCATION
- DIRECTION OF DITCH DRAINAGE
- B546 — BUILDING
- FENCE LINE
- UNDERGROUND FUEL PIPELINE
- B248 — LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF THE DEMOLITION EFFORTS CONDUCTED IN MAY/JUNE 1995

N

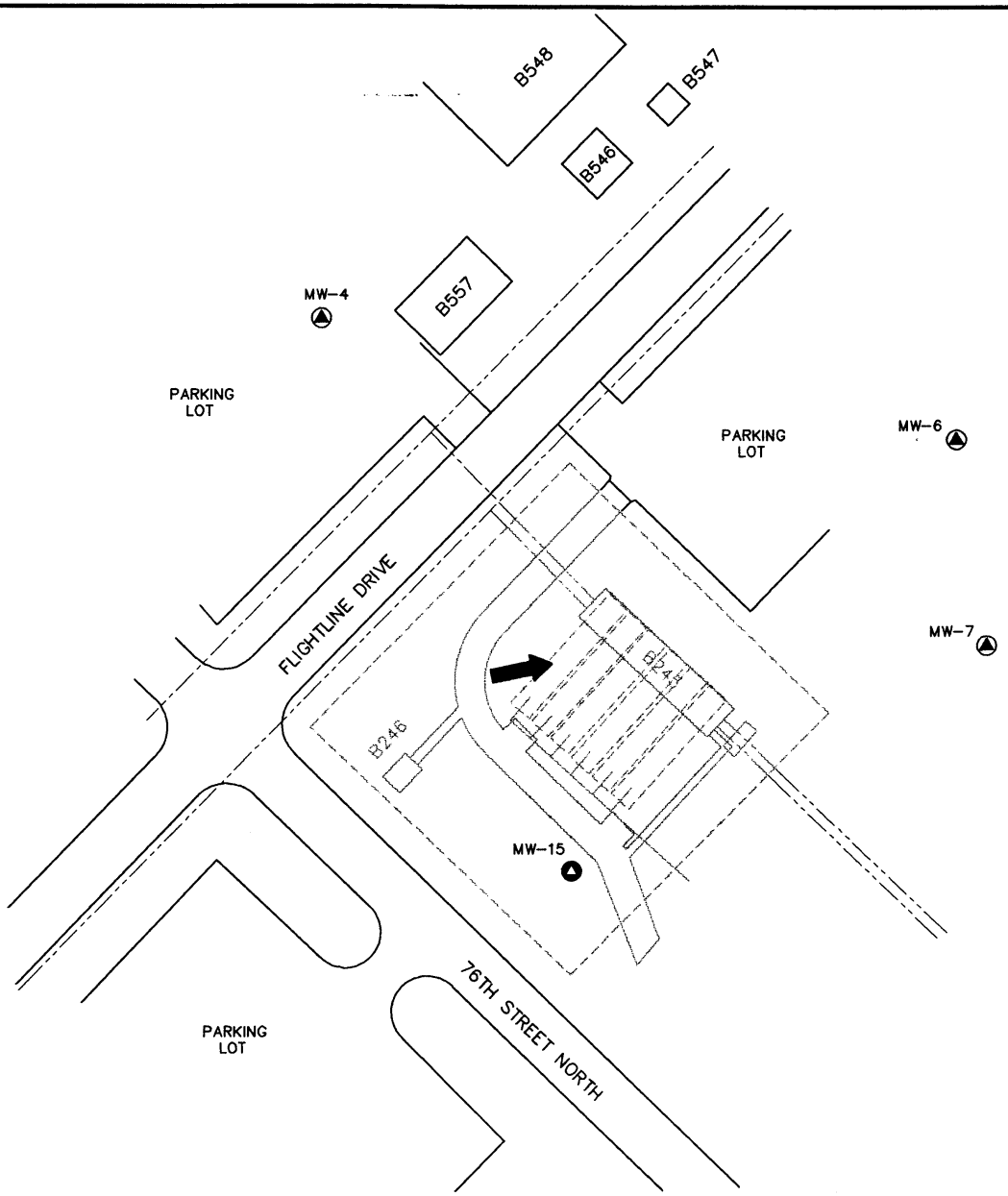
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FIGURE 2.7
1994
SURFACE WATER AND SEDIMENT SAMPLING LOCATIONS

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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LEGEND

MW-7 — SLUG TEST LOCATION

GROUNDWATER FLOW DIRECTION

B546 — BUILDING

FENCE LINE

UNDERGROUND FUEL PIPELINE

B246 — LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF THE DEMOLITION EFFORTS CONDUCTED IN MAY/JUNE 1995

N

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FEET

FIGURE 2.8

SLUG TEST LOCATIONS

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

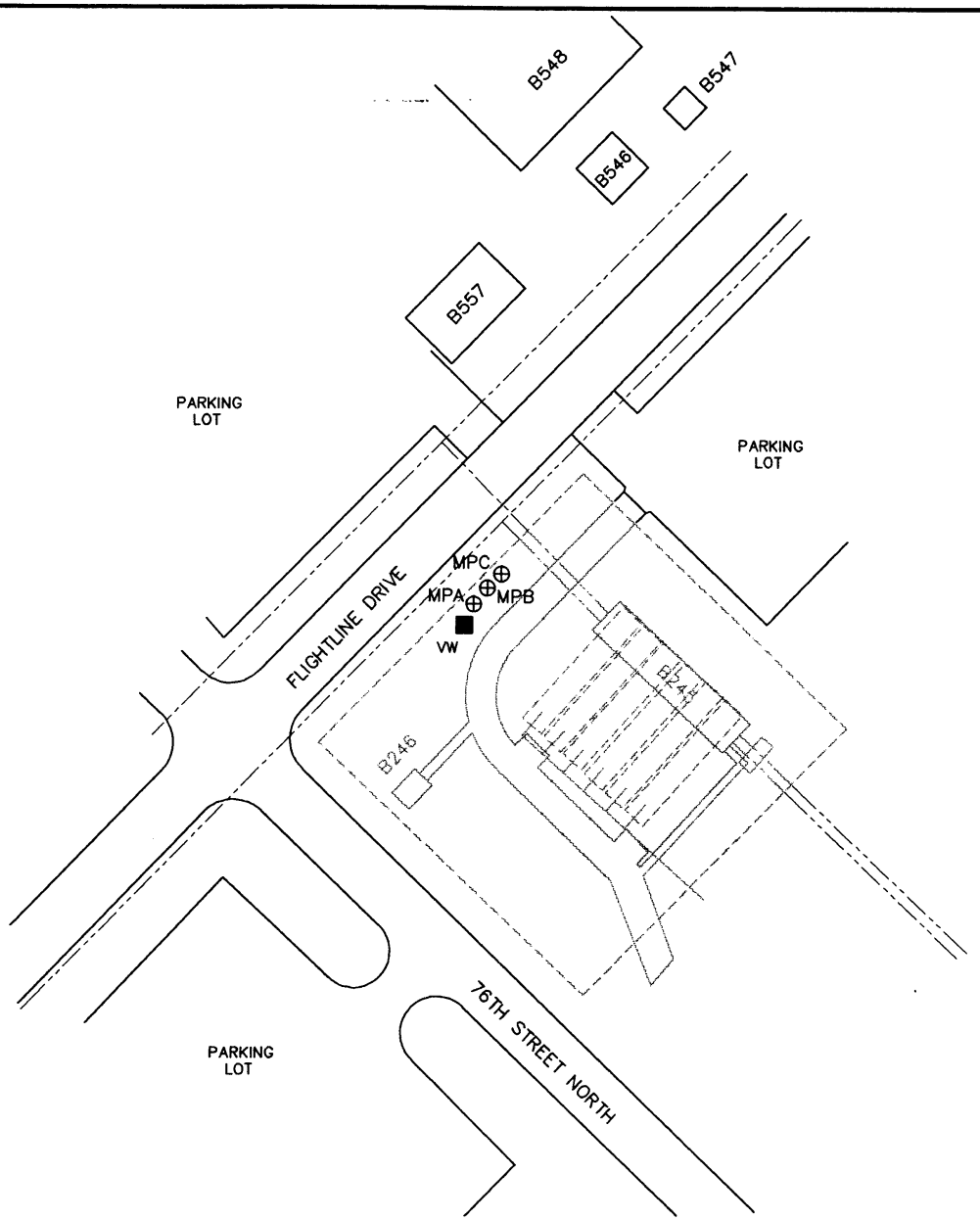
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pilot test was performed as part of a nation-wide AFCEE bioventing initiative unrelated to the current risk-based program. In October 1993, three vapor monitoring points and one air injection bioventing test well were drilled and installed at the site. Air injection well and monitoring point locations are shown on Figure 2.9. Respiration testing, an air permeability test, and an oxygen influence test were completed in accordance with the procedures described in the AFCEE bioventing protocol documents (Hinchee *et al.*, 1992; Downey and Hall, 1994).

In April 1994, 6-month respiration testing was performed at the site to assess system performance. During the EE/CA field effort in October 1994, final respiration testing was performed, and confirmatory soil gas and soil samples were collected. Data related to the bioventing feasibility test are summarized in Section 7, and demonstration data and analyses are presented in Appendix F.

A biosparging pilot test was also conducted as part of the risk-based field investigation. Biosparging involves the injection of air into saturated soils with the purpose of increasing dissolved oxygen (DO) concentrations to enhance the biodegradation and volatilization of VOCs. A single biosparging test well was constructed at Pumphouse #2 as part of the risk-based demonstration at Pumphouse #2 (Figure 2.5). The goal of the biosparging test was to measure the increase in the DO concentrations created by sparging and to determine the flow rates required for a full-scale biosparging system in the event that this type of remediation is warranted. Test results are presented in Section 7, and treatability data are presented in Appendix F.



LEGEND

MPA ⊕	SOIL GAS MONITORING POINT
VW ■	VENT WELL
B546	BUILDING
- - - - - - -	FENCE LINE
———	UNDERGROUND FUEL PIPELINE
B246	LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF THE DEMOLITION EFFORTS CONDUCTED IN MAY/JUNE 1995

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FEET

FIGURE 2.9

BIOVENTING PILOT TEST LOCATION

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of the Pumphouse #2 site, as determined from data collected during the IRP and RFI field investigations, bioventing system installation in 1993, and the risk-based field investigation conducted by Parsons ES in the fall of 1994. Data incorporated into this section from previous investigations were taken from various stages of the IRP investigation performed by JRB Associates (1985), Battelle (1988), and SAIC (1991), as well as the RFI performed by HDR (1994). The majority of the previous site data were taken from the draft RFI report, which summarizes all investigations conducted at the site prior to the Parsons ES 1994/1995 risk-based field investigation. A summary of all site characterization activities performed by Parsons ES at Pumphouse #2 as part of the risk-based project was presented in Section 2 of this EE/CA.

3.1 REGIONAL TOPOGRAPHY AND SURFACE WATER HYDROLOGY

Malmstrom AFB is located in Cascade County, Montana, at the eastern edge of the City of Great Falls. The topography of this region of north-central Montana is typified by rolling plains. The Base is set on a plateau that slopes to the north toward the Missouri River, located approximately 1 mile north of the Base (refer to Figure 1.2). The average elevation of the Base is 3,535 feet above mean sea level (msl). Terrain across the Base typically consists of rolling hills intersected by ephemeral stream valleys. These valleys are dry most of the year and generally flow only during significant storm events and spring run-off (HDR, 1994).

One body of surface water, Pow Wow Pond, is located within the boundaries of Malmstrom AFB. The pond, located in the eastern portion of the Base, is man made and is used as a recreation facility for Base personnel. Surface water drainage on the Base generally follows the topographic slope, flowing to the north and northeast. Once reaching the northern boundary of the Base, storm water is directed into coulees or ditches that flow toward the Missouri River. Several small, unnamed ponds are located just to the north the northern Base boundary (Figure 1.3). The nearest of these surface water bodies is about 2,500 feet north of Pumphouse #2.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

3.2.1 Geology

Malmstrom AFB is located in an area of continental glaciation that eroded and redeposited glacially derived sediments over the Lower Cretaceous Kootenai Formation. Glacial till and glaciolacustrine sediments form the majority of the surface

sediments in the vicinity of the Base. These deposits reach a maximum thickness of over 200 feet in the ancestral valley of the Missouri River along the northern boundary of the Base. Holocene aeolian sand deposits are also common in the northwestern portion of the Base (HDR, 1994).

Glacial deposits that form the surface sediments at Malmstrom AFB are underlain by the red and maroon mudstones and shales of the Kootenai Formation. Depth of the formation varies from surface exposure near the southern edge of the Base to approximately 200 feet below ground surface (bgs) at the northwestern corner of the Base. The Kootenai is successively underlain by the mudstone, shale, and limestone sequences of the upper Jurassic Morrison Formation, the sandstone of the middle and upper Jurassic Swift Formation, and the limestone of the Mississippian-age Madison Group (HDR, 1994).

Glacial till, the most common surface sediment at Malmstrom AFB, is exposed at the surface on most of the southeastern portion of the Base. The till is typically a unstratified glacial drift containing clay, silt, and sand with scattered pebble-, cobble-, and boulder-sized clasts. Samples of till collected from Malmstrom AFB as part of the RFI investigation contained approximately 42 to 49 percent clay. The till has been shown to be relatively impermeable and is characterized by a low moisture content. Typical estimates for the conductivity of fractured glacial till average 1.0×10^{-7} centimeter per second (cm/sec). The average porosity of 70 samples collected for geotechnical analysis during the RFI was 33.8 percent. Glacial till encountered during the RFI investigation was typically gray to tan-dark brown in color, moist, and stiff to very stiff. Random gravel, carbon deposits, calcareous nodules, and gypsum deposits were all observed in the till (HDR, 1994).

3.2.2 Hydrogeology

Several sandstones within the Kootenai Formation have been shown to be viable deep groundwater aquifers. Reported yields from the deep aquifers have ranged from 5 to 50 gallons per minute (gpm), with an average yield from 24 off-Base wells reported at 19 gpm (HDR, 1994). Water-bearing sandstone beds in the formation are 180 to 200 feet bgs and appear to be noncontinuous and isolated. Depending on location, groundwater may be under perched, confined, or unconfined conditions. In the vicinity of Malmstrom AFB, the Kootenai is likely under confined conditions due to the overlying impermeable glacial till (HDR, 1994).

Shallow groundwater in the region is confined to isolated areas of discontinuous, perched groundwater in fill or aeolian sand deposits above glacial till. During previous investigations at Malmstrom AFB, groundwater was not encountered in shallow borings advanced into glacial till in the southern and eastern portions of the Base. This is consistent with the reported low permeability of glacial till. Shallow borings in the northwestern portion of the Base encountered shallow groundwater in aeolian deposits underlain by glacial till. These deposits did not extend below 10 to 12 feet bgs and appeared to be isolated and nonuniform. Groundwater also has been encountered in shallow fill resting on glacial till. In addition, it is probable that underground utility corridors and other backfilled areas are receptive to the flow and storage of perched shallow groundwater (HDR, 1994).

Recharge of the shallow, perched groundwater may occur due to infiltration, percolation of precipitation and irrigation water, stream flow and drainage ditch discharge, and water line leakage. Discharge of groundwater may occur by evapotranspiration, stream flow gain, seeps, and leakage through fractures in the underlying till. It is likely that perched, shallow groundwater is discontinuous, and movement will be slow and affected by the presence of disturbed fill (e.g., pipeline backfill and backfilled excavations) (HDR, 1994).

3.3 SITE TOPOGRAPHY AND SURFACE WATER HYDROLOGY

The topography of Pumphouse #2 and the surrounding area generally slopes toward the northeast, paralleling Flightline Drive and the runway. The slope is very gentle, with a total relief across the site of approximately 3 feet over 230 horizontal feet. Deep ditches along either side of Flightline Drive are the most prominent topographical features in the vicinity of Pumphouse #2. Immediately to the northwest of Pumphouse #2, the bottom of the ditch is approximately 4 feet below road grade. The average surface elevation of the site is 3,440 feet above msl.

All surface and subsurface structures and USTs at the site were removed in May and June of 1995. This action effectively removed any possible source of fuel remaining at the site. The site currently consists of fill material covered with graded gravel. Several fuel transfer lines paralleling Flightline Drive and the hydrant refueling system underneath the aircraft ramp to the south of the site were abandoned in place (Figure 1.4).

There are no permanent surface water bodies in the immediate vicinity of Pumphouse #2. The closest permanent surface water body is Pow Wow Pond, located in the eastern portion of the Base approximately 1 mile southeast of Pumphouse #2. The only surface water drainage features in the vicinity of Pumphouse #2 are two drainage ditches on either side of Flightline Drive. These ditches contain water only after precipitation events. Surface drainage at Pumphouse #2 is toward the northeast, paralleling Flightline Drive. Upon reaching the northern boundary of the Base, storm runoff is routed to ditches and coulees that drain to the Missouri River, approximately 1 mile north of the Base.

3.4 SITE GEOLOGY AND HYDROGEOLOGY

The vadose zone, phreatic soils, and shallow groundwater at Pumphouse #2 were characterized by Parsons ES personnel during October and November 1994. Data collected as part of this field test were used to supplement geologic and hydrogeologic data collected during previous IRP and RFI investigations at the site.

3.4.1 Site Lithology and Stratigraphic Relationships

Drilling and soil sampling results at Pumphouse #2 show that the local geology consists of a veneer of fill and aeolian sand deposits overlying glacial till. Generally, the stratigraphy of the deposits can be described as 1 to 2 feet of gravel, fill, and/or asphalt overlying 2 to 6 feet of sandy clay, which rests on glacial till. Isolated lenses of coarse sand and gravel were encountered in several boreholes at Pumphouse #2.

Lenses were typically 6 inches thick and well graded. North-south and east-west hydrogeologic cross sections are shown in Figures 3.1 and 3.2, respectively.

Typical glacial till encountered at the site was tan to dark brown, moist, very stiff, and contained carbon and calcareous deposits. The sandy clay found above the till was typically gray and very moist with a uniform sand content. No boreholes were completed more than 2 feet into the till (approximately 10 feet bgs). Based on previous investigations, the till is known to be at least 10 feet thick in the vicinity of Pumphouse #2. No borings at the site have ever been completed deeper than 21 feet bgs. The relatively impermeable till is considered to be the lower confining layer of the shallow, perched groundwater at Pumphouse #2.

3.4.2 Site Hydrogeology

Hydrogeology at Pumphouse #2 is highly variable and nonuniform. Several wells in the area did not produce any measurable quantities of groundwater during the field investigation. Other wells, however, produced large volumes of groundwater. In several cases, producing wells were less than 60 feet from wells that either produced no groundwater or recharged extremely slowly (approximately 0.1 gallon per month). It appears that shallow groundwater at the site is perched and discontinuous. It also appears that perched groundwater may be preferentially flowing across the site through higher permeability utility corridors and other backfilled areas at the site. Wells in the vicinity of the utility corridors paralleling Flightline Drive produced large quantities of groundwater. Wells placed away from Flightline Drive typically were either dry or very slow to recharge.

During UST removal activities in May and June 1995, approximately 40,000 gallons of groundwater was removed from the excavation. A seep was apparent in the northwestern wall of the excavation in the vicinity of the bioventing system. Wells placed in this area during the risk-based site investigation readily produced large quantities of water. To determine what effect the removal of large quantities of groundwater had on local hydrogeology, water levels were collected from all wells at the site on December 5, 1995 by Malmstrom AFB personnel at the request of Parsons ES. A December 1995 groundwater surface map for Pumphouse #2 is presented in Figure 3.3. Several wells that were used in past investigation could not be located in December 1995. These wells were either destroyed during UST removal or buried during backfilling. Wells no longer available for use are shown in gray on the figure. Using water level data from nine wells at the site, the inferred groundwater flow gradient at the site is to the east-northeast. It does not appear that the removal of the USTs from the site greatly affected site hydrogeology. The gradient appears to be uniform across the site. Depth to water ranged from 1.99 to 5.81 feet bgs in December 1995. Groundwater was uniformly higher in December 1995 than March 1995, again indicating that groundwater removal during UST excavation had little effect on local hydrogeology. The groundwater elevation difference between MW-8 and MW-6 was approximately 5.9 feet at the time of measurement. This corresponds to an average hydraulic gradient of 0.018 foot per foot (ft/ft) across the site. Figure 3.4 presents the groundwater surface map for the October 1996 sampling event. The new wells installed in October 1996 provided a more refined estimate of groundwater flow, particularly near Flightline Drive.

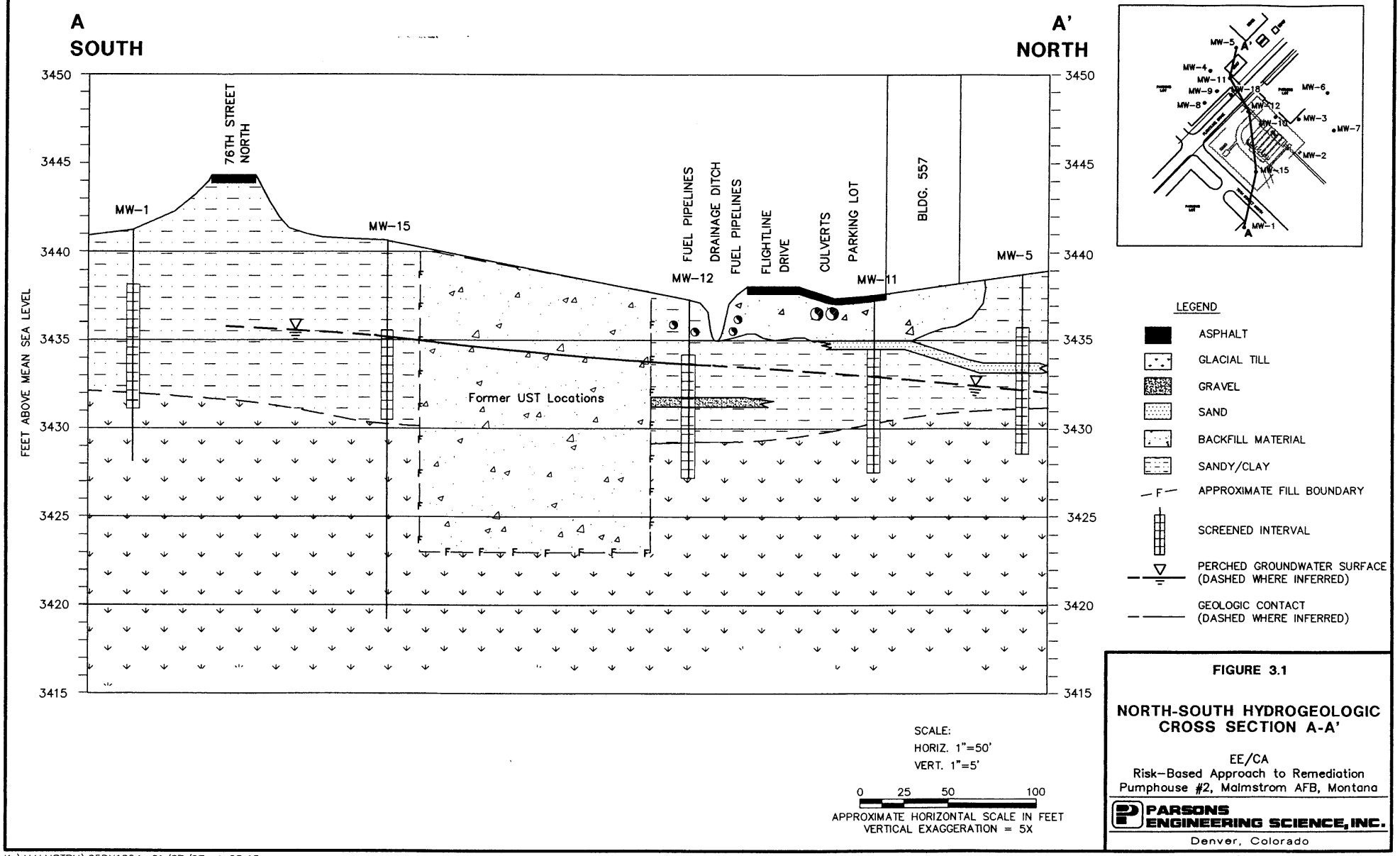


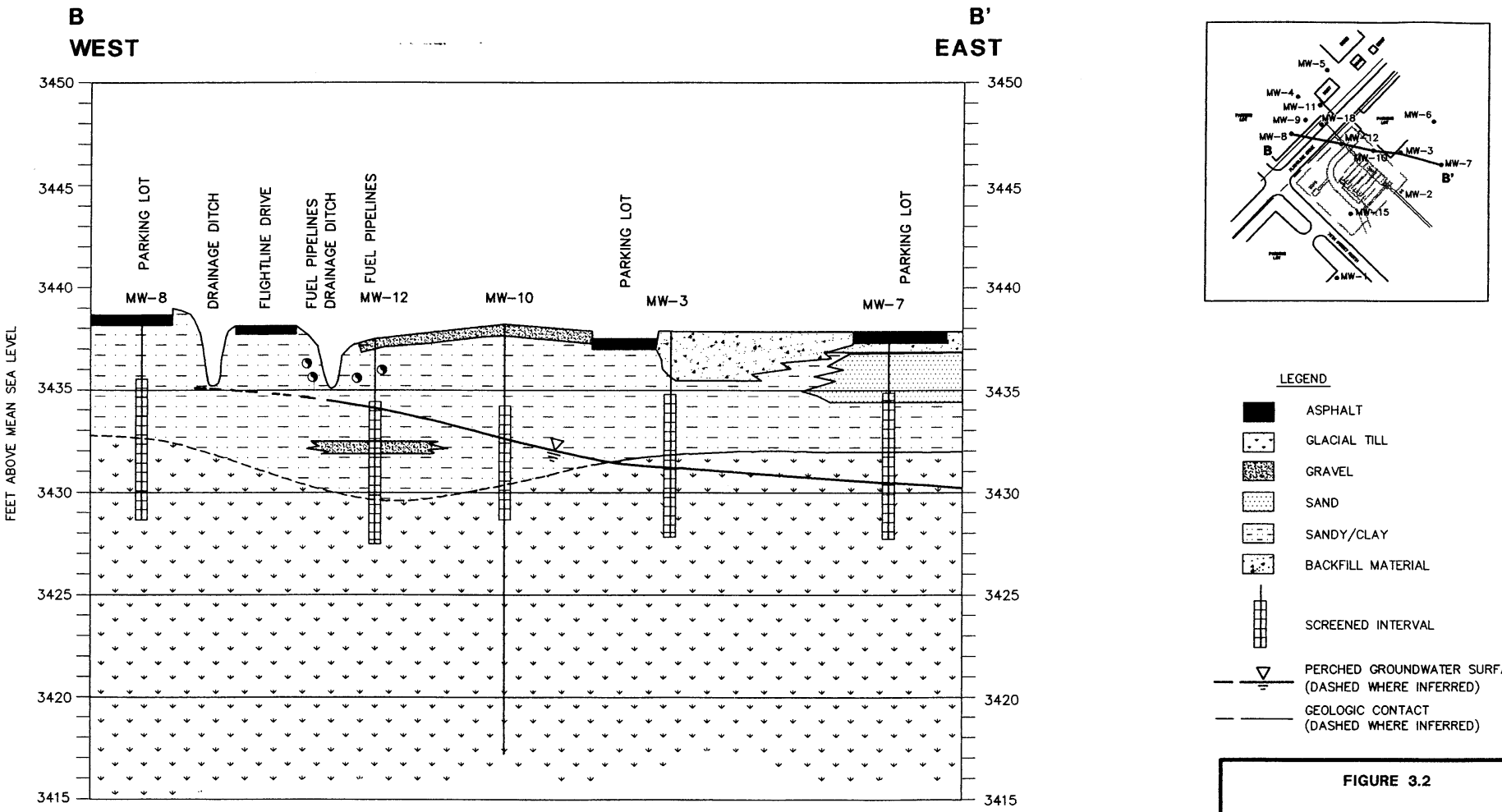
FIGURE 3.1

NORTH-SOUTH HYDROGEOLOGIC CROSS SECTION A-A'

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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LEGEND

- ASPHALT
- GLACIAL TILL
- GRAVEL
- SAND
- SANDY/CLAY
- BACKFILL MATERIAL
- SCREENED INTERVAL
- PERCHED GROUNDWATER SURFACE (DASHED WHERE INFERRED)
- GEOLOGIC CONTACT (DASHED WHERE INFERRED)

SCALE:
HORIZ. 1"=50'
VERT. 1"=5'

0 25 50 100

APPROXIMATE HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION = 5X

FIGURE 3.2

EAST-WEST HYDROGEOLOGIC CROSS SECTION B-B'

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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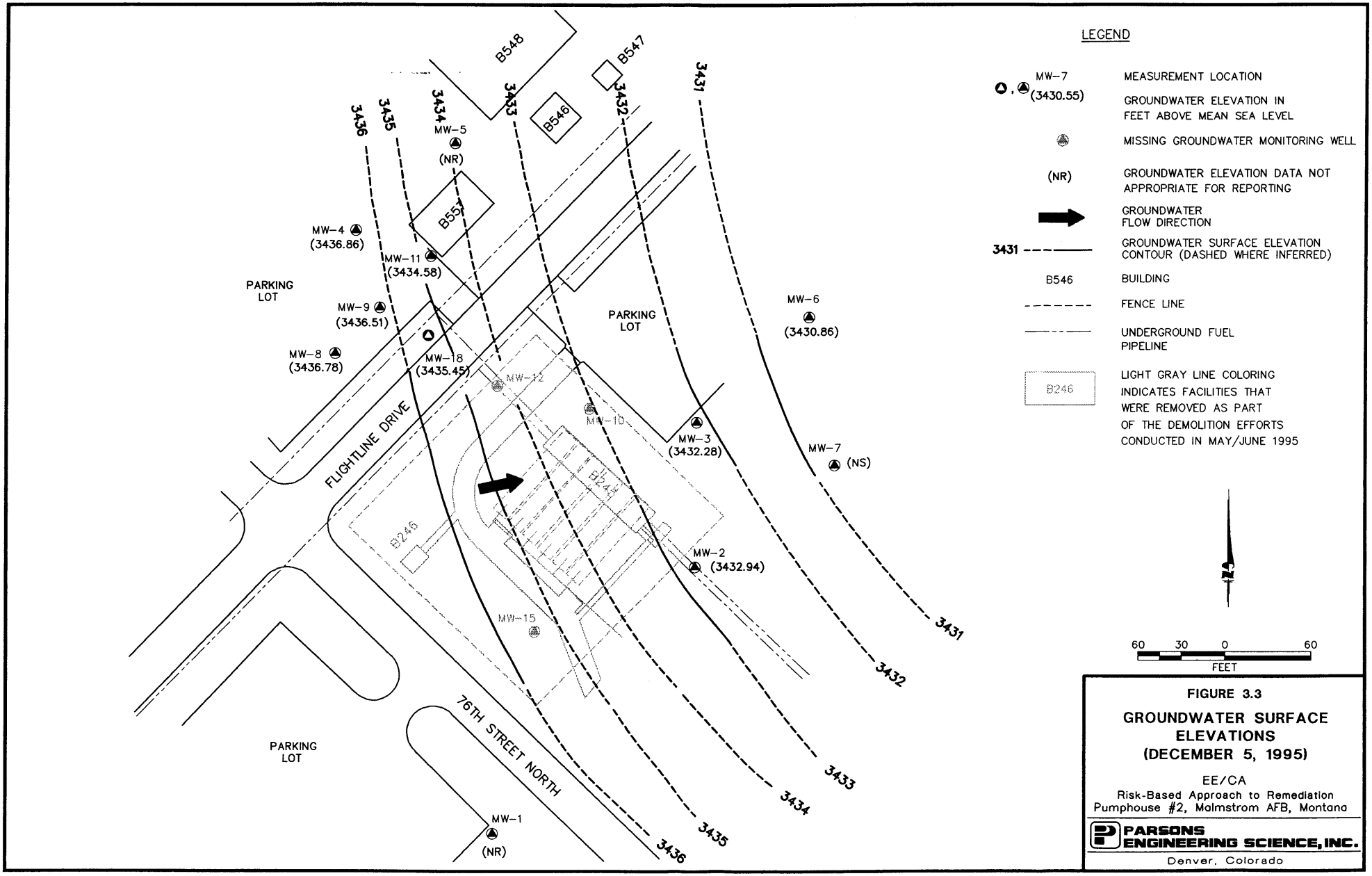


FIGURE 3.3

GROUNDWATER SURFACE ELEVATIONS (DECEMBER 5, 1995)

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

K:\AFCEE\725525\95DN1156, 12/26/95 at 11:00

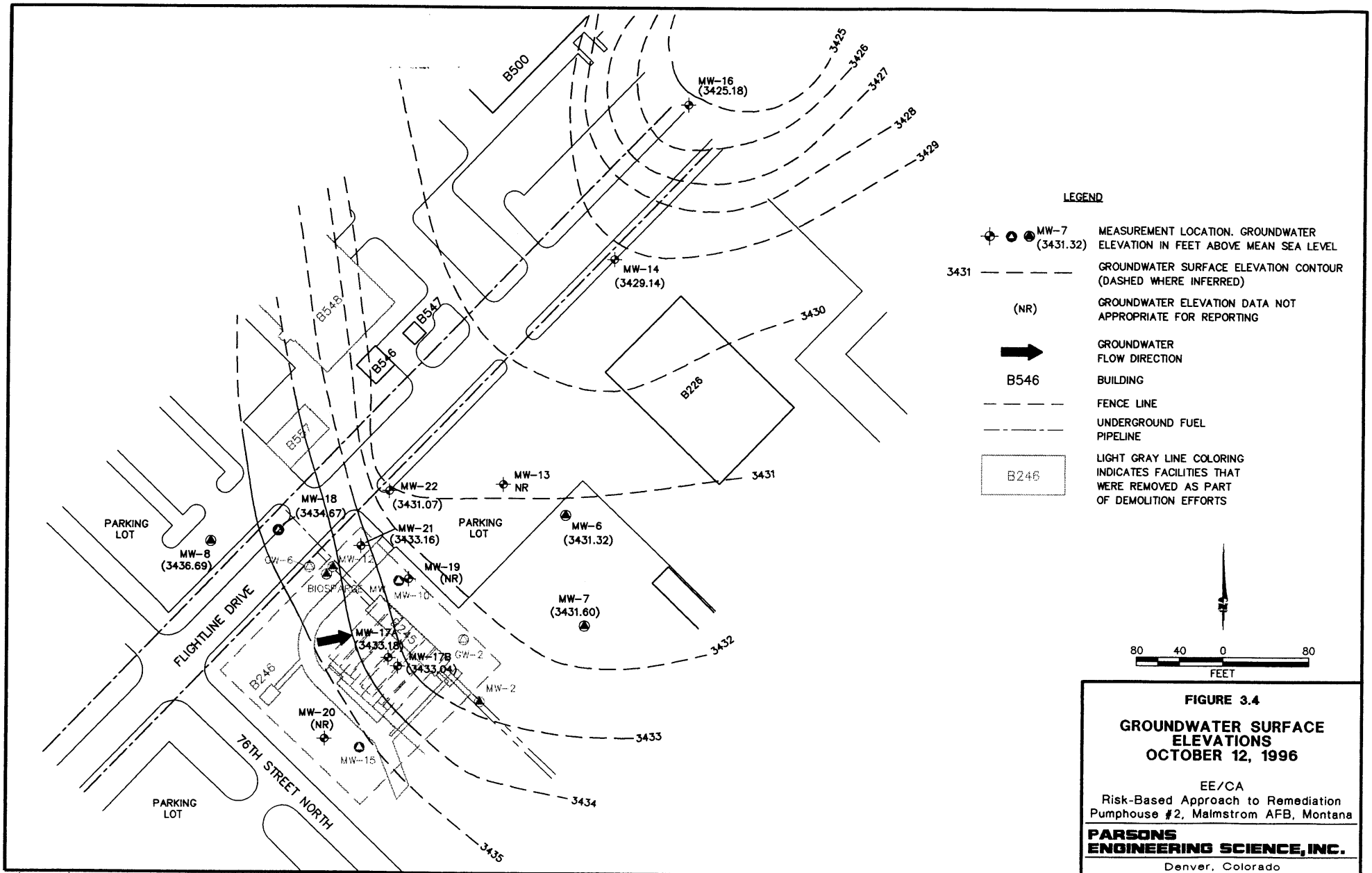


FIGURE 3.4

GROUNDWATER SURFACE ELEVATIONS OCTOBER 12, 1996

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Slug tests were performed at four groundwater monitoring wells that produced adequate quantities of water. Hydraulic conductivities ranged from 6.5×10^{-4} to 1.1 x 10^{-5} foot per minute (ft/min), or 3.3×10^{-4} to 5.4×10^{-6} cm/sec. A maximum linear groundwater velocity of 0.06 foot per day (ft/day), or approximately 22 feet per year (ft/yr), was calculated for the site using the highest observed hydraulic conductivity, the average gradient across the site, and an assumed average porosity of 0.30. Groundwater may flow at a greater velocities within utility corridors at the site due to the greater permeability of bedding material; however, there is no practical way to quantify this.

3.5 CLIMATOLOGICAL CHARACTERISTICS

Malmstrom AFB is located in a semi-arid area with a climate characterized by low humidity, warm, dry summers, and cold winters. Mean monthly temperatures range from 19 degrees Fahrenheit (°F) in January to 70°F in July. Average annual precipitation is 15.24 inches, including an average annual snowfall of 58 inches. Prevailing wind direction is from the southwest (HDR, 1994).

3.6 LAND USE

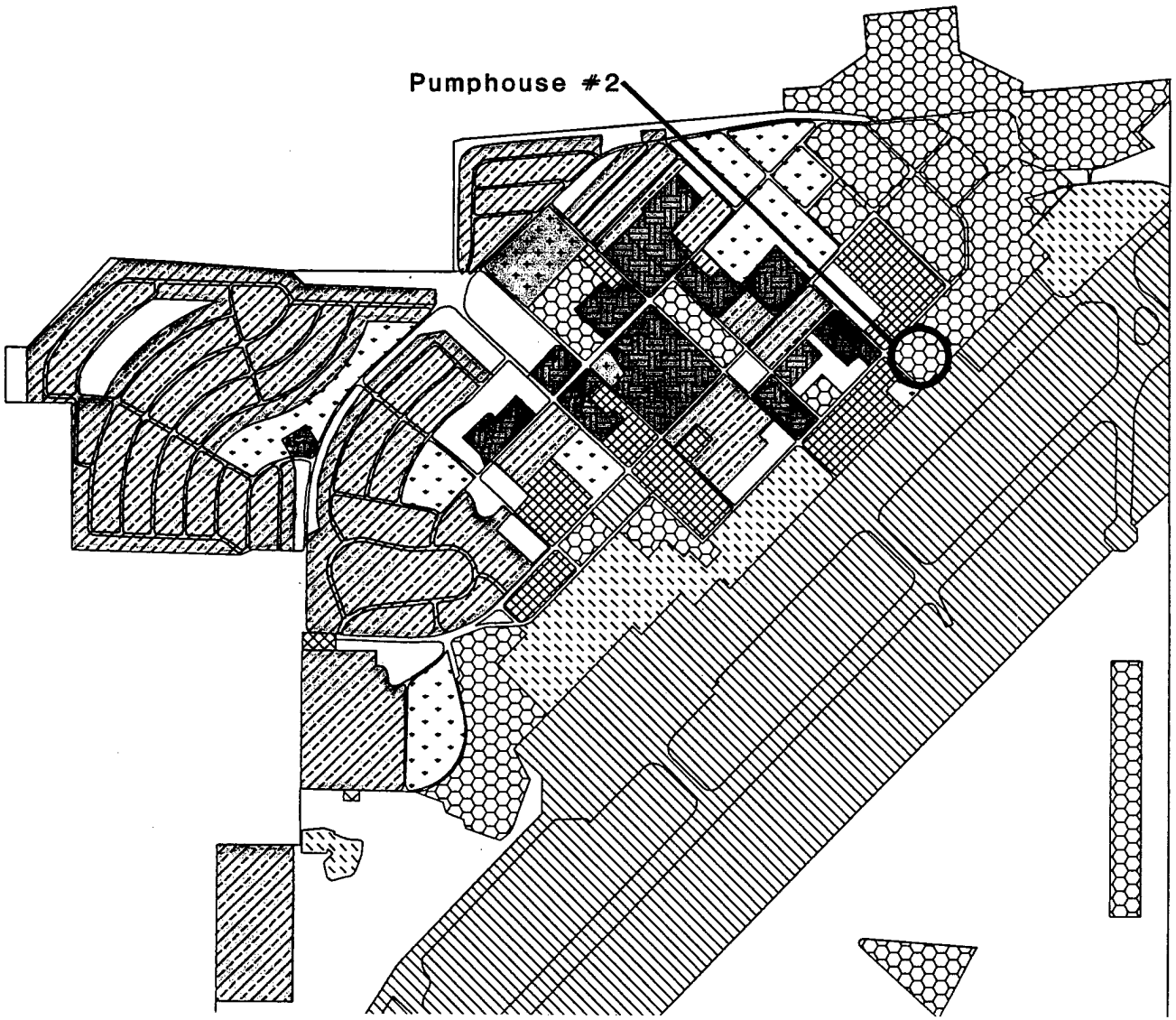
3.6.1 Site Access

Pumphouse #2 is located in an industrial area in the northeastern portion of the Base. Currently, the site is not fenced and is accessible to anyone on the Base. The ditches, parking lots, and other areas adjacent to the site also are not in controlled-access areas. The entire Base is surrounded by a barbed-wire or chain-link fence. Primary access to the Base is through the main gate located off of 2nd Avenue North. The guard station at the main gate is manned 24 hours per day, 7 days per week.

3.6.2 Current Land Use

The site is currently vacant and zoned for industrial use. No future plans have been made for the site. The site is surrounded by industrial operations and asphalt parking lots. Current land uses for Malmstrom AFB are presented in Figure 3.5. An asphalt parking lot is located directly northeast of the site. Beyond this parking lot is a large industrial building used for snow removal equipment maintenance. Large asphalt parking lots are also located southwest of the site, across 76th Street North, and to the northwest, across Flightline Drive (refer to Figure 1.4). Four buildings are located directly north of the site across Flightline Drive. One of these buildings, Building 548, is an administrative building, and the other three are unoccupied industrial buildings. A grass embankment leading up to the aircraft flightline is located east and southeast of the site. All administrative buildings in the vicinity of the site are typically occupied only during normal working hours. Industrial buildings in the area are only occupied occasionally. The residential area closest to Pumphouse #2 is a group of Base housing residences located approximately 0.5 mile northwest of (crossgradient from) the site.

The areas surrounding Malmstrom AFB are predominantly utilized for agriculture and ranching. Figure 3.6 details land uses around the perimeter of the Base. The areas to the north, south, and east of the Base are zoned for agricultural use. The land immediately to the west of the Base has a mixture of industrial, commercial, and



LEGEND

- AIRFIELD
- AIRFIELD (RUNWAY/TAXIWAY)
- AIRFIELD OPERATIONS & MAINTENANCE
- INDUSTRIAL
- ADMINISTRATION
- COMMUNITY (COMMERCIAL)
- COMMUNITY (SERVICE)
- MEDICAL
- HOUSING
- OUTDOOR RECREATION
- OPEN SPACE

NORTH

0 1000 2000

SCALE IN FEET

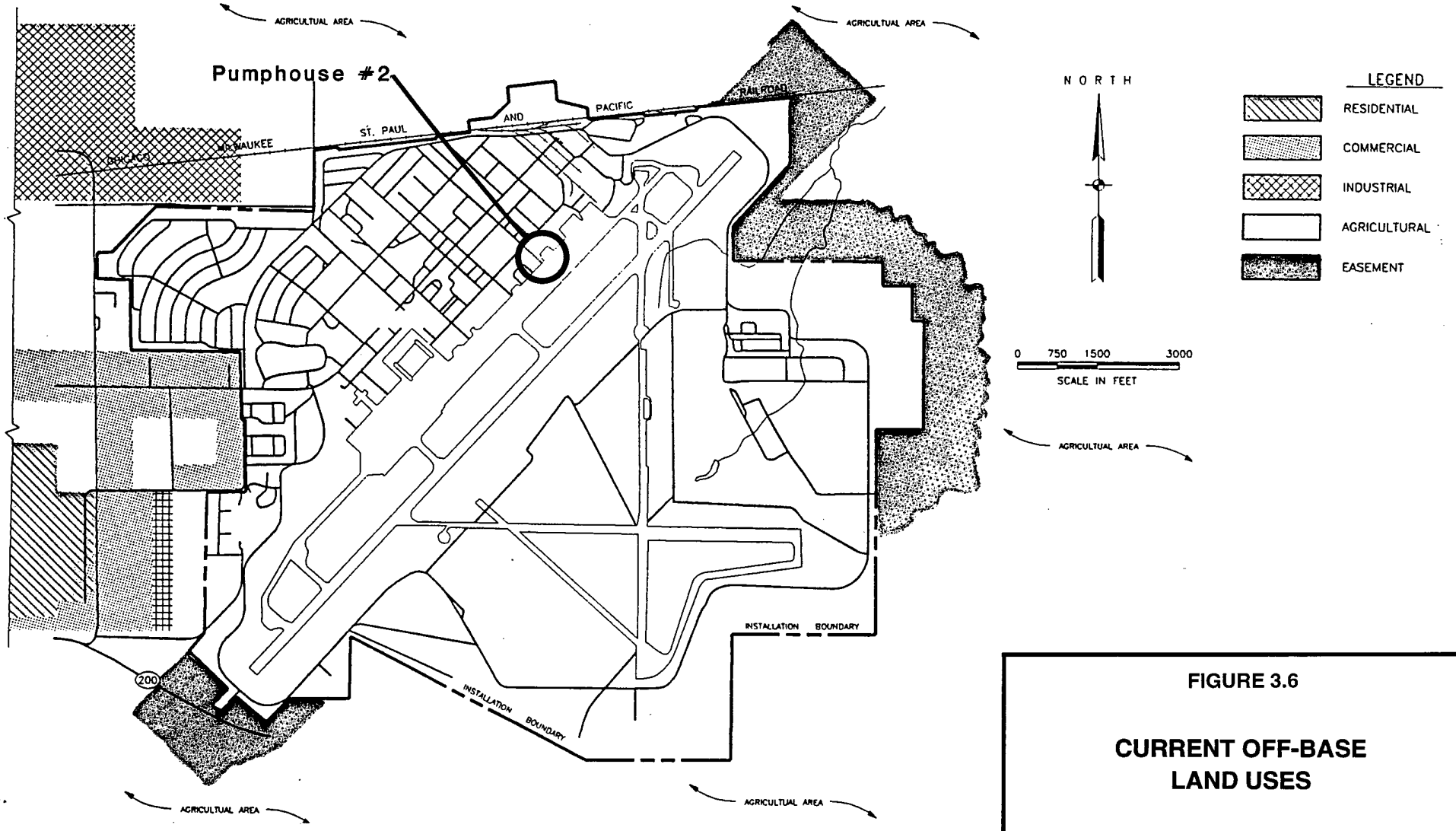
Source: MAFB, 1992.

FIGURE 3.5

CURRENT ON-BASE LAND USES

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



Source: MAFB, 1992.

FIGURE 3.6

CURRENT OFF-BASE LAND USES

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

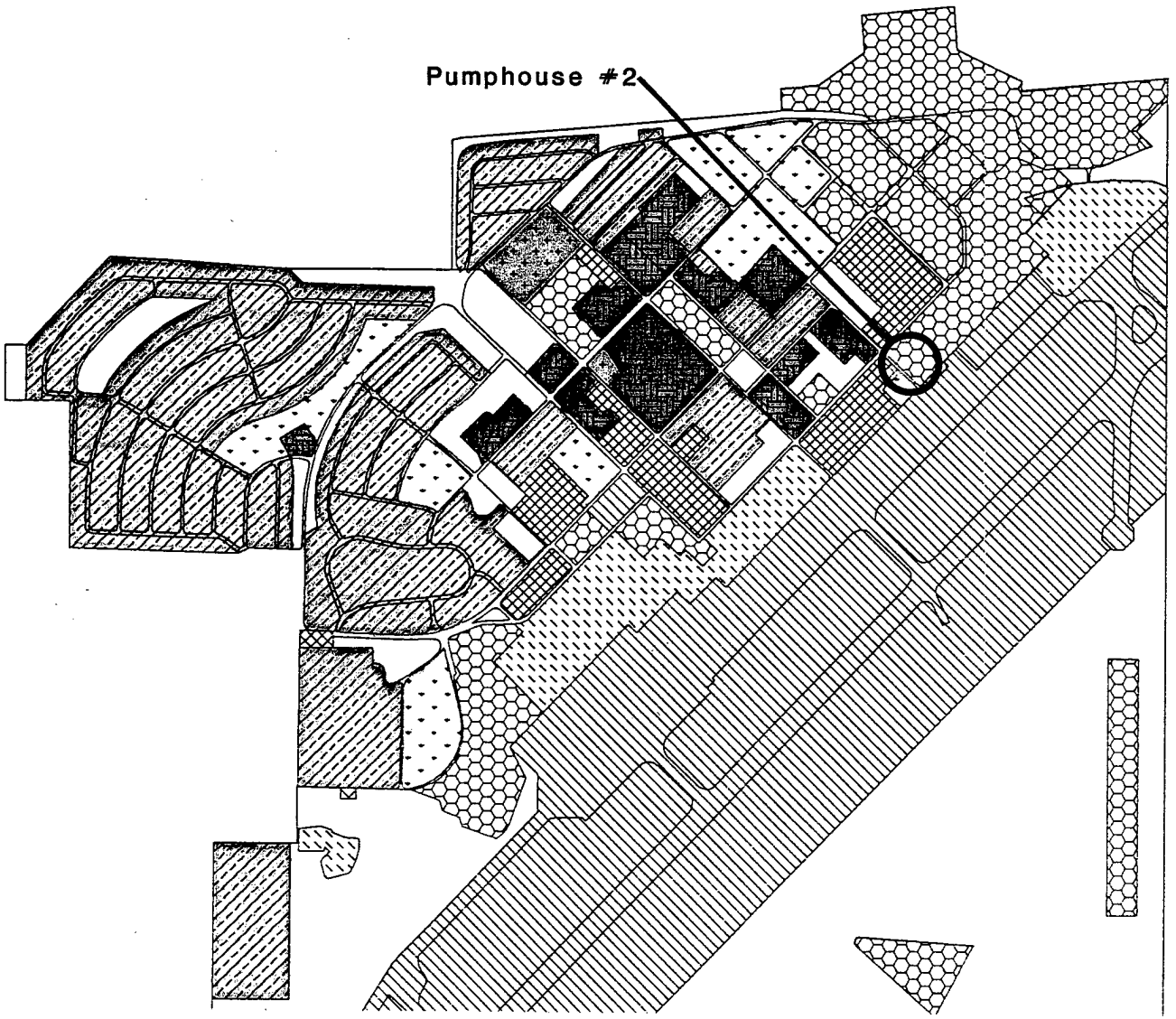
residential uses. A large residential area and the eastern edge of the City of Great Falls are located approximately 1 mile to the west of the Base.

3.6.3 Proposed Land Use

The Base is active and is not on any known closure lists. Future land uses have been proposed for some portions of the Base; however, the area of Pumphouse #2 remains designated as an industrial area in these plans. Figure 3.7 details future land use plans for the Base (MAFB, 1992). No redevelopment plans currently exist for the site.

3.6.4 Groundwater Use

Domestic water is supplied to Malmstrom AFB by the City of Great Falls. The Base also uses the city's municipal sewage treatment system. No production groundwater wells exist on the Base. Three wells were completed into a deep sandstone aquifer in the Kootenai Formation for investigation purposes during the RFI at the Base. None of these wells are used for drinking water supply, and no plans exist to use them as a source of potable water. It is unlikely that shallow groundwater in the vicinity of Pumphouse #2 could ever be used to produce a reliable water supply due to its discontinuous nature and extremely variable yields.



LEGEND

- AIRFIELD
  AIRFIELD (RUNWAY/TAXIWAY)
- AIRFIELD OPERATIONS & MAINTENANCE
- INDUSTRIAL
- ADMINISTRATION
- COMMUNITY (COMMERCIAL)
  COMMUNITY (SERVICE)
- MEDICAL
- HOUSING
- OUTDOOR RECREATION
- OPEN SPACE

NORTH

0 1000 2000

SCALE IN FEET

Source: MAFB, 1992.

FIGURE 3.7

FUTURE ON-BASE LAND USES

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

SECTION 4

NATURE AND EXTENT OF CONTAMINATION

4.1 OVERVIEW

This section summarizes the nature and extent of contamination at Pumphouse #2 based on the findings of site characterization activities conducted under the US Air Force IRP, the RFI in 1993, the bioventing pilot test conducted by ES/Parsons ES at the site in 1993 and 1994, the risk-based remediation site investigation conducted in 1994-1996, and the tank closure sampling performed in 1995. Data collected under the IRP investigations were used to describe the historical nature and extent of soil and groundwater contamination at the site. Data collected during the RFI, the 1993/1994 bioventing pilot test, the 1994-1996 risk-based investigation, and UST removal were used to delineate the current nature and extent of site-related contamination. It should be noted that data for the 1994 RFI draft report was collected in the summer of 1993. When referring to data from the RFI report, the 1993 date will be used. When referring to other contents of the RFI report, the 1994 publication date will be cited.

As described in the work plan (ES, 1994a), conservative contaminant screening criteria for soil and groundwater are used initially to define the nature and extent of contamination in soil and groundwater pursuant to evaluating remedial requirements to protect human health and the environment. The conservative contaminant screening levels, or "trigger levels," used in this evaluation were defined by EPA (1994a) for soils, and are either equal to or less than the most conservative promulgated groundwater quality standard. The conservative contaminant screening criteria used to identify media warranting more in-depth consideration are explained more fully in Section 4.3.

4.2 SOURCES OF CONTAMINATION

Contamination at Pumphouse #2 is the result of leaking USTs or fuel transfer lines, surface releases, or a combination thereof. After failing a tank integrity test in 1992, five of the USTs were removed from service. An unknown amount of fuel was released into the subsurface from an unknown point in the fuel system at Pumphouse #2. SAIC (1991) indicated during the IRP investigation that the primary contaminant source at the site was diesel fuel. Subsurface soil, soil gas, sediment, and groundwater samples collected from the vicinity of the fuel transfer lines to the northwest of Building 245 during the RFI and risk-based investigation contained the greatest concentrations of contaminants found at the site. These data indicate that JP-4 released

from the fuel transfer lines may be the primary source of contamination at the site. It is very likely that there have been multiple releases of various substances at the site, resulting in a variety of subsurface hydrocarbon contaminants. A small (<2,000 gallons) surface spill of an unknown fuel type also has been reported at the site in the vicinity of MW-15. In addition to the USTs and transfer lines formerly located at Pumphouse #2, four large jet fuel transfer lines parallel Flightline Drive and pass either immediately adjacent to or underneath the site. Smaller transfer lines ran from these main lines to the pumps in Building 245. The joints and valves at the intersections of the larger and smaller transfer lines are suspected sources of JP-4 jet fuel contamination at the site. These smaller lines were removed as part of the demolition activities performed in June 1995. The larger lines paralleling Flightline Drive have been filled with grout and abandoned in place. At least three potential sources of contamination have been documented at the site: leaking USTs, leaking fuel transfer lines, and a surface spill.

4.3 CHEMICALS OF POTENTIAL CONCERN

It is the intention of the Air Force to obtain regulatory approval from MDEQ for a remedial action for Pumphouse #2 that will be protective of human health and the environment. To accomplish this objective, the specific chemical constituents or COPCs that may drive potential risks and impact the final remedial requirements at Pumphouse #2 were identified. Previous site investigations (Battelle, 1988; SAIC, 1991; ES, 1993; HDR, 1994) and the work plan (ES, 1994a) preliminarily identified COPCs for Pumphouse #2 as the BTEX compounds and possibly naphthalene, the most mobile of the PAH compounds. These specific chemical constituents were initially defined as COPCs based on existing site characterization data, the chemical nature of the suspected source (i.e., JP-4 jet fuel and/or diesel fuel), and the analytical requirements specified by the MDEQ (1994) for petroleum-contaminated soils and groundwater. Emphasis has been given to defining the nature and extent of contamination that must be addressed to protect human health and the environment. Only compounds that may pose a health threat (i.e., a carcinogenic and/or noncarcinogenic risk) to potential human receptors, or are relevant to conducting remedial technology assessments, have been considered as part of this risk-based approach to remediation. For example, although total petroleum hydrocarbon (TPH) contamination may be useful as a gross indicator of JP-4 fuel contamination, toxicity data for use in a risk-based assessments are not available.

4.3.1 Contaminant Screening Criteria

Conservative contaminant screening criteria for each of the BTEX compounds and naphthalene for soils and groundwater were developed based on a combination of risk-based and promulgated target cleanup levels. Risk-based contaminant screening levels were developed for each of the BTEX compounds and naphthalene in soil based on recent EPA (1994a) soil screening guidance. The EPA has calculated generic soil contaminant screening levels for more than 100 individual chemicals. Screening levels are intended to be protective of human health under the most conservative exposure scenario (i.e., unlimited or residential land use). These generic screening levels were developed as part of a three-tiered framework to provide guidance on how to quickly

identify soils that may warrant further study and, possibly remedial action, to protect human health and the environment (EPA, 1994b).

Generic contaminant screening criteria developed by the EPA (1994a) for soils were used as part of this initial screening step for Pumphouse #2. Three types of potential exposure routes were used to identify soil contaminant screening criteria: incidental soil ingestion, inhalation of VOCs, and ingestion of groundwater impacted by chemicals leaching from soils. The generic contaminant screening concentrations for carcinogens were calculated to be the concentrations representing an increased cancer risk of one in one million (i.e., 10^{-6} risk level). Benzene is the only chemical potentially present in site soils that may be defined as a carcinogen (Appendix D). Generic risk-based contaminant concentrations for noncarcinogens were calculated by EPA (1994a) to represent no adverse effects on humans (i.e., a hazard quotient of ≤ 1). Toluene, ethylbenzene, total xylenes, and naphthalene have been identified as toxic to humans, but are not carcinogenic (Appendix D).

The most conservative (i.e., stringent) of the three exposure-route, risk-based criteria for each of the BTEX compounds was used as the site-specific contaminant screening level for Pumphouse #2. Appendix D presents the derivation of these soil contaminant screening criteria in detail. Application of these standardized equations to define soil COPCs is conservative at this site, because Pumphouse #2 is not currently or planned to be available for unlimited use. However, these criteria were used as a simple method to identify the full spectrum of soil COPCs that could be considered when defining remedial requirements for the site to protect human health and the environment. If measured soil concentrations did not exceed these conservative screening criteria, the chemical was not identified as a COPC. If measured soil concentrations exceeded these site-specific screening levels, the chemical was identified as a COPC and considered in subsequent analysis included this EE/CA.

MDEQ (1994) also has promulgated a soil cleanup standard for benzene of 1 mg/kg. A goal also exists for total BTEX in soil; however, this standard is not compound specific and is not presented. Benzene also was identified as a COPC if it was detected in soil at concentrations that exceeded the MDEQ standard. Table 4.1 compares each of the exposure-route risk-based soil contaminant screening criteria and applicable MDEQ standards for the BTEX compounds to the maximum concentrations of these compounds measured in soils at the site.

Contaminant screening criteria for groundwater and surface water were based on a combination of promulgated standards and risk-based criteria. Risk-based contaminant screening criteria for groundwater were developed similarly to generic soil criteria, except the only exposure pathway incorporated into the derivation of the target levels was ingestion of contaminated groundwater (Appendix D). Table 4.1 presents both the MDEQ promulgated groundwater quality standards and the risk-based groundwater/surface water contaminant screening levels that were calculated to be protective of human health under the most conservative exposure scenario. These screening criteria are compared to the maximum contaminant concentrations determined from groundwater sampling events conducted in 1993 and 1994. A specific compound was identified as a groundwater COPC if any measured concentration at the

TABLE 4.1
IDENTIFICATION OF SOIL AND GROUNDWATER CONTAMINANT SCREENING CRITERIA EXCEEDANCES
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Compound (units)	1988 IRP Phase II Stage 1 Maximum Concentration	1991 IRP Phase II Stage 2 Maximum Concentration	1993 Initial Bioventing Results Maximum Concentration	1994 1-Year Bioventing Results Maximum Concentration	1993 RFI Maximum Concentration	1994 Risk-Based Investigation Maximum Concentration	1995 Tank Closure Sampling Maximum Concentration	Risk-Based Criteria			MDEQ Guideline[d/]
								Ingestion[a/]	Inhalation[b/]	Leaching[c/]	
Soil											
Benzene (mg/kg)	--[e/]	--	0.65U	0.05U	0.023	2.3U	< 0.05	22	0.5	0.02	1.0
Toluene (mg/kg)	6.9	--	1.1	0.12	6.1U	11	0.703	16,000	520	5	--
Ethylbenzene (mg/kg)	36.3	75	2.2	0.55	83	35	1.86	7,800	260	5	--
Total xylenes (mg/kg)	243	270	4.4	0.29	300	210	9.91	1.60E+05	320	74	--
Groundwater											
Benzene (µg/L)	--	--	--	--	890	680	--	12	--	--	5
Toluene (µg/L)	--	--	--	--	50U	95	--	1,400	--	--	1,000
Ethylbenzene (µg/L)	--	--	--	--	870	710	--	700	--	--	700
Total xylenes (µg/L)	--	--	--	--	7,100	4,200	--	14,000	--	--	10,000
Naphthalene (µg/L)	--	--	--	--	150	10U	--	280	--	--	--

NOTE: Shading indicates concentration exceeds the most stringent contaminant screening criterion. Both concentration and exceeded criterion are shaded.

[a/] Risk-based screening criteria calculated to protect against health risks associated with incidental ingestion of contaminated soils or ingestion of contaminated groundwater under unlimited land use scenario.

[b/] Risk-based screening criteria calculated to protect against health risks associated with inhalation of volatiles and fugitive dusts under unlimited land use.

[c/] Risk-based screening criteria calculated to protect against health risks associated with ingestion of groundwater affected by chemicals leaching from soils (unlimited land use scenario).

[d/] MDEQ, 1994.

[e/] Not available.

site was equal to or exceeded the most stringent of the chemical specific groundwater screening criteria. Surface water data are not presented because no BTEX compound has ever been detected at a measurable concentration in surface water at the site.

All nondetect analytical results obtained during the previous site investigations, the 1994 risk-based remediation investigation, and tank closure sampling are reported on Table 4.1 at the PQL with a "U" data qualifier. This is consistent with EPA (1989a and b) guidance on how to use non-detect values in quantitative risk assessments. All analytical results measured above the MDL but below the PQL were identified as estimated but usable data (J qualified). All MDLs achieved for the 1994 investigation are consistent with the MDEQ recommendations for analytical sensitivity, and are below the most stringent contaminant screening criteria (see Table 2.1). All analytical results measured above the PQL were identified as detected concentrations and not qualified.

Data collected as part of the 1994 risk-based remediation investigation also were subjected to a usability/acceptability review that included (1) a review of chain-of-custody records, reported holding times, status of instrument calibration, and reported recoveries for laboratory control samples and matrix spike/matrix spike duplicates; (2) analyzing and using laboratory and field blanks to qualify reported sample concentrations; and (3) measuring the reproducibility of sampling techniques and laboratory analytical precision using blind field duplicates/replicates. Appendix A presents the analytical results for all samples collected under this project, organized by environmental medium, and a summary of the data evaluation methodology and results.

4.3.2 Identifying Screening Criteria Exceedances

Table 4.2 lists the specific chemicals that were measured during previous investigations, the 1994 risk-based site investigation, and/or tank closure sampling at concentrations that exceeded any of the contaminant screening criteria for soil and groundwater. Based on these exceedances, the COPCs for soil at Pumphouse #2 are all of the BTEX compounds. The COPCs for groundwater are benzene and ethylbenzene.

All BTEX compounds are included as soil COPCs based on 1994 risk-based site investigation data. Various BTEX compounds exceeded screening criteria during previous investigations (IRP Phase II, Stage 1 and 2, and the RFI); however, the risk-based site investigation was the only investigation in which all four compounds exceeded screening criteria. Benzene and ethylbenzene were identified as groundwater COPCs based on 1993 RFI and 1994 risk-based sampling data. These compounds are considered in detail in subsequent sections. Compounds measured at the site at concentrations that did not exceed these conservative screening criteria have not been carried forward in this analysis.

4.4 SOIL/SEDIMENT CHEMISTRY

The following sections summarize analytical data results for COPCs measured in surface and subsurface soil, and sediment samples collected during the 1988 IRP Phase II Stage 1 and 1991 Phase II Stage 2 investigations, installation of the pilot bioventing

TABLE 4.2
LIST OF CHEMICALS OF POTENTIAL CONCERN
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Chemicals of Potential Concern	Rationale [a/]
Soil	
Benzene	1993 RFI maximum and 1994 risk-based maximum concentration > risk-based leaching criterion 1994 risk-based maximum concentration > risk-based inhalation criterion and MDEQ guideline
Toluene	1988 IRP Phase II, Stage 1 maximum and 1994 risk-based maximum concentration > risk-based leaching criterion
Ethylbenzene	1988 IRP Phase II, Stage 1 maximum, 1991 IRP Phase II, Stage 2 maximum, 1993 RFI maximum, and 1994 risk-based maximum concentration > risk-based leaching criterion
Total xylenes	1988 IRP Phase II, Stage 1 maximum, 1991 IRP Phase II, Stage 2 maximum, 1993 RFI maximum, and 1994 risk-based maximum concentration > risk-based leaching criterion
Groundwater	
Benzene	1993 RFI maximum and 1994 risk-based maximum concentration > risk-based ingestion criterion and MDEQ guideline
Ethylbenzene	1993 RFI maximum and 1994 risk-based maximum concentration > risk-based ingestion criterion and MDEQ guideline

[a/] See data ranges presented in Table 4.1.

system in October 1993, the 1-year bioventing system test conducted in 1994, the 1993 RFI site investigation, the 1994 risk-based remediation investigation, the 1995 tank closure sampling, and eight shallow soil samples collected during the 1996 long-term monitoring event.

4.4.1 BTEX Soil/Sediment Contamination

Soil data were collected during two discrete sampling events conducted under the IRP program. Eight subsurface soil samples were collected as part of the Phase II, Stage 1 investigation (Battelle, 1988), and 15 surface soil (0 to 1 foot bgs) and sediment (0 to 1 foot bgs in a drainage) samples were collected during the Phase II, Stage 2 investigation (SAIC, 1991). Subsurface soil samples were analyzed for toluene, ethylbenzene, and total xylenes. Surface soil samples were analyzed for ethylbenzene and total xylenes. Concentrations of individual compounds were detected in 3 of the 8 subsurface soil samples and in 4 of the 15 surface soil samples submitted for chemical analysis. The maximum concentration of toluene detected in subsurface samples at the site in 1988 was 6.9 milligrams per kilogram (mg/kg) at SS-C, located at the southern edge of the site (Figure 2.3). The maximum subsurface concentrations of ethylbenzene and total xylenes, 36.3 and 243 mg/kg, respectively, were detected at SS-G in the northern portion of the site (Figure 2.3). The maximum concentrations of ethylbenzene and total xylenes in surface or sediment soils, 75 and 270 mg/kg, respectively, were detected in sediment sample SL-55 collected from the bottom of the drainage ditch at the northern edge of the site (Figure 2.3). Relevant soil sample results from both investigations are presented in tabular form in Table 4.3.

Three discrete soil samples also were collected along the north-western edge of the site during installation of the pilot bioventing system at the site in October 1993 (Figure 2.9). The concentrations of total BTEX in these soil samples were significantly less than those measured in the majority of the soil samples collected during the IRP, RFI, and risk-based investigations at the site. The maximum 1993 concentration of total BTEX measured in soil was 7 mg/kg at MPC. Total xylenes accounted for between 58 and 65 percent of the total BTEX in contaminated soils sampled in October 1993. These soil analytical results also are included in Table 4.3.

In October 1994, 1-year soil confirmation samples were collected near the pilot bioventing system to assess the efficiency of the system at removing BTEX mass from unsaturated soils at Pumphouse #2. In 1 year of operation, the maximum concentration of total BTEX in soil was reduced from 7 to 0.1 mg/kg near MPC. A more detailed discussion of bioventing system performance is presented in Section 7.1 of this EE/CA. Relevant soil analytical results are included in Table 4.3.

Forty-five samples were collected from 10 locations and analyzed for BTEX as part of the 1993 RFI investigation at Pumphouse #2. Individual BTEX compounds were detected in 13 of the 45 samples. The 5-foot-bgs interval appeared to be the area of greatest subsurface soil contamination. Eight of 10 soil samples collected from this interval contained detectable concentrations of BTEX. In contrast, only 1 of 10 soil samples collected from the 15 feet bgs interval had detectable concentrations of BTEX. No BTEX compounds were detected in any soil samples collected from 20 feet bgs

TABLE 4.3
SUMMARY OF OTHER SOIL SAMPLING RESULTS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Investigation Name	IRP PHASE II, STAGE 1 (1988)								INITIAL BIOVENTING (10/93)			FINAL BIOVENTING (10/94)		
Sample Location	SS-A	SS-B	SS-C	SS-D	SS-E	SS-F	SS-G	SS-H	MPA-2	MPB-3.5	MPC-5.5	MPA-2	MPB-3.5	MPC-5.5
Compound (units)														
Benzene (mg/kg)	--[a]	--	--	--	--	--	--	--	0.65U	0.64U	0.31U	0.05U	0.05U	0.05U
Toluene (mg/kg)	--	1.7	6.9	--	--	--	1.3U	--	0.7	0.64U	1.1	0.05U	0.12	0.057
Ethylbenzene (mg/kg)	--	3.7	1.6	--	--	--	36.3	--	1.2	2.2	1.5	0.05U	0.55	0.067
Total xylenes (mg/kg)	--	12.9	10.6	--	--	--	243.9	--	3.6	3.1	4.4	0.1U	0.29	0.1U
TRPH (mg/kg) [b]	131U[c]	166	120U	875	122U	371	2390	127U	300	270	150	146	33.5	74.4

Investigation Name	IRP PHASE II, STAGE 2 (1991)														
Sample Location	SL-83	SL-34	SL-2	SL-60	SL-61	SL-58	SL-49	SL-54	SL-57	SL-64	SL-67	SL-66	SL-56	SL-84	SL-55
Compound (units)															
Benzene (mg/kg)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Toluene (mg/kg)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ethylbenzene (mg/kg)	--	--	--	--	--	--	--	--	--	33U	--	4.0	--	20.0	75.0
Total xylenes (mg/kg)	--	--	--	--	--	--	--	--	--	65.0	--	107.0	--	68.0	270.0
TRPH (mg/kg)	44	10,100	160	29	120	31	160	190	72	14	280	400	100	10U	100

Investigation Name	TANK CLOSURE SAMPLING (1995)														
Sample Location	T3E	T4E	T5E	T6E	T1E	PN	T7E	T7W	T1W	T2W	T3W	T4W	T5W	T6W	T2E	PS
Compound (units)																
Benzene (mg/kg)	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Toluene (mg/kg)	< 0.05	0.703	0.434	< 0.05	< 0.05	0.086	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ethylbenzene (mg/kg)	< 0.05	1.86	0.796	< 0.05	< 0.05	0.077	1.13	0.164	0.096	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.0661
Total xylenes (mg/kg)	< 0.05	9.91	4.53	< 0.05	< 0.05	0.22	0.804	0.192	0.287	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.193
TRPH (mg/kg)	9	1965	762	9.59	2.5	37.38	3887	615.9	256.3	6.09	U	U	U	4.59	3.61	40.5

[a] -- = Not available.

[b] TRPH = Total recoverable petroleum hydrocarbons.

[c] U = Analyte not detected at concentrations above the method detection limit.

confirming that the glacial till is relatively impermeable to vertical migration. The maximum concentration of total BTEX measured in soil during the RFI investigation was 383 mg/kg at 5 feet bgs at SB-18 (MW-18), located across Flightline Drive from the former pumphouse location (Figure 2.3). A maximum benzene concentration of 0.23 mg/kg was measured at 5 feet bgs at SB-12. This sample was the only soil sample collected during the RFI that contained a detectable concentration of benzene. Ethylbenzene and total xylenes accounted for all of the total BTEX detected in the remaining soil samples. Toluene was not found in soils at concentrations above MDLs during the RFI investigation at Pumphouse #2. Figure 4.1 shows the areal extent of BTEX contamination in soils at Pumphouse #2 based on data collected during the 1993 RFI investigation, the 1994 risk-based investigation, and the 1996 long-term monitoring event. In instances where more than one sample was collected at one location, data from the most contaminated depth interval is presented. Complete soil analytical results from the 1993 RFI site investigation are presented in Appendix A.

Seventeen subsurface soil samples were collected from 14 new soil boreholes and analyzed for BTEX compounds as part of the 1994 risk-based remediation investigation. Individual BTEX compounds were detected in 11 of the 17 soil samples. Eight sediment samples also were collected from the bottom of the drainage ditches paralleling Flightline Drive. Individual BTEX compounds were detected in four of these samples. The maximum concentration of total BTEX measured in subsurface soils during the risk-based site investigation in 1994 was 27.1 mg/kg at 5 feet bgs at MW-3, located northeast of the former location of the pumphouse (Figure 4.1). The maximum concentration of total BTEX measured in ditch sediment during the 1994 investigation was 258 mg/kg at sampling location SED-9 near the JP-4 pipeline (Figure 4.1). This sample was the only sediment sample that contained benzene at a concentration exceeding screening criteria (Table 4.1). Additionally, the sediment sample collected at SED-9 had the highest concentration of each of the BTEX compounds. In 1996, a shallow soil sample collected from 2 feet bgs at SB-24, adjacent to SED-9, had a total BTEX concentration of 28.4 mg/kg. An additional shallow soil sample collected in 1996 on the east side of Flightline Drive (SB-23) had a total BTEX content of 53.8 mg/kg. Complete soil analytical results from the 1993 RFI and the 1994 and 1996 risk-based investigation are presented in tabular form in Appendix A

To further document the vertical extent of contamination at Pumphouse #2, soil samples were collected from 9 to 10 feet bgs at two locations during the risk-based investigation. Based on data collected during the RFI, little to no contamination exists below approximately 10 feet bgs at Pumphouse #2. During installation of MW-3, a soil sample was collected from an apparently contaminated interval at 6 feet bgs. Another soil sample was collected from 9 feet bgs in the same borehole. Total BTEX in the shallow sample was 27 mg/kg. In contrast, total BTEX in the deeper sample was 0.006 mg/kg. Similar results were found at MW-12, where a shallow sample had a total BTEX concentration of 0.05 mg/kg whereas a deeper sample had no detectable concentration of BTEX. These data also suggest that the glacial till found below approximately 8 feet bgs at Pumphouse #2 is effectively limiting vertical migration of contaminants.

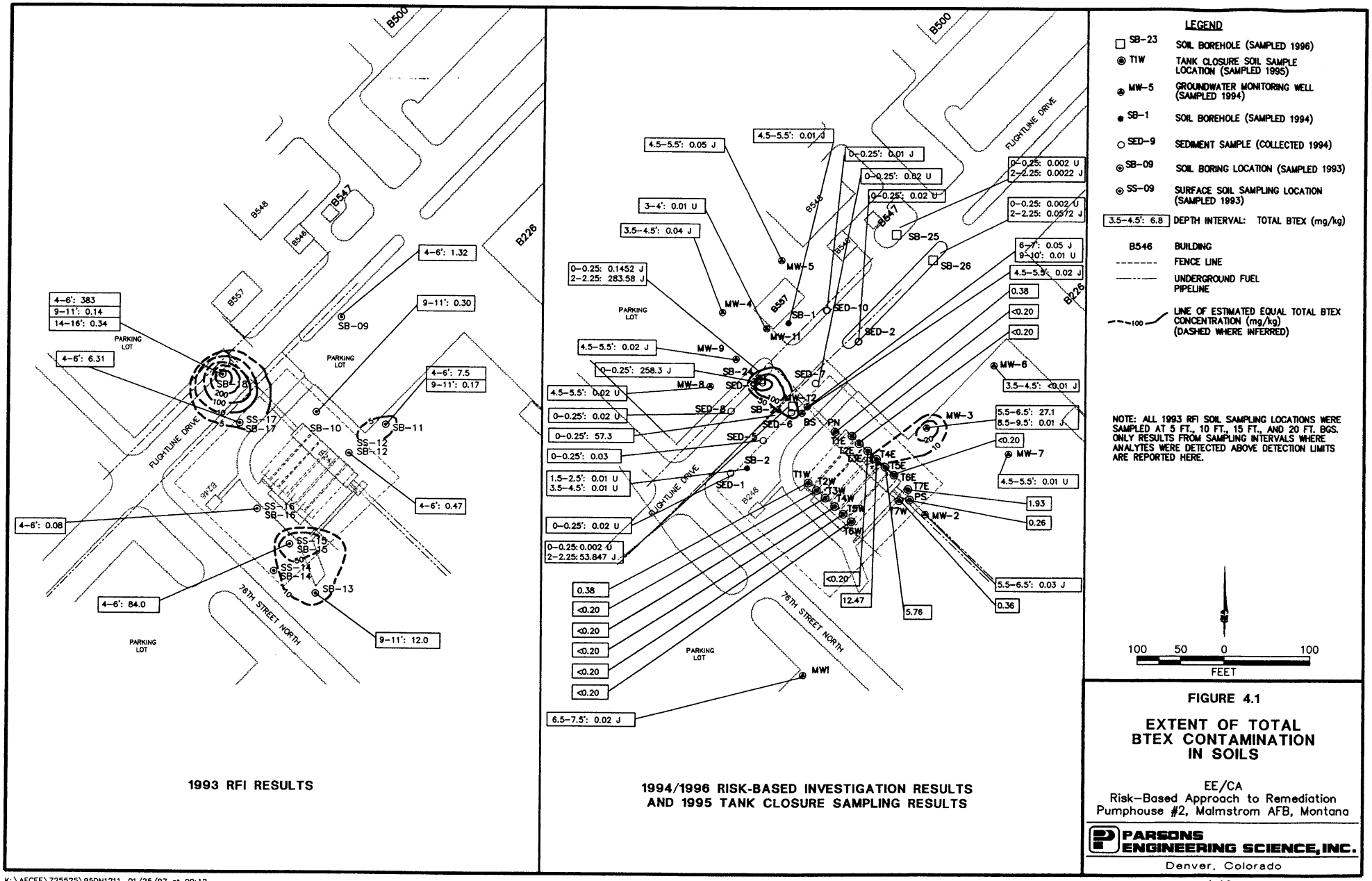


FIGURE 4.1

EXTENT OF TOTAL BTEX CONTAMINATION IN SOILS

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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During May and June 1995, 16 soil samples were collected from the bottom of the UST excavation. One sample was collected from underneath the concrete anchor slab at each end of each tank. Samples were collected from unsaturated glacial till at approximately 15 feet bgs. Two additional samples were collected in the vicinity of fuel transfer lines at the site. Sample locations are shown in Figure 2.4. Individual BTEX compounds were detected in 7 of the 16 soil samples. The maximum concentration of total BTEX measured in subsurface soils during tank removal activies in 1995 was 12.47 mg/kg at the northeast end of tank #4 (Figure 2.4). Benzene was not detected in any of the samples collect at the site during tank removal. In general, contamination remaining under the former tank pit is very minimal and does not pose a risk to human health and/or the environment. Complete soil analytical results from the 1995 tank closure sampling event are presented in tabular form in Appendix A

4.4.2 Soil Gas Sampling Results

Soil gas samples were used as supplemental confirmation of the nature and extent of soil contamination at a site. Soil gas samples were used to obtain a better representation of soil contamination because the sample is extracted from a larger volume of soil than discrete soil grab samples collected from a split spoon. Analytical results from discrete soil samples are usually nonhomogeneous and vary from sampling location to sampling location. Thus, soil gas samples provide a valuable indication of the average type and magnitude of VOC contamination in the soil surrounding the soil gas probes.

Soil gas samples were collected from approximately 3 to 4 feet bgs during installation of the pilot-scale bioventing system in 1993, and during the 1-year bioventing test in October 1994. In 1993, the maximum concentration of benzene in soil gas was 59 micrograms per liter (µg/L) of air. The maximum concentration of total BTEX measured in soil gas in 1993 was 178 µg/L of air at MPC. After 1 year of system operation, the maximum concentration of total BTEX in soil gas had been reduced to 1.86 µg/L of air. Analytical results for these 1993 and 1994 soil gas samples are presented in Section 7.1.4 of this EE/CA.

Soil gas samples collected at Pumphouse #2 during the 1994 field effort were analyzed for BTEX compounds and TVH. Soil gas samples were collected from approximately 3 feet bgs at five locations in the vicinity of Pumphouse #2 (Figure 2.1). Benzene and toluene were detected in three of the five soil gas samples collected at the site. Ethylbenzene and total xylenes were detected in all five samples. The maximum detected concentration of benzene of 290 µg/L [290 milligrams per cubic meter (mg/m^3)] was detected in the soil gas sample collected at SG-4. Toluene was detected at its maximum concentration of 0.36 µg/L (0.36 mg/m^3) at SG-2. Ethylbenzene and total xylenes were detected at their maximum concentrations of 110 µg/L (110 mg/m^3) and 410 µg/L (410 mg/m^3), respectively, at SG-4.

The soil gas results correlate well with 1994 soil analytical results, which indicate that the predominant soil and groundwater contamination at the site is in the vicinity of SG-4. Except for benzene, all of the measured soil gas concentrations of the BTEX compounds are below the time-weighted-average (TWA) 8-hour permissible exposure

limits (PELs) (toluene: 375 mg/m^3, ethylbenzene: 435 mg/m^3, and total xylenes: 435 mg/m^3) defined for air contaminants by the Occupational Safety and Health Administration (OSHA). The concentration of benzene in the sample from SG-4 exceeded its PEL of 3.25 mg/m^3. Consequently, the concentration of benzene in soil gas in the vicinity of SG-4 could pose a risk to workers involved in long-term, deep excavation activities unless appropriate health protection precautions are taken. This potential exposure pathway is evaluated further in Section 6 of this EE/CA. All analytical results for soil gas samples collected during the 1994 field effort are presented in Appendix A.

4.4.3 Soil Flux Sampling Results

Soil gas flux samples also were collected at Pumphouse #2 in October 1994, and analyzed for the BTEX compounds and TVH. Analytical results for the soil gas flux samples were used to estimate the potential for gaseous emissions to the atmosphere. Sampling was completed in accordance with the procedures described in EPA's (1986) guidance document entitled *Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber.* Briefly, the calculation transforms concentration data into emission-rate data. The calculation sheets for soil gas flux samples collected at Pumphouse #2 are presented in Appendix A.

Low concentrations of xylenes were measured at all flux sampling locations (Figure 2.1). Toluene was detected at low levels in four of five samples. Ethylbenzene also was detected at low concentrations during flux testing at flux testing locations 3 and 4. Benzene was not detected in any of the flux samples. Total xylenes from flux sampling location 3 were calculated to have the maximum emission rate of the all BTEX compounds measured during flux testing. The calculated emission rate of xylenes at flux testing location 3 was 3.15 micrograms per square meter per minute ($\mu g/m^2$-min). The emission rate of xylenes varied slightly at all soil flux sampling locations, ranging from a maximum rate of 3.15 $\mu g/m^2$-min at location 3, which is located in the vicinity of fuel transfer lines, to a minimum of 0.55 $\mu g/m^2$-min at location 1, which is located upgradient from the site (Figure 2.1). Toluene emission rates were uniformly low, ranging from 0.62 $\mu g/m^2$-min at location 3 to 0.26 $\mu g/m^2$-min at both locations 2 and 5. Ethylbenzene emission rates, where calculated, also were very low.

Even assuming no atmospheric dispersion, these measured soil gas flux concentrations would result in an ambient air concentrations that are well below the OSHA TWA 8-hour PELs for each specific compound. For example, the maximum concentration of total xylenes expected in the breathing zone over an 8-hour time period, assuming no atmospheric dispersion, would be 1.51 mg/m^3. This is significantly below the OSHA TWA PEL of 435 mg/m^3 for total xylenes. Based on these results, soil gas flux emissions do not represent a source of risk to onsite workers or offsite Base workers or residents. The low rates of emission suggest that the volatilization pathway and inhalation route in ambient air at the surface of the site are not significant at Pumphouse #2.

4.5 GROUNDWATER CHEMISTRY

The following sections describe the results of groundwater sampling events conducted during the 1993 RFI site investigation and the 1994 focused field investigation in support of a risk-based remediation at Pumphouse #2. Only groundwater COPCs are described in detail. Total BTEX concentrations are presented only as an indicator of gross contamination.

All of the groundwater monitoring wells at the site are screened across the entire saturated interval of the perched shallow aquifer. Apparent saturated thickness ranged from no evidence of groundwater to approximately 2 feet of saturated sand and gravel. Background groundwater well MW-1 is upgradient from and outside of the zone of contaminant influence.

4.5.1 Groundwater Benzene and Ethylbenzene Contamination

Groundwater samples were collected and analyzed for the BTEX compounds at three permanent groundwater monitoring wells during the 1993 RFI field investigation (HDR, 1994). Benzene and ethylbenzene were the only BTEX compounds measured in groundwater above MDEQ (1994) promulgated groundwater quality standards and/or risk-based contaminant screening criteria (Table 4.1). The maximum concentration of benzene detected in groundwater at Pumphouse #2 during the RFI was 890 µg/L at MW-18. Both benzene screening criteria also were exceeded by a sample from MW-15, which had a benzene concentration of 37 µg/L. The concentration of benzene measured in the third groundwater monitoring well installed as part of the investigation, MW-10, was equal to the screening criterion of 1.2 µg/L. No LNAPLs were noted at any of the three sampling locations during the investigation.

Ethylbenzene, the only other BTEX compound exceeding screening criteria, was detected at a concentration of 870 µg/L in MW-18 (Table 4.1). No other samples analyzed for ethylbenzene exceeded screening criteria. Table 4.4 summarizes the analytical data for BTEX compounds in groundwater at Pumphouse #2 collected during the 1993 RFI field investigation.

Groundwater samples collected at Pumphouse #2 in 1994-1996 during the risk-based site investigation also were analyzed for the BTEX compounds. During the 1994 investigation, benzene was detected in groundwater at concentrations exceeding screening criteria in samples collected from wells MW-5, MW-15, and MW-18. Benzene concentrations also exceeded screening criteria in samples collected from temporary sampling locations GW-2 and GW-6. Concentrations of benzene measured above the most stringent contaminant screening criterion of 1.2 µg/L at the site in 1994 ranged from 1.4 µg/L at MW-5 to 680 µg/L at MW-18. Ethylbenzene was detected at a concentration in excess of the screening criteria at one monitoring well, MW-18, at a concentration of 710 µg/L. Total BTEX concentrations in groundwater in 1994 ranged from below the MDL to a maximum of 5,680 µg/L at MW-18. Table 4.5 presents analytical results for each groundwater sample collected and analyzed during the 1994 risk-based remediation investigation that exceeded the most stringent groundwater contaminant screening criteria. A full report of the analytical results for the BTEX

TABLE 4.4
SUMMARY OF 1993 RFI GROUNDWATER SAMPLING RESULTS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

	SAMPLE LOCATION		
Compound (µg/L)	MW-10	MW-15	MW-18
Benzene	1.2	37	890
Toluene	0.5 U [a/]	3.4 U	50 U
Ethylbenzene	14	24	870
Total xylenes	15	260	7100

[a/] U = Analyte not detected at concentrations above the method detection limit.

TABLE 4.5
1994 GROUNDWATER SAMPLES IN EXCEEDANCE OF SCREENING CRITERIA
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

	SAMPLE LOCATION				
Compound (µg/L)	GW-2	GW-6	MW-5	MW-15	MW-18
Benzene	53	490	1.4J [a/]	160	680
Toluene	95	20	4.0U [b/]	4.0U	18J
Ethylbenzene	102	580	0.9J	50	710
Total xylenes	330	2500	4.0U	270	4200

[a/] J = Analyte detected between the MDL and PQL.

[b/] U = Analyte not detected at concentrations above the method detection limit.

compounds in groundwater samples collected during the 1994 field effort is presented in Appendix A.

During the 1996 long-term monitoring event, benzene was detected in groundwater at concentrations exceeding screening criteria in samples collected from wells MW-17B, MW-18, MW-20, and MW-22. Concentrations of benzene measured above the most stringent contaminant screening criterion of 1.2 µg/L at the site in 1996 ranged from 1.5 µg/L at MW-22 to 430 µg/L at MW-18. Ethylbenzene was detected at a concentration in excess of the screening criteria at one monitoring well, MW-18, at a concentration of 920 µg/L. Total BTEX concentrations in groundwater in 1996 ranged from below the MDL to a maximum of 5,478 µg/L at MW-18. Table 4.6 presents analytical results for each groundwater sample collected and analyzed during the 1996 monitoring event that exceeded the most stringent groundwater contaminant screening criteria.

Concentrations of dissolved benzene and total BTEX measured at each groundwater sampling location in 1994 are compared to concentrations of dissolved benzene and total BTEX measured during the 1993 RFI site investigation in Figure 4.2. All three wells installed as part of the RFI (MW-10, MW-15, and MW-18) were resampled in 1994. BTEX compounds were detected in all three of the wells during both sampling events. Isoconcentration lines have been included for the 1994 sample data on Figure 4.3 to delineate the probable extent of total BTEX contamination in groundwater.

The maximum concentration of dissolved benzene found in groundwater was 890 µg/L at MW-18 in 1993. In 1994, a maximum dissolved benzene concentration of 680 µg/L was measured in the same groundwater monitoring well. The maximum total BTEX concentrations ranged from 8,860 µg/L at MW-18 in 1993 to 5,680 µg/L in 1994 and 5,478 µg/L in 1996. BTEX concentrations at MW-15 increased slightly from 321 µg/L in 1993 to 484 µg/L in 1994. Concentrations of total BTEX in MW-10 decreased from 30.2 µg/L in 1993 to 2.9 µg/L in 1994.

Site characterization data collected during the 1994 field investigation indicates that contaminated groundwater has not migrated an appreciable distance from the area of known contamination. Total BTEX concentrations have decreased in two of three wells sampled in consecutive years at the site. As shown in Figure 4.3, no appreciable concentrations of total BTEX were found outside of the area bounded by the RFI groundwater monitoring wells (MW-10, MW-15, and MW-18). Wells around the perimeter of the site (MW-2, MW-3, MW-8, MW-9, and MW-11) all had concentrations of BTEX compounds below screening criteria. Based on 1994 analytical data, approximately 1 acre-foot of groundwater underlying the suspected source areas appears to be affected by elevated concentrations of dissolved benzene and ethylbenzene.

During the October 1996 long-term monitoring event, groundwater was resampled at nine new monitoring wells and four of the original 1993-1994 wells. Based on this sampling event, significant BTEX migration is not occurring at the site and benzene and total BTEX concentrations in the most contaminated well (MW-18) appear to be

TABLE 4.6
1996 GROUNDWATER SAMPLES IN EXCEEDANCE OF SCREENING CRITERIA
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

	SAMPLE LOCATION			
Compound (µg/L)	MW-17B	MW-18	MW-20	MW-22
Benzene	47	430	180	1.5
Toluene	10	28	0.4 U[a/]	0.4 U
Ethylbenzene	20	920	300	140
Total xylenes	330	4100	1900	280

[a/] U = Analyte not detected at concentrations above the method detection limit.

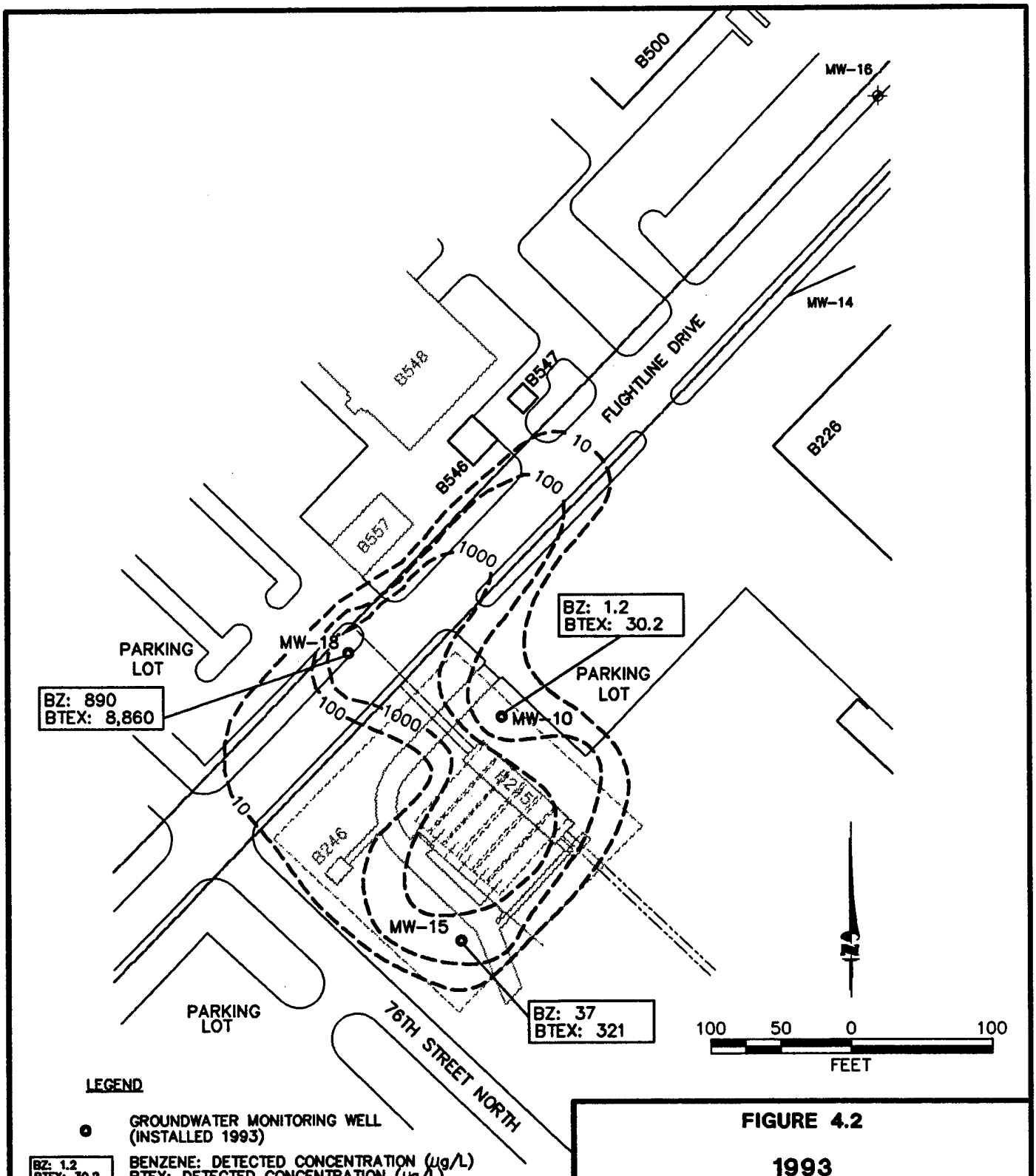
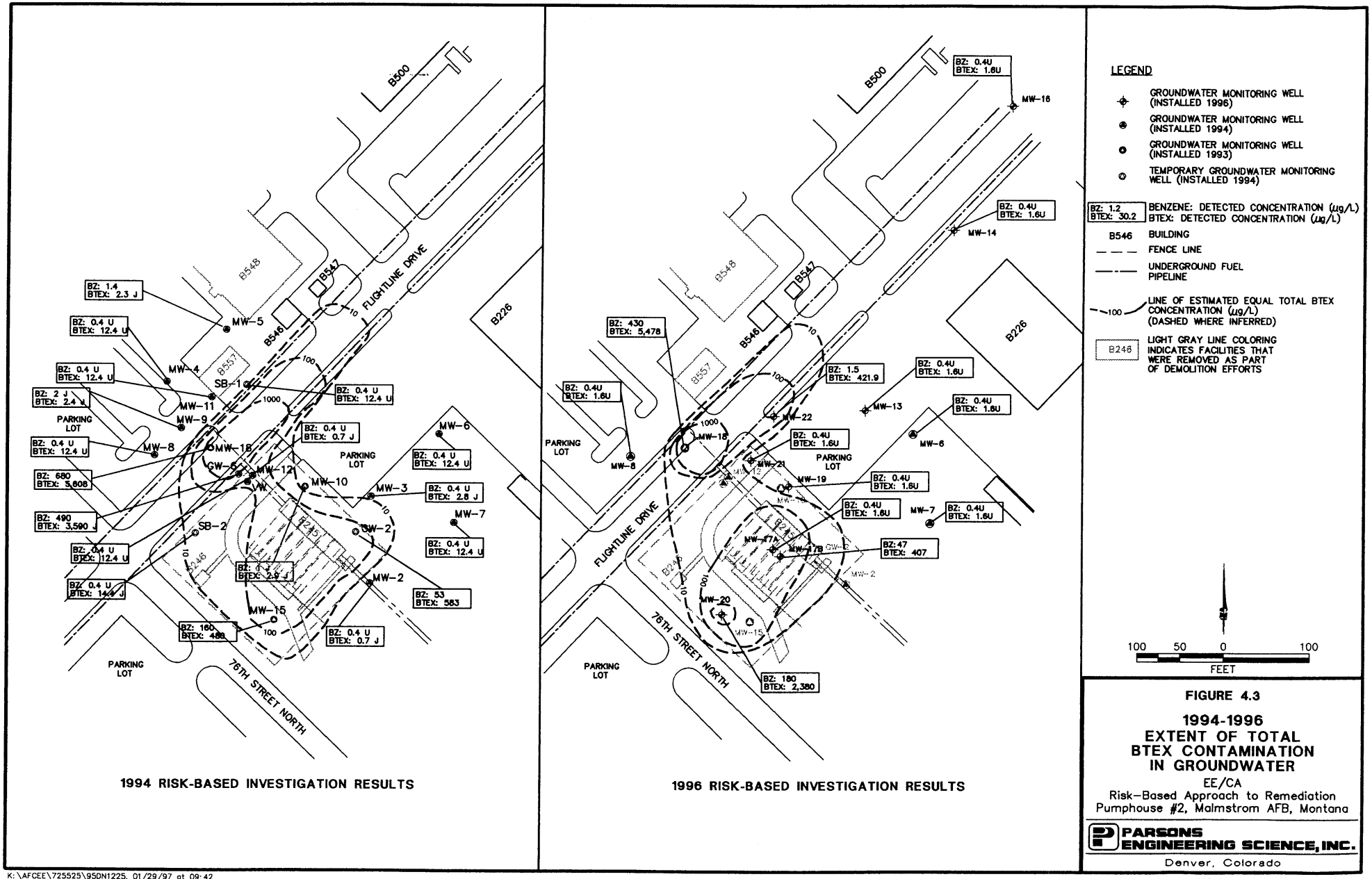


FIGURE 4.2

1993
EXTENT OF TOTAL BTEX CONTAMINATION IN GROUNDWATER

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



1994 RISK-BASED INVESTIGATION RESULTS

1996 RISK-BASED INVESTIGATION RESULTS

FIGURE 4.3

1994-1996 EXTENT OF TOTAL BTEX CONTAMINATION IN GROUNDWATER

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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Denver, Colorado

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decreasing. The 1996 groundwater data will provide a new baseline for monitoring long-term natural attenuation at Pumphouse 2.

4.6 SURFACE WATER CHEMISTRY

Three surface water samples were collected from areas of standing water in the drainage ditch north of the site during the IRP Phase II, Stage 2 investigation (SAIC, 1991). Samples were analyzed for the BTEX compounds and TRPH. No constituents were detected above MDLs in any of the samples. Three surface water samples also were collected from the drainage ditches as part of risk-based site investigation in 1994. These samples, collected from areas of standing water in the ditches, were taken to ascertain if shallow soil and groundwater contamination is adversely affecting surface water quality at the site. No detectable concentrations of BTEX were measured in any of the samples. Analytical data from the three samples collected in 1994 are presented in tabular form in Appendix A.

4.7 SUMMARY

Total BTEX contamination in soils at the site apparently is limited in horizontal and vertical extent, and is found in three discrete areas:

- Around the junction of a small transfer pipeline and a main fuel transfer line running parallel to Flightline Drive;
- In the vicinity of a previous surface spill of an unknown type of fuel; and

  Immediately downgradient from the former location of USTs.

All of the BTEX compounds have been measured at concentrations above the conservative contaminant soil screening criteria during at least one of the recent soil sampling events. The need to remediate soil contamination at the site to protect human health and prevent further groundwater degradation is evaluated in subsequent sections.

Measurable concentrations of total BTEX impacted about 1 acre-foot of groundwater in 1994. However, the magnitude and extent of dissolved benzene and total BTEX groundwater contamination may be decreasing at the site over time. Total BTEX decreased in two of three wells sampled in both 1993 and 1994. This decrease may be attributable to natural physical, chemical, and biological contaminant attenuation processes occurring at the site, because no full-scale engineered action for the remediation of contaminated groundwater has been employed at the site. Based on hydrogeologic data for the site, it is possible that the dissolved contaminant plume has not migrated appreciably from the source areas and is slowly biodegrading in place. This potential is further explored in Section 6 of this EE/CA.

Surface water data collected during the IRP Phase II, Stage 2 investigation and the 1994 risk-based site investigation indicate that shallow soil and groundwater contamination is not adversely affecting surface water quality in the drainages adjacent to the site.

The chemical fate of soil and groundwater COPCs based on their chemical characteristics and site-specific characteristics is considered quantitatively in Section 6. Emphasis is given to documenting the effects of natural physical, chemical, and biological processes on contaminant mass, concentration, persistence, toxicity, and mobility.

SECTION 5

PROPOSED DEGREE OF CLEANUP REQUIREMENTS

Section 4 discusses the nature and extent of contamination at Pumphouse #2 and identifies COPCs based on the most stringent contaminant screening criteria (i.e., the most stringent risk-based criterion or promulgated standard). The soils and groundwater contaminant screening criteria used in Section 4 to focus data presentation were calculated by assuming that the resulting compound-specific concentrations in affected media should be sufficient to protect human health and the environment under the most conservative land use scenario (i.e., residential or unlimited use). Although implementation of this degree of remediation may be desirable and should be pursued when site circumstances so indicate, such cleanups should not be required at industrial sites where unrestricted activities are not planned or expected at the completion of the remedial action.

The goal of the risk-based approach to remediation is to identify and implement an appropriate remedial action for Pumphouse #2 that is protective of human health and the environment under the reasonably expected land use scenarios. To clearly identify a proposed remedial action for Pumphouse #2, it was necessary to assess what level of risk reduction would be necessary to protect potential human and ecological receptors, given the current and foreseeable uses of the site and natural resources in question. Toxicity-based, matrix-specific cleanup goals, or site-specific target levels (SSTLs) were developed for Pumphouse #2 incorporating reasonable, site-specific exposure assumptions. These SSTLs were then used to identify which contaminants and environmental media may require some type of remediation or exposure control to protect likely current or future receptors from risks due to exposure to chemical contamination at Pumphouse #2. Legally applicable or relevant and appropriate federal and state public health and environmental requirements also were considered as possible cleanup objectives, as necessary and where appropriate.

5.1 EXPOSURE PATHWAYS ANALYSIS

An exposure pathways analysis describes the paths a chemical takes from the source of contamination to a potentially exposed individual (EPA, 1989a). A completed exposure pathway must consist of a source, a release mechanism (e.g., leaching or volatilization), a transport medium (e.g., groundwater or air), a potential human or ecological receptor (e.g., current onsite workers, current and future offsite receptors, or terrestrial plants), a potential exposure point (i.e., locations where receptors could come into contact with site-related contamination), and potential routes of exposure (e.g., ingestion or inhalation). Each of these elements must be present before a particular exposure pathway can be considered complete. If any one of these elements is missing, the exposure pathway is considered incomplete, and there is no risk. Site-

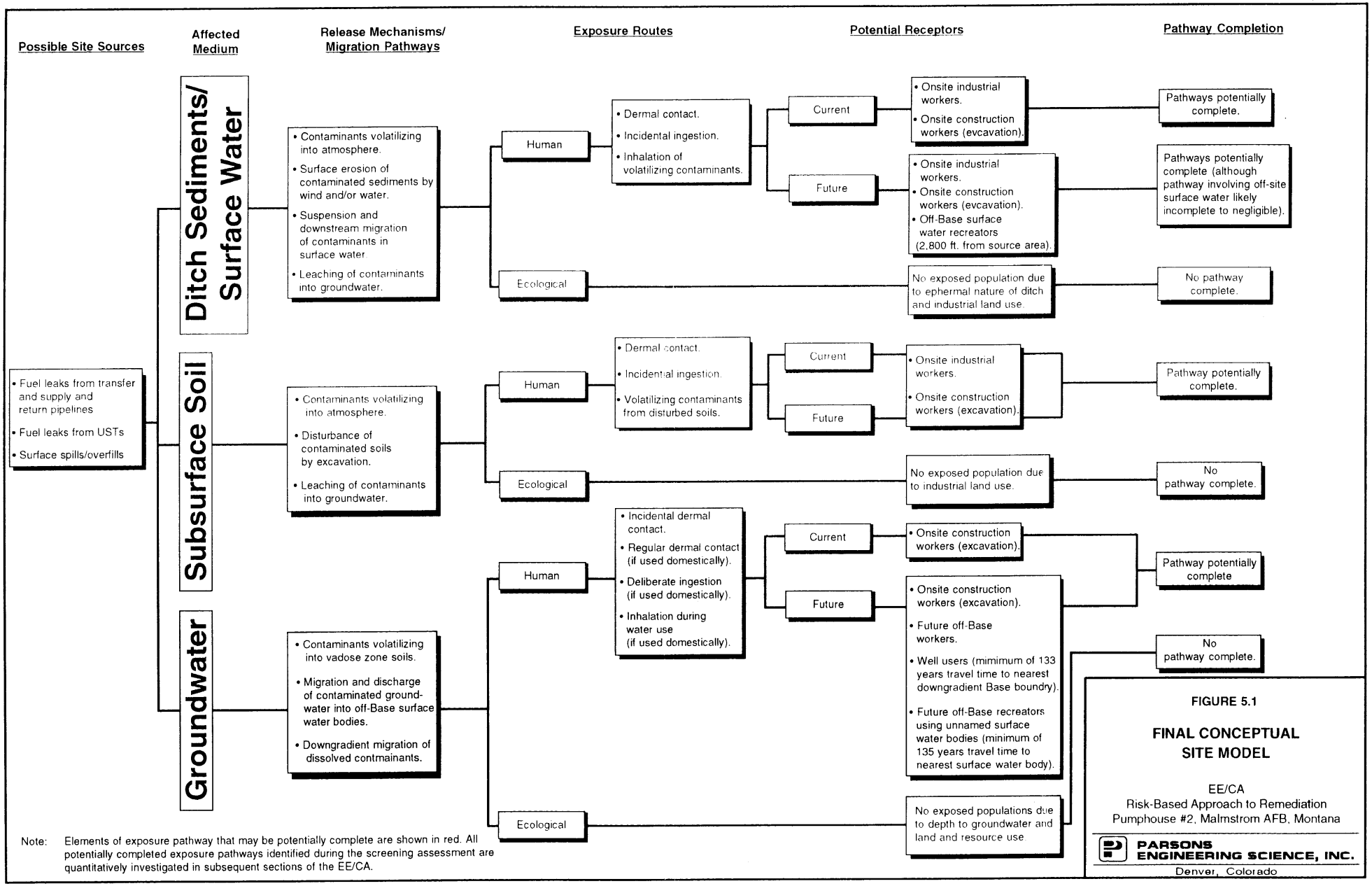
related contamination can present a potential risk to receptors only if exposure pathways are complete.

A site-specific exposure pathways analysis was completed for Pumphouse #2 to determine the likelihood of human or ecological contact with site-related contamination. The first step in the exposure pathway analysis was to conduct a qualitative screening of potential pathways. The objective of this screening assessment was to determine which, if any, exposure pathways are complete (EPA, 1992). Emphasis was given to identifying those pathways where released contaminants may migrate within the environment, but through which potential receptors currently do not come into contact with these chemicals and are not likely to do so in the future. These incomplete exposure pathways were eliminated from further consideration. Exposure pathways that present negligible risks also were identified. The remedial requirements for Pumphouse #2 do not include addressing chemical contamination that does not and will not pose an actual risk to human health or the environment.

Those exposure pathways that were considered complete and significant as a result of the qualitative screening assessment were retained for quantitative evaluation. Toxicity-based SSTLs were developed for all environmental media and contaminants involved in potentially complete exposure pathways. A quantitative evaluation of the type of contaminant released from a site, the impact on environmental media, and the environmental transport and transformation of contaminants following such a release was then conducted for potentially complete exposure pathways. Measured and predicted concentrations of COPCs were then compared to the SSTLs to evaluate the likely risk implications for human health or the environment. The effectiveness of various remedial technologies in eliminating potentially complete exposure pathways, or in minimizing exposure-point concentrations, was investigated. The remedial action recommended for implementation at the site is designed to reduce the potential risks posed by site-related contamination based on site-specific conditions.

5.1.1 Conceptual Site Model

A conceptual site model (CSM) is used to define the type of potential exposures to contaminants at and migrating from a site (i.e., to systematically evaluate the impact of site COPCs in relevant media on potential receptors). The CSM qualitatively describes each onsite release point, the types of contaminant transport and fate mechanisms that may be involved at the site, each group of potentially exposed populations or receptors, and how each receptor group could come into contact with site-related contamination. The CSM is used to summarize existing site characterization data, including assumptions about land and groundwater use, and to complete the qualitative exposure pathway screening assessment. A preliminary CSM for Pumphouse #2, which was used to identify data gaps and guide data collection activities, is included in the work plan (ES, 1994a). The revised CSM for Pumphouse #2 (Figure 5.1), which is developed in the following sections, incorporates data collected during the site investigation conducted in October and November 1994 and March 1995 into the preliminary CSM.



Note: Elements of exposure pathway that may be potentially complete are shown in red. All potentially completed exposure pathways identified during the screening assessment are quantitatively investigated in subsequent sections of the EE/CA.

FIGURE 5.1

FINAL CONCEPTUAL SITE MODEL

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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5.1.1.1 Source and Release Mechanisms

The first component of the CSM is contaminant source and release screening. The likelihood of release from a source, the nature of the contaminants involved, and the probable magnitude of their release all must be considered (EPA, 1989a and 1992). The largest source of chemical contamination at the site is suspected to be a subsurface release of JP-4 from fuel transfer lines at the site. This conclusion is based on BTEX concentrations in groundwater and soil samples collected adjacent to fuel transfer lines (MW-18, SED-6, and SED-9). Jet fuel was apparently released into soils and possibly into underlying groundwater from a leaking transfer line. It should also be noted that four USTs at the site also failed a pressure test in 1992. Releases of diesel fuel from these tanks are also a probable but limited source of contamination at the site. Soil samples collected from beneath the tanks during closure sampling contained minimal concentrations of BTEX. A surface spill of an unknown type of fuel also has been documented in the southern corner of the site in the vicinity of MW-15.

No LNAPL has been documented at the site. However, soil sampling and analysis completed as part of previous investigations at the site and the 1994 risk-based site investigation indicated elevated concentrations of all of the BTEX compounds in unsaturated soil. Subsurface soil sampling locations were selected during these sampling events to target soils having the highest potential for soil contamination. The objective of the 1993 RFI soil sampling event was to estimate the probable location of a subsurface fuel release. The 1993 bioventing sampling event considered these soil data when identifying an appropriate location to test the effectiveness of *in situ* bioventing. The soil results from the 1993 RFI sampling event represent baseline soil contaminant concentrations in the suspected release area prior to implementing a pilot-scale engineered soil remedial technology.

A total of 106 soil samples were collected during the IRP Phase II, Stage 1 and 2 site investigations, the 1993 initial bioventing pilot test, the 1994 1-year bioventing pilot test, the 1993 RFI site investigation, the 1994 risk-based site investigation and 1995 tank closure sampling. Figures 2.2, 2.3, and 2.4 show locations of soil samples collected during each of the sampling events. Table 4.3, in combination with Appendix A, contains a complete list of soil samples collected during all sampling events.

Of the 106 soil samples collected from this site, 96 samples were collected from the suspected source areas, 9 samples were collected from downgradient locations, and 1 was collected from an upgradient location. Forty-three of the soil samples had detections of one or more of the individual BTEX compounds. During the 1994 risk-based site investigation, all of the BTEX compounds were measured in soil at concentrations exceeding the chemical-specific, conservative contaminant criteria calculated to protect groundwater from adverse impacts due to leaching (Table 4.1). Benzene was measured in soil at concentrations above the most conservative contaminant screening criterion (leaching) in 2 of the 67 soil samples analyzed for benzene. Toluene was measured at concentrations above the chemical-specific leaching screening criterion in 3 of the 75 soil samples analyzed for toluene. Ethylbenzene and total xylenes were measured at concentrations above their contaminant screening criteria in 10 and 5, respectively, of the 90 soil samples.

Most of the BTEX compounds were measured at concentrations above their leaching screening criteria in soil samples collected near the intersections of fuel transfer lines and fuel transport lines on either side of Flightline Drive. During the 1994 risk-based sampling event, all of the BTEX compounds were also measured at concentrations above the chemical-specific leaching screening criteria in a sediment sample collected from the bottom of the drainage ditch adjacent to MW-18. This sample location is within 10 feet of the junction of a transfer line to Pumphouse #2 and a main transport line running parallel to Flightline Drive. The most contaminated soil gas sample (SG-4) also was collected from this area.

Based on the data collected to date, it appears that limited, concentrated areas of unsaturated soil contamination may be significant sources of chemical contamination at the site. Possible release mechanisms from soil include volatilization and leaching. Chemicals most likely to be released via these mechanisms are volatile and water soluble. Because BTEX compounds are volatile and highly to moderately water soluble, they are the chemicals most likely to be released from residual soil contamination into surrounding environmental media at the site. A more detailed evaluation of the nature and magnitude of chemical releases expected at the site is presented in Section 6.

5.1.1.2 Contaminant Environmental Transport

The second component of the CSM is a screening assessment of contaminant transport, transformation, and fate in the environment following release. This screening step involves identifying each type of transport process that may govern the movement of contaminants within and among environmental media, determining the direction and general rate of contaminant movement from the site, and defining the areas to which contaminants may have been or are expected to be transported (EPA, 1992). This screening analysis is designed only to identify likely pathways of contaminant migration. An in-depth, quantitative evaluation of contaminant transport, transformation, and fate over time and distance at Pumphouse #2 is presented in Section 6.

Volatilization of chemicals from contaminated media into the atmosphere is a possible release/transport mechanism at the site. The soil flux data collected during the 1994 risk-based investigation indicate that adverse ambient air quality impacts due to chemical volatilization from the ground surface are not likely to be significant (Section 4.4.5). However, benzene vapors could cause a carcinogenic risk to onsite workers if excavation of the soils in the vicinity of MW-18 is required for future remedial and/or maintenance activities unless appropriate personnel protective measures are taken. The concentration of benzene found at 3 feet bgs in a soil gas sample collected from this area exceeded the OSHA 8-hour TWA PEL. Therefore, volatilization of contaminants from disturbed subsurface soils and transport into the atmosphere is considered to be a potentially significant exposure pathway for onsite workers. This pathway was retained for further consideration and analysis.

Benzene was also the only BTEX compound detected at concentrations above the contaminant screening criterion calculated to eliminate potential health risks due to inhalation of volatilizing contaminants (Table 4.1). One sample, sediment sample SED-9, collected during the 1994 risk-based sampling event exceeded the health-based

screening criterion of 0.5 mg/kg for inhalation. No other samples collected at the site have exceeded the inhalation criterion. It is important to note that water flow in the ditches adjacent to Flightline Drive is ephemeral. Although sediments in the ditch are often not saturated and could pose an inhalation hazard, the contaminant screening criterion developed to protect against risks due to inhalation of volatilizing contaminants was based on an unlimited or residential land use scenario. The nature and type of exposures to these near-surface soils and sediments under an industrial land use scenario are different than under a residential scenario. It is possible that an exposure pathway involving volatilization from disturbed shallow soils and sediments may be significant at this site. Therefore, contaminant transport from soils via volatilization was retained in the CSM for evaluation.

Groundwater data collected as part of the 1993 RFI site investigation and the 1994 risk-based field investigation, which are presented in Section 4, confirm that chemicals have been released into groundwater at the site. March 1995 groundwater elevation data suggest that groundwater flow at the site is toward the east-northeast (Figure 3.3). The general direction of groundwater migration is an important component of the final CSM. These data are critical to identifying the groups of potential human and ecological receptors that could be exposed to site-related contamination as it is transported in groundwater.

If the effects of natural chemical attenuation processes such as adsorption and biodegradation are not considered during this initial screening step, it is possible that site-specific contamination could eventually migrate in groundwater to areas beyond Base control. The maximum linear advective groundwater velocity was calculated to be 0.06 ft/day, or 22 ft/year (Section 3.4.2). Assuming that groundwater underlying Pumphouse #2 could migrate uninterrupted at this velocity, it would take a minimum of 133 years for groundwater impacted by contamination at Pumphouse #2 to migrate to the nearest downgradient Base boundary, which is located approximately 0.5 mile north of the source area. Downgradient wells beyond the Base boundary are the closest possible exposure points for human receptors to contaminated groundwater because no groundwater potable water supplies are located on-Base (Section 3.6.4).

This is an extremely conservative exposure assumption, however, because of the effects of natural chemical attenuation on dissolved contaminant concentration, mass, mobility, persistence, and toxicity (e.g., toxicity of a chemical could change as it transforms to compounds such as carbon dioxide and water). The chemical fate of dissolved contaminants can be quantitatively investigated using both historical monitoring data and fate and transport calculations. For the purposes of this screening assessment, however, it has been conservatively assumed that contaminant transport in groundwater may be involved in complete exposure pathways to offsite human receptors.

No permanent bodies of surface water are present in the immediate vicinity of Pumphouse #2. As described in Section 3.3, deep drainage ditches parallel either side of Flightline Drive along the northwestern edge of the site. These ditches, however, are ephemeral and contain water only during and after precipitation events. Although no BTEX was detected in surface water samples collected from these ditches in 1994, elevated concentrations of BTEX were measured in sediment samples SED-6 and SED-9 collected from the bottoms of the drainage ditches on either side of Flightline Drive

(Figure 2.7 and Section 4.4.1). Consequently, it is possible that contaminated sediments and soils at Pumphouse #2 may affect surface water quality in the drainage ditches adjacent to the site during precipitation events and/or spring runoff. Thus, for the purposes of this screening assessment, leaching of chemicals from contaminated sediments and soils into surface water is considered a reasonable pathway for contaminant migration at Pumphouse #2 and was retained for further evaluation.

The nearest permanent surface water bodies located downgradient from the leading edge of dissolved contamination are several small, unnamed ponds to the north of the northern Base boundary (Figure 1.3). The nearest of these surface water bodies is about 2,800 feet north of Pumphouse #2. Given the maximum linear advective velocity of groundwater at the site (i.e., 0.05 ft/day), it would take contaminants approximately 150 years to migrate in groundwater to and possibly into the nearest surface water body. This is a conservative contaminant transport assumption since the effects of natural chemical attenuation processes on chemical concentration, mass, mobility, persistence, and toxicity are not considered. Additionally, given the discontinuous nature of shallow groundwater at this site, it is highly unlikely that dissolved contamination can migrate uninterrupted to these downgradient surface water bodies. However, similarly to the groundwater migration to offbase locations, contaminant transport in groundwater and eventual discharge into off-Base surface water bodies conservatively is considered a viable pathway for contaminant migration at Pumphouse #2.

5.1.1.3 Potentially Exposed Populations

The final major component of the CSM for Pumphouse #2 is the identification of potentially exposed populations. The objective of this step is to draw upon the results of the contaminant transport and fate screening assessment to qualitatively determine the likelihood and extent of human or ecological receptor contact with site-related contaminants (EPA, 1989a and 1992). Land use assumptions are critical to defining the types of receptors that are now present or may be reasonably expected to be present in the foreseeable future at Pumphouse #2, or in immediately adjacent areas and areas outside the Base property that could be impacted by site-related contamination.

Current Onsite Conditions

As described in Section 3.6.2, the site is currently vacant and is zoned for industrial use. Pumphouse #2 is not within an restricted-access area. The site can be accessed by anyone on the Base. Use of the site is industrial, so only onsite workers could come into regular contact with site environmental media. No ecological receptors are permanent inhabitants of the area due to the industrial nature of the site. Worker activities are primarily associated with maintenance of utility corridors paralleling Flightline Drive, and possibly grounds maintenance such as grass mowing. No groundwater is withdrawn from areas within or downgradient from Pumphouse #2 to meet potable or nonpotable water requirements. The water supply for Base facilities is currently derived from the City of Great Falls (Section 3.6.4).

The contaminant release and transport screening assessments showed that ditch sediments, soils, soil gas vapor, groundwater, and surface water are the environmental media that could possibly be involved in significant completed exposure pathways

(Figure 5.1). Site subsurface soil gas data demonstrate that volatilization from disturbed soils could be a significant contaminant release mechanism, although soil flux data indicate that surface emissions are negligible under nonintrusive conditions. Impacts on adjacent surface water bodies (i.e., drainage ditches along Flightline Drive) may be possible due to leaching from contaminated sediments during precipitation events.

Therefore, current onsite worker populations engaged in nonintrusive industrial activities could be exposed to site-related contamination via surface water and sediments. Current onsite construction worker populations could be exposed via soil gas vapors, sediments, subsurface soils, surface water, and groundwater during excavation or other intrusive site activities. As evidenced by the June 1995 excavation and demolition activities, limited amounts of shallow groundwater could collect in excavations at the site and pose a potential risk to onsite workers. Workers also can be exposed to contaminated subsurface soils during these types of activities.

Because groundwater is not extracted and used by onsite workers to meet potable or nonpotable water demands, site workers will not come into contact with groundwater contamination through ingestion (i.e., the only potential route of exposure could be incidental dermal contact). It is reasonable to assume that several exposure pathways involving contaminated site media and onsite current receptors could be complete under both normal (i.e., nonintrusive industrial) and highly disruptive site conditions (e.g. excavation or construction).

Current Offsite Conditions

Pumphouse #2 is surrounded by industrial areas and parking lots. Dissolved groundwater contamination appears to be migrating in an east-northeasterly direction. The area immediately to the east and northeast of the site is a parking lot. A large portion of the land between monitoring wells MW-3, MW-6, and MW-7 was used to store road sand during the winter of 1994-1995. The nearest occupied area northeast of Pumphouse #2 is a snow removal equipment maintenance garage, located about 275 feet northeast of the former location of the pumphouse. All areas beyond this on-Base facility to the nearest Base boundary north and northeast of the site may be classified as light to heavy industrial areas. No site-related contamination has migrated more than 65 feet beyond the former location of the pumphouse, as indicated by 1994 risk-based soil and groundwater sampling results. This means that current offsite and off-Base populations could not come into contact with site-related contamination in soils and groundwater. All exposure pathways to offsite and off-Base populations are incomplete under current conditions.

Future Conditions

As described in Section 3.6.3, no changes in onsite land use or land use in areas immediately downgradient of the site are planned. All receptor groups and their activities should remain identical to those noted for current conditions. This is important because it means that all reasonable future exposure pathways to onsite and off-site receptors will be identical to those under current site conditions. Future onsite Base workers could be exposed to soil gas, sediments, surface water, subsurface soil, and groundwater contamination as a result of construction/excavation activities that

disturbed the ground surface. Workers also could be exposed to contaminated sediments and contaminated surface water during nonintrusive activities.

The potential exposure of future off-site receptors depends on contaminant transport, transformation, and fate mechanisms. If site-related contaminants were to be transported with and at the same linear velocity as groundwater (ignoring the beneficial effects of natural chemical attenuation processes), groundwater contamination could migrate beyond the northern Base property boundary within 133 years (Section 5.1.1.2). As discussed previously, all areas downgradient from Pumphouse #2 are used to support light to heavy industrial operations. The area directly beyond the northern Base property boundary is zoned for agricultural use (Section 3.6.2). The actual anticipated nature and extent of contaminant migration through the environment over time is quantitatively explored in Section 6. These data will be used to determine which offsite receptors, if any, could come into contact with contamination originating from Pumphouse #2. It is important to note, however, that no off-Base shallow groundwater wells are used to meet potable water demands.

5.1.2 Summary of Potentially Completed Exposure Pathways

Figure 5.1 presents the revised CSM, which incorporates the results of the site-specific exposure pathway screening assessment. Incidental exposure to onsite contamination in sediments and surface water is possible during nonintrusive (i.e., no excavation) activities at the site. Additionally, incidental exposure to contaminated shallow subsurface soils, soil gas, sediments, surface water, and groundwater is possible if excavation/construction activities are conducted in and immediately downgradient from the source area at Pumphouse #2. It is important to note that, due to the ephemeral nature of the ditches, sediments may be a part of two complete exposure pathways. When saturated, contaminants may leach from sediments into water in the ditches and impact surface water quality. When the ditches do not contain water, the dry sediments may be a source of chemicals volatilizing into the atmosphere. Onsite workers are the primary group of receptors that could have incidental contact with site-related contamination under both of these scenarios.

Geochemical data and simple chemical fate are used in Section 6 to determine how site-related contamination will behave in the environment over time at and around Pumphouse #2. The effects of transformation processes and other contaminant characteristics that influence contaminant concentration, mass, mobility, persistence, and toxicity have been factored into this analysis. This assessment will be used to determine the type and magnitude of remediation necessary to reduce or eliminate potential risks to onsite workers associated with exposure to chemical contamination. This analysis also is necessary to determine if any exposure pathways involving offsite or off-Base receptors could be complete in the future.

The conclusions of this site-specific exposure pathways analysis are important for several reasons. First, the screening assessment demonstrates that exposure of onsite workers to contaminated environmental media is possible as a result of both nonintrusive and intrusive activities at the site. Under normal site conditions (i.e., no excavation), site workers potentially are exposed to contaminated sediments and surface water. This is important because it means that active remediation may be necessary to minimize or eliminate any imminent risks associated with the chemical contamination

in sediments in the drainage ditches at the site. Under an excavation/construction scenario, workers may be exposed to contaminated soil, soil gas, and groundwater in addition to sediments and surface water. If excavation activities are undertaken at the site, proper precautions will have to be taken. It is important to note, however, that large-scale removal and demolition activities have been completed, and there is likely little need for future excavation activities at the site. Second, the screening assessment shows that groundwater contamination could take up to 133 years to migrate to the downgradient Base property boundary. This gross estimate of contaminant travel time assumes that all contaminants migrate as fast as groundwater, and are not subject to the natural chemical attenuation processes described in Section 6. Therefore, onsite groundwater contamination does not pose an immediate threat to downgradient media. Third, the screening assessment indicates that future offsite exposure pathways involving groundwater are not likely to be complete and significant for Pumphouse #2. The discontinuous nature of the shallow groundwater and the lack of on-Base and off-Base exposure points likely will result in an interrupted pathway. The lack of a complete exposure pathway involving groundwater and any offsite receptors is quantitatively evaluated in Section 6. This type of information helps to focus the range of remedial objectives and requirements.

5.2 PROPOSED TYPE OF CLEANUP

The Air Force intends to implement a risk-based remedial action at Pumphouse #2 that is sufficient to minimize contaminant migration and eliminate potential risks to human health and the environment. The concentration of contaminants that can remain in onsite media and not present an unacceptable residual risk must be defined. Additionally, the proposed remedial action must be sufficient to prevent site-related contaminants from migrating at concentrations above state standards to areas beyond appropriate exposure controls.

5.2.1 Site-Specific Target Levels for Contaminated Soils and Groundwater

On the basis of the exposure pathway analysis summarized in the CSM (Figure 5.1), site-related contamination may pose a risk to onsite worker health under nonintrusive and intrusive site activities. The site and the land immediately downgradient from Pumphouse #2 are used as industrial areas, and Base access restrictions are enforced. To implement a risk-based site closure, it is necessary to demonstrate that contaminant concentrations are not increasing and do not pose a short- or long-term risk to human health and the environment. To accomplish this, the level of contamination that can remain in soils and groundwater at the site, without posing a risk to onsite workers or to future offsite receptors downgradient from Pumphouse #2, must be defined.

Table 5.1 presents risk-based SSTLs for contaminated subsurface soils, sediments, groundwater, and surface water that would reduce potential risks associated with exposure to site contamination at Pumphouse #2 to acceptable levels. Cross-media contamination of groundwater or surface water from contaminated soil also was factored into the development of the risk-based SSTLs for soils. This approach ensures that residual contaminant concentrations in soil will not degrade groundwater and/or surface water quality if contaminants leach from soils.

TABLE 5.1

SUMMARY OF CHEMICAL-SPECIFIC SSTLs

ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Compound (units)	Onsite Worker - Nonintrusive Conditions[a] Health-Based[b]			Onsite Worker - Intrusive Conditions[f] Health-Based			Cross-Media Impacts Leaching from Soils: Site-Specific K_d Values[g]				Cross-Media Impacts Leaching from Soils: Literature K_d Values[i]			
	10^{-6} risk level[c]	10^{-4} risk level[d]	HQ = 1[e]	10^{-6} risk level	10^{-4} risk level	HQ = 1	10^{-6} risk level	10^{-4} risk level	HQ = 1	MCL[h]	10^{-6} risk level	10^{-4} risk level	HQ = 1	MCL
Soil (mg/kg)														
Benzene	40.75	4.08E+03	--	30.85	3.08E+03	--	0.80	80.05	--	0.06	0.02	2.12	--	1.50E-03
Toluene	--	--	3.22E+04	--	--	2.48E+04	--	--	1.19E+03	43.68	--	--	12.50	0.46
Ethylbenzene	--	--	1.57E+04	--	--	1.29E+04	--	--	790.29	66.91	--	--	3.42	0.29
Xylenes	--	--	3.32E+05	--	--	2.72E+05	--	--	6.68E+03	436.85	--	--	75.59	4.94
Groundwater (µg/L)														
Benzene	70.33	7.03E+03	--	70.33	7.03E+03	--								
Toluene	--	--	2.72E+04	--	--	2.72E+04								
Ethylbenzene	--	--	8.27E+03	--	--	8.27E+03								
Xylenes	--	--	1.53E+05	--	--	1.53E+05								

MDEQ Standard
5
1000
700
10000

[a] This receptor group represents current and potential future workers that may come into contact with onsite environmental media as a part of nondisruptive (i.e., nonintrusive) industrial activities.

[b] Health-based SSTLs are calculated to define the concentration of contaminant that can remain in onsite media and not pose an unacceptable carcinogenic or noncarcinogenic health risk to onsite workers. Soil SSTLs are calculated to be the concentration that would prevent potential health risks due to incidental ingestion of soil particles, inhalation of volatilizing chemicals, and dermal contact using a combination of default and site-specific exposure assumptions. Groundwater SSTLs are calculated to be the concentration that would prevent potential health risks due to incidental dermal contact using a combination of default and site-specific exposure assumptions. See Appendix G for details on the derivation of these SSTLs.

[c] Target risk level used to calculate risk-based SSTLs that represent a one-in-one-million excess cancer risk due to exposure to a carcinogen. Commonly known as the point of departure.

[d] Target risk level used to calculate risk-based SSTLs that represent a one-in-ten-thousand excess cancer risk due to exposure to a carcinogen. Upper bound target risk level that triggers the need for remedial action per NCP and EPA risk guidance.

[e] Target hazard quotient used to calculate risk-based SSTLs that represent no adverse health risk due to exposure to a single noncarcinogen. No attempt was made to define the SSTL for noncarcinogens given the presence of multiple substances.

[f] This receptor group represents current and potential future workers that may come into contact with onsite environmental media as a part of disruptive (i.e., intrusive or construction) site activities.

[g] Risk-based SSTL calculated to define the concentration of contaminant that can remain in soils and not pose a risk to groundwater quality. Target soil leaching SSTLs are sufficient to prevent contaminants from leaching at concentrations greater than risk-based SSTLs for groundwater using site-specific soil/water partition coefficients derived from sampling data. See Appendix G for details on how these SSTLs were derived.

[h] Risk-based SSTL calculated to define the concentration of contaminant that can remain in soils and not pose a risk to groundwater quality. Target soil leaching SSTLs are sufficient to prevent contaminants from leaching at concentrations greater than the MCLs using site-specific soil/water partition coefficients derived from sampling data. See Appendix G for details on how these SSTLs were derived.

[i] Risk-based SSTL calculated to define the concentration of contaminant that can remain in soils and not pose a risk to groundwater quality. Target soil leaching SSTLs are sufficient to prevent contaminants from leaching at concentrations greater than target SSTLs for groundwater or MCLs using soil/water partition coefficients based on literature values of K_{oc} and site-specific f_{oc} data. See Appendix G for details on how these SSTLs were derived.

These numerical concentration goals are based on carcinogenic and/or noncarcinogenic toxicity values and reasonable exposure assumptions appropriate for an industrial setting. Risk-based SSTLs for onsite media for known or suspected carcinogens were calculated to define the level of residual site contamination that represents an excess upperbound cancer risk between one in ten thousand (10^{-4}) and one in one million (10^{-6}) for workers engaged in both nonintrusive and intrusive activities at the site. Similarly, risk-based SSTLs for systemic toxicants (i.e., noncarcinogens) were calculated to eliminate any appreciable risk of deleterious effects to workers that could be incidentally exposed to contaminated media.

The sources of toxicity information included the Integrated Risk Information System (IRIS) (Micromedex, Inc., 1995) and the Health Effects Assessment Summary Tables (HEAST) (EPA, 1994b). SSTLs were developed using procedures described in EPA (1991a) Office of Solid Waste and Emergency Response (OSWER) Directive 9285.7-01B, entitled *Human Health Evaluation Manual, Part B: Development of Risk-Based Preliminary Remediation Goals,* and EPA (1991b) OSWER Directive 9481.00-6C, entitled *Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual, Part C: Risk Evaluation of Remedial Alternatives.* Additional EPA (1989a, 1991c, 1992, 1994a, and 1994b) guidance relevant to developing risk-based SSTLs that are protective of human health and the environment also were used. The derivation of these risk-based SSTLs, including the algorithms and exposure assumptions, are presented in Appendix D.

5.2.2 Promulgated Remedial Standards for Contaminated Soils and Groundwater

Other possible sources of remedial action goals or SSTLs for contaminated media are chemical-specific standards defined by state and federal environmental law. These chemical-specific concentrations may be used as a basis for establishing desired cleanup levels at a defined POA based on legally enforceable federal and state requirements. Regulations that were identified as potentially relevant include the following:

- National Primary Drinking Water Standards - MCLs [Title 40, Code of Federal Regulations Part 141 (40 CFR 141)];
- Secondary Drinking Water Standards - Secondary MCLs [40 CFR 143];
- Maximum Contaminant Level Goals (MCLGs) for Drinking Water [40 CFR 141];
- Clean-up guidelines for petroleum releases under the Montana UST program (MDEQ, 1994)

The shallow groundwater underlying Pumphouse #2 is not now used and is not planned to be used as a drinking water source. Additionally, shallow groundwater is not in hydraulic communication with deeper aquifers in the area that are used to produce water for beneficial use. Thus, the primary federal MCLs were not identified to be relevant and appropriate as cleanup objectives for *in situ* groundwater restoration at Pumphouse #2.

MDEQ (1994) has also promulgated state groundwater quality standards for benzene and ethylbenzene. The state has adopted the primary MCL of 5 µg/L for benzene as the state groundwater quality standard. The state has also adopted the primary MCL of 700 µg/L for ethylbenzene as the state groundwater quality standard. Finally, MDEQ has promulgated a standard of 1 mg/kg for benzene in soil. No other chemical-specific standards for soils have been set by MDEQ. Theses promulgated groundwater quality standards may serve as cleanup objectives at the POA established for Pumphouse #2. The risk-based SSTLs listed in Table 5.1 define the residual levels of contamination that can remain onsite without posing a risk to human health and the environment, given the current and likely future use of the site. Therefore, attainment of the MDEQ groundwater quality standards at every point in the impacted area is not necessary to protect human health and the environment.

5.3 REMEDIATION REQUIREMENTS

Table 5.1 summarizes the relevant risk-based SSTLs developed to be protective of human health and the environment and other chemical-specific standards for each of the COPCs in soil and groundwater at Pumphouse #2. The SSTLs are the most appropriate cleanup levels to provide the desired level of risk reduction for potential onsite receptors based on defensible toxicity data and site-specific exposure assumptions. The degree of cleanup implied by the promulgated standards is more than is necessary to protect human health and the environment given current and foreseeable land use and exposure potential. Imposing compliance with MDEQ groundwater quality standards at every point in groundwater at this site would directly conflict with a risk-based approach to remediation, and is not required to protect human health and the environment. These promulgated standards may be considered appropriate concentration goals at and beyond the POA.

Table 5.2 identifies, by environmental medium, the concentrations of Pumphouse #2 COPCs that were measured during either the IRP site investigations, the 1993 RFI site investigation, or 1994 field efforts at concentrations in excess of the risk-based SSTLs. None of the COPCs were measured in soils or sediments at concentrations above the risk-based SSTLs calculated to protect onsite workers against risks due to inhalation of volatilizing chemicals, incidental ingestion of contaminated soil particles, and dermal contact with contaminated medium. However, each of the BTEX compounds were measured at concentrations above the risk-based SSTLs calculated to protect groundwater or surface water quality from adverse impacts due to chemical leaching. Benzene, ethylbenzene, and total xylenes were measured in soils or sediments at concentrations that could result in groundwater or surface water concentrations above the risk-based SSTL developed to protect onsite workers from risks due to exposure via incidental dermal contact with contaminated water at the site. The maximum concentration of benzene measured in sediments in 1994 exceeded both the risk-based SSTL for leaching developed using a site-specific soil/water partition coefficient (K_d) (derived from soil and water data collected at MW-18) and the risk-based SSTL for leaching developed using a K_d based on literature values (Table 5.2 and Appendix D). The maximum concentrations of ethylbenzene and total xylenes measured in soils or sediments at Pumphouse #2 also could result in contaminants leaching to groundwater at concentrations above the worker protection SSTL if the literature K_d values

TABLE 5.2

COMPARISON OF COPC CONCENTRATIONS TO CHEMICAL-SPECIFIC SSTLs

ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

COPC (units)	1988 IRP Max. Conc.	1991 IRP Max. Conc.	1993 Bioventing Max. Conc.	1993 RFI Max. Conc.	1994 Bioventing Max. Conc.	1994 Risk-Based Max. Conc.	1995 Tank Sampling Max. Conc.	Worker - Nondisruptive Conditions			Worker - Disruptive Conditions			MDEQ Standard
								Worker - Nondisruptive Conditions			Worker - Disruptive Conditions			
								10^{-6} risk level	10^{-4} risk level	HQ = 1	10^{-6} risk level	10^{-4} risk level	HQ = 1	
Soil (mg/kg)														
Benzene	--	--	0.65U	0.023	0.05U	2.3J	< 0.05	40.75	4.08E+03	--	30.85	3.08E+03	--	1.00E+00
Toluene	6.9	--	1.1	6.1U	0.12	11	0.703	--	--	3.22E+04	--	--	2.48E+04	--
Ethylbenzene	36.3	75.1	2.2	83	0.55	35	1.86	--	--	1.57E+04	--	--	1.29E+04	--
Total xylenes	243	270	4.4	300	0.29	210	9.91	--	--	3.32E+05	--	--	2.72E+05	--
Groundwater (µg/L)														
Benzene	--	--	--	890	--	680	--	70.33	7.03E+03	--	70.33	7.03E+03	--	5
Ethylbenzene	--	--	--	870	--	710	--	--	--	8.27E+03	--	--	8.27E+03	700

COPC	1988 IRP Max. Conc.	1991 IRP Max. Conc.	1993 Bioventing Max. Conc.	1993 RFI Max. Conc.	1994 Bioventing Max. Conc.	1994 Risk-Based Max. Conc.	1995 Tank Sampling Max. Conc.	Cross-Media Impacts: Site-Specific K_d				Cross-Media Impacts: Literature K_d			
								10^{-6} risk level	10^{-4} risk level	HQ = 1	MCL	10^{-6} risk level	10^{-4} risk level	HQ = 1	MCL
Soil (mg/kg)															
Benzene	--	--	0.65U	0.023	0.05U	2.3J	< 0.05	0.80	80.05	--	0.06	0.02	2.12	--	1.50E-03
Toluene	6.9	--	1.1	6.1U	0.12	11	0.703	--	--	1.19E+03	43.68	--	--	12.50	0.46
Ethylbenzene	36.3	75.1	2.2	83	0.55	35	1.86	--	--	790.29	66.91	--	--	3.42	0.29
Total xylenes	243	270	4.4	300	0.29	210	9.91	--	--	6.68E+03	436.85	--	--	75.59	4.94

NOTE: Shading indicates concentration exceeds risk-based SSTL. Both concentration and exceeded SSTL are shaded.

adequately describe chemical partitioning behavior at the site. These compounds were not present at sufficient concentrations to pose a threat to groundwater quality if only site-specific K_d values are considered.

However, all of the BTEX compounds were measured in soils or sediments at concentrations that could result in groundwater concentrations above the MDEQ (1994) groundwater quality standards. Benzene and ethylbenzene were measured in soils or sediments at concentrations in excess of the risk-based SSTLs for leaching contaminants at concentrations above the promulgated standards based on site-specific K_d values. Using literature-based K_d values, all of the BTEX compounds are present at concentrations in soils or sediments that will result in groundwater concentrations above the promulgated standards. This means that at least maximum levels of existing soil contamination are likely to be a significant source of contaminant mass to receiving groundwater and possibly surface water. Any soils or sediments that are contaminated above these risk-based SSTLs may pose an indirect risk to worker health or the environment.

Benzene was the only groundwater COPC to be measured above the risk-based SSTL calculated to protect onsite workers from risks due to incidental dermal contact with contaminated groundwater (Table 5.2). This means that some type of exposure control and/or groundwater remediation may be necessary to protect onsite workers engaged in intrusive activities from risks due to incidental dermal contact with groundwater or surface water contamination. The ability of natural chemical attenuation processes to minimize contaminant mass, concentration, and toxicity over time within the source area at the site is considered in Section 6.

Both benzene and ethylbenzene were measured at concentrations above the MDEQ (1994) groundwater quality standards. Although meeting these promulgated standards is not necessary to protect human health and the environment at Pumphouse #2, these criteria will have to be considered at the POA. This means that the chemical fate of these compounds in groundwater should be quantitatively evaluated. If the assessment indicates that chemical contamination could migrate at concentrations above the promulgated standards to areas beyond potential exposure controls, some type of groundwater remediation or control may have to be considered. Section 6 presents a site-specific chemical fate assessment for the BTEX compounds in groundwater. The results of this analysis will be important in determining whether groundwater contamination above the promulgated standards could migrate to areas beyond exposure controls (i.e., the POA for Pumphouse #2).

Therefore, all of the BTEX compounds in soils and/or sediments qualify as site-specific remediation target chemicals or chemicals of concern (COCs) that may need to be addressed during the remedial action. Benzene in groundwater qualifies as a groundwater COC, because the maximum measured concentration exceeded the risk-based SSTL for worker protection.

SECTION 6

EVALUATION OF NATURAL CHEMICAL ATTENUATION

6.1 INTRODUCTION

Section 3 of this EE/CA is devoted to describing the physical site conditions at Pumphouse #2. Section 4 summarizes the nature and extent of site-related contamination. Section 5 of the EE/CA presents the proposed SSTLs for impacted media necessary to protect human health and the environment. Section 5 also conservatively identifies all of the BTEX compounds in soil, and benzene and ethylbenzene in groundwater, as COCs that exceed SSTLs and must be addressed to achieve the desired level of risk reduction at the site. This section documents what effect natural chemical attenuation processes, operating in both soils and groundwater, have had and will have on the extent of migration, mass, persistence, and toxicity of each of the BTEX compounds. This section summarizes and interprets site characterization data used to document the effectiveness of natural chemical, physical, and biological processes that can minimize BTEX migration and reduce contaminant mass.

Based on the analysis completed in Section 5, all of the BTEX compounds were conservatively identified as soil COCs. Although only benzene and ethylbenzene were identified as groundwater COCs, the chemical fate of all the BTEX compounds in soils and the underlying groundwater are considered in this evaluation as a conservative measure. The decision to include all of the BTEX compounds in the quantitative evaluation of chemical fate is based on two primary considerations. First, the soil SSTLs calculated for the protection of groundwater quality through cross media contact were exceeded by each of the BTEX compounds. Second, the beneficial impact of natural chemical attenuation processes must account for the total mass of hydrocarbons in saturated media. If the fate of COCs were evaluated exclusive of other site related contaminants, the actual impacts of chemical attenuation processes at the site may be overestimated. To provide a conservative estimate of the effects of these processes on contaminant mass, concentration, mobility, persistence, and toxicity, all of the BTEX compounds were included in the analysis.

6.2 OPERATIVE MECHANISMS OF CONTAMINANT ATTENUATION

Understanding the fate of each of the BTEX compounds in environmental media is critical to evaluating and predicting contaminant migration and distribution over time. There are several physical, chemical, and biological processes that influence how a chemical behaves in soil and groundwater. The following sections present a brief overview of the major attenuation processes that control the fate of fuel constituents in

soils and groundwater at Pumphouse #2. These attenuation factors ultimately determine if the mass of contaminants in the environment can be eliminated or rendered immobile by natural processes. The positive effects of these natural processes on reducing the actual mass of BTEX and/or minimizing the extent of migration in groundwater and soil is termed natural attenuation.

6.2.1 Nondestructive Attenuation Mechanisms

The relative solubility, sorptive nature, and volatility of a chemical can govern the effectiveness of nondestructive chemical attenuation processes at Pumphouse #2. The hydrogeologic conditions present in the subsurface also influence the advective transport of groundwater and any chemicals dissolved in the groundwater. Nondestructive attenuation processes are those physical and chemical processes that may prohibit significant contaminant migration, but may not result in a permanent reduction in contaminant mass. Examples of nondestructive attenuation processes include sorption, advection, dispersion, and volatilization. These processes must be evaluated when determining if a compound poses an actual risk to human health and the environment. If the contaminant is not likely to reach a potential receptor at concentrations exceeding health-protective SSTLs, the contaminant will not pose an unacceptable risk.

6.2.1.1 Solubility

The water solubility of a chemical species defines how that particular chemical could partition from a contaminant source such as residual LNAPL in soils and dissolve into groundwater. In general, lighter hydrocarbon chains tend to be more water soluble than heavier hydrocarbon chains. For example, the water solubilities of benzene, toluene, ethylbenzene, and the various xylene isomers are 1,700 milligrams per liter (mg/L), 500 mg/L, about 160 mg/L, and about 145 to 175 mg/L, respectively (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Verschueren, 1983; Isnard and Lambert, 1988; Howard, 1990). Consequently, even though the BTEX compounds may comprise a low mass fraction of the initial source of contamination (i.e., typically 4 percent in JP-4), these compounds preferentially leach from contaminated soils into groundwater and migrate as dissolved contamination (Lyman *et al.*, 1992). Even though hydrocarbon fuels typically have low mass fractions of the BTEX compounds, these compounds can account for up to 80 percent of the total hydrocarbons dissolved in groundwater.

Free product was not encountered at the site during the 1993 RFI field investigation or the 1994 risk-based field investigation. Therefore, dissolution of contaminants from free product is not considered to be a contaminant source at Pumphouse #2. The dissolution of soluble contaminants from residual subsurface soil or sediment contamination could potentially act as a significant source of groundwater/surface water contamination at Pumphouse #2. The long-term effects of contaminant leaching from these media on groundwater quality and surface water quality are qualitatively investigated in Section 6.6.1.

6.2.1.2 Sorption

Another chemical characteristic that governs how a compound is attenuated in soil, surface water, and groundwater is its sorptive properties. If a contaminant sorbs strongly to the soil matrix, the compound will be less mobile and less likely to be transported great distances from the source area. The BTEX compounds are less sorptive than other petroleum hydrocarbons. Benzene does not sorb readily to soil and is considered the most mobile of the BTEX compounds. Toluene sorbs more readily to soil than benzene, but is still very mobile. Ethylbenzene sorbs more strongly to soil than benzene but less strongly than toluene. Of all the BTEX compounds, xylenes sorb most strongly to soil, but can still leach from unsaturated soil and migrate slowly in groundwater (Abdul *et al.*, 1987). In comparison, heavier hydrocarbons such as naphthalene and other PAH compounds sorb more strongly to the soil matrix, and migration in soil and groundwater is limited (Verschueren, 1983).

The total organic carbon (TOC) content of both unsaturated and saturated soils will often determine the sorptive capacity of soil and was measured as part of the 1994 risk-based investigation. TOC concentrations measured at Pumphouse #2 ranged from 0.24 percent to 0.65 percent (Appendix A). A background TOC concentration of 0.65 percent was measured in a sample collected from glacial till at MW-11. However, because lower TOC concentrations can contribute to lower rates of contaminant retardation (i.e., greater mobility in groundwater) a TOC content of 0.24 percent, measured in a soil sample collected from a sandy gravel lens at MW-12, is more conservative than the 0.65 percent TOC measured at MW-11. The level of TOC encountered in the sandy gravel at the site is not likely to significantly retard chemicals, but is sufficient to slow contaminant leaching and migration processes. Because the effects of sorption tend to be more pronounced with increases in molecular weight and complexity, the effects of sorption processes on chemical migration should be most pronounced for xylenes and least pronounced for benzene. The effects of sorption on toluene and ethylbenzene should be somewhere between these two extremes. The effect of sorption on the amount of contaminant mass that can leach from unsaturated and saturated soils into groundwater and surface water is further discussed in Section 6.6.1.

6.2.1.3 Volatility

The volatility of the BTEX compounds also affects how the contaminants behave in the environment. All of the BTEX compounds are classified as volatile chemicals because they have vapor pressures in excess of 0.1 millimeter of mercury (mm Hg). Benzene is the most volatile of the BTEX compounds, with a vapor pressure of about 95 mm Hg, and xylenes are the least volatile with vapor pressures between 6.0 and 9.0 mm Hg.

Volatilization from contaminated media into the atmosphere was directly investigated as a mass transport mechanism at Pumphouse #2. Soil flux concentrations of BTEX were measured at the site (Appendix A). Benzene contamination was not detected in any flux samples collected at the site, and toluene, ethylbenzene, and xylenes were detected only at very low concentrations. These analytical data imply that

the clayey nature of the vadose soils present at Pumphouse #2 has minimized the importance of volatilization to the atmosphere at the site.

6.2.1.4 Advection and Dispersion

Advective transport of contaminants is the movement of dissolved contaminants by virtue of their presence in groundwater that is moving. After contaminants enter groundwater, they advectively migrate in the direction of groundwater flow at a rate that is retarded as a result of sorption to organic carbon found in aquifer matrix. Subsurface features that control the direction and rate of groundwater flow also control the direction and rate of advective contaminant migration. Whereas advection is controlled by macroscopic movement of groundwater, dispersion is typically govern by molecular diffusion and/or tortuosity of groundwater flow through pore spaces. Dispersive transport of contaminants tends to cause contaminant plumes to spread radially relative to the primary direction of groundwater flow. Dispersive migration of contamination typically broadens a contaminant plume in the downgradient direction. Advective transport processes tend to have a more pronounced effect on contaminant migration than dispersive transport processes. For this reason, elongation of contaminant plumes in the downgradient direction is typically more pronounced than radial broadening of contaminant plumes.

When advective transport of contamination is restricted by low-permeability soils, the extent of contamination is also limited. The low permeability of the glacial till underlying Pumphouse #2 appears to be minimizing the horizontal and vertical extent of contaminant migration. Contamination has not spread away from the known source areas at the site and no contamination has been detected below 15 feet bgs. As discussed in Section 3, groundwater beneath Pumphouse #2 appears to be discontinuous and possibly perched. Lack of significant contaminant migration and the discontinuous nature of groundwater in the subsurface at Pumphouse #2 suggest that advective transport of contaminants is limited. However, contaminant migration may be occurring along artificial preferential corridors created in areas where the backfill permeability is greater than the permeability of the glacial till. Groundwater flow rates and transport rates of dissolved contamination within these preferential flow corridors is most likely greater than flow rates within native soil at the site.

Advective transport of dissolved contaminants from the source area near the JP-4 transfer lines along Flightline Drive appear to have been affected by the low permeability of the glacial till at Pumphouse #2. Groundwater contamination near the fuel transfer lines on either side of Flightline Drive near MW-18 and GW-6 does not appear to be migrating downgradient. MW-12, located approximately 15 feet downgradient from MW-18 and GW-6, contained minimal dissolved BTEX contamination (0.7 µg/L). The hydraulic gradient measured in 1995 and shown in Figure 3.3 suggests that contamination from MW-18 and GW-6 would impact groundwater at MW-12 if dissolved contamination were actively migrating. The absence of significant dissolved total BTEX contamination in groundwater samples collected from MW-12 suggests that downgradient advective migration of contaminants is restricted by the low permeability of the glacial till.

It is possible that contamination near GW-6 and MW-18 is migrating along Flightline Drive in the more permeable road base and pipeline backfill material. Because groundwater samples have not been collected from below the road or the utility corridors topographically downgradient from the suspected source area, it is not currently possible to discern if groundwater along Flightline Drive is isolated. As part of the proposed remedial alternative, it will be necessary to collect additional groundwater samples along Flightline Drive to evaluate if any preferential flow corridors exist near MW-18 and GW-6. Recommended additional sampling activities are described in Section 10, the site specific long-term monitoring plan. In summary, results from both the 1993 RFI and the 1994 risk-based investigations indicate that significant concentrations of dissolved BTEX compounds near MW-18 and GW-6 have not migrated away from the ditches on either side of Flightline Drive.

6.2.1.5 Summary of Nondestructive Attenuation

The preceding discussion suggests that geochemical properties and site-specific hydrogeologic conditions are important in determining how dissolved hydrocarbon contamination may be nondestructively attenuated at Pumphouse #2. The BTEX compounds, which are characterized by relatively high water solubilities and low sorptive properties, can be rapidly introduced into and transported with groundwater. However, the actual migration of BTEX at Pumphouse #2 appears to be limited by the low permeability of the glacial till and the discontinuity of the shallow groundwater at the site.

6.2.2 Biodegradation of BTEX Compounds in Soil and Groundwater

Biodegradation also may act as an important chemical attenuation process. In comparison to the nondestructive chemical attenuation processes described above, biodegradation is a destructive chemical attenuation processes which results in the permanent removal of contaminant mass from the environment. Documenting and distinguishing the effects of destructive attenuation processes, such as biodegradation, from nondestructive attenuation processes is critical in evaluating the potential for natural chemical attenuation to bring about a reduction in contaminant mass over time. The effectiveness of destructive attenuation processes in reducing contaminant mass at a site depends on how amenable the contaminant chemical is to biodegradation and the sites particular physical, chemical, and biological conditions.

Numerous laboratory and field studies have shown that bacteria can participate in the degradation of many of the chemical components of hydrocarbon fuels, including the BTEX compounds and the PAHs, under both aerobic and anaerobic conditions (e.g., Jobson *et al.*, 1972; Perry, 1977; Atlas, 1981, 1984, and 1988; Gibson and Subramanian, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, 1990; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989, 1990; Leahy and Colwell, 1990; Parker *et al.*, 1990; Stieber *et al.*, 1990, 1994; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Bauman, 1991; Borden, 1991; Brown and McFarland, 1991a; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994; ES, 1994b and 1994c; Parsons ES, 1994a, 1994b, 1995). Biodegradation of fuel

hydrocarbons will occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the soil and groundwater, and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms. Soils and groundwater with a history of exposure to the BTEX compounds generally contain microbial populations competent in facilitating biodegradation reactions (Zobell, 1946; Litchfield and Clark, 1973; Borden, 1994). The chemical process for the biodegradation of BTEX compounds is described in more detail in Section 6.4, where geochemical data relevant to documenting biodegradation on a field scale at Pumphouse #2 are presented.

6.3 EVIDENCE OF FIELD-SCALE CONTAMINANT MASS LOSS

The first step in determining if BTEX compounds are biodegrading in saturated soils and groundwater at Pumphouse #2 is to compare analytical data collected in 1993 to data collected in 1994. These data are valuable indicators of how contaminant conditions and concentration gradients are changing over time. Unfortunately, the limited amount of data collected from the same locations in 1993 and 1994 do not allow quantitative determination of biodegradation and/or attenuation rates. Only three groundwater monitoring wells have been sampled more than once and those three wells were only sampled twice. Additional long-term monitoring will be necessary to obtain the historical data required for quantitative analyses of biodegradation. Parsons ES has been funded to conduct the first year of additional groundwater sampling at Pumphouse #2. Details on proposed additional sampling can be found in Sections 8, 9, and 10 of this document. After sufficient data (i.e. three or more sampling events at the same sampling locations) have been collected, site-specific degradation rates will be evaluated.

6.3.1 Qualitative Changes in COC Concentrations in Soils

Measured BTEX concentrations in subsurface soils at Pumphouse #2 generally decreased between 1993 and 1994. The average total BTEX concentration in samples collected from 5 feet bgs during the 1993 RFI investigation was 48.2 mg/kg (10 samples). Samples collected from a similar interval during the 1994 risk-based investigation had an average total BTEX concentration of 1.95 mg/kg (14 samples). It appears that two natural mechanisms may be acting to reduce soil contaminant concentrations at the site. First, aerobic biodegradation has been shown to be an active mechanism at the site during bioventing pilot testing. BTEX was readily biodegraded in subsurface soils supplied with oxygen. Detailed results of this test are presented in Section 7.1. Since contaminated soils at the site are shallow, it is probable that some atmospheric oxygen is diffusing to contaminated soils and promoting the gradual aerobic biodegradation of BTEX compounds.

Additionally, leaching and dissolution of residual fuel contamination from the soil matrix into groundwater also appears to be a likely attenuation mechanism at the site. Since groundwater velocities at the site are very slow, the amount of time that groundwater spends in contact with contaminated soils is long. This allows a large portion of the available BTEX to dissolve from the soil matrix into groundwater. The same hypothesis applies to BTEX leaching into water (in the form of precipitation) at it

percolates down to the groundwater surface. The clayey nature of the topsoil at the site slows percolation and increases contact time with residual contamination.

6.3.2 Observed Changes in COC Concentrations in Groundwater

Three groundwater wells, MW-10, MW-15, and MW-18, were installed as part of the 1993 RFI. All of these wells were sampled for each of the BTEX compounds during both the 1993 RFI and 1994 risk-based investigations (Table 6.1). Concentrations in MW-10 and MW-18 appear to have decreased over time. A sample collected from MW-18 had a BTEX concentration of 8860 µg/L during the 1993 RFI. The total BTEX concentration measured at this same sampling location during the 1994 risk-based investigation was 5,608 µg/L. Total BTEX concentrations measured in groundwater samples collected from MW-10 also decreased from 30.2 µg/L to 2.9 µg/L between the two sampling events.

Concentrations of total BTEX measured at MW-15 appear to have slightly increased during the elapsed time between sampling events. Total BTEX concentrations increased from 321 µg/L measured in a sample collected during the 1993 RFI, to 480 µg/L measured in a sample collected during the 1994 risk-based investigation. MW-15 is located near the suspected source area associated with the surface spill that occurred in 1991. Contamination from that spill appears to be slowly moving downward through the low-permeability glacial till and into the groundwater as a result of precipitation infiltration. Concentrations of contaminants measured in groundwater samples collected from MW-15 will most likely increase slightly until maximum soil concentrations of fuel contamination migrate into contact with and dissolve into groundwater.

In general, it appears that BTEX concentrations are decreasing with time. This, coupled with the fact that little or no contaminant migration has been observed at the site, indicates that the groundwater pathway is not completed to off-site human receptors. Groundwater use controls should be implemented and kept in place until benzene and ethylbenzene concentrations in groundwater naturally attenuate to levels below SSTLs. Annual sampling is proposed to further document the natural attenuation of dissolved contamination at Pumphouse #2. Parsons ES has been contracted to perform the first round of long-term groundwater monitoring at the site.

6.3.3 Determination of Attenuation Rates

After sufficient data has been collected, groundwater contaminant concentrations can be used to determine site specific biodegradation rates for benzene and ethylbenzene. Currently sufficient historical data do not exist to perform the calculations required to obtain a site-specific attenuation rate. In lieu of site-specific data, literature values for the attenuation of the BTEX compounds in groundwater were used to determine the approximate length of time that will be required to obtain SSTLs and state groundwater standards at Pumphouse #2.

Since benzene and ethylbenzene are the only two groundwater contaminants detected above SSTLs at the site, only the attenuation of these two constituents will be analyzed. Using a range of attenuation rates measured in shallow groundwater at two other sites

TABLE 6.1
COMPARISON OF RFI AND RISK-BASED GROUNDWATER DATA
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

MW-10		
Compound	1993 RFI Groundwater Result (µg/L)	1994 Risk-Based Groundwater Result (µg/L)
Total BTEX	30.2	2.9 J
Benzene	1.2	1.0 J
Toluene	0.50 U	4.0 U
Ethylbenzene	14	1.9 J
Total xylenes	15	4.0 U

MW-15		
Compound	1993 RFI Groundwater Result (µg/L)	1994 Risk-Based Groundwater Result (µg/L)
Total BTEX	321	480
Benzene	37	160
Toluene	3.4 U	4.0 U
Ethylbenzene	24	50
Total xylenes	260	270

MW-18			
Compound	1993 RFI Groundwater Result (µg/L)	1994 Risk-Based Groundwater Result (µg/L)	1996 Risk-Based Groundwater Result (µg/L)
Total BTEX	8,650	5,608	5,478
Benzene	890	680	430
Toluene	50 U	18 J	28
Ethylbenzene	860	710	920
Total xylenes	6,900	4,200	4,100

Source: HDR, 1994.

in the northern US, the attenuation rate of ethylbenzene at Malmstrom and Ellsworth AFBs has been estimated to be 0.00075 to 0.008 day^{-1} (Parsons ES, 1995b and 1995c). At this rate, it will take approximately 1 year for contaminated groundwater at Pumphouse #2 to reach the SSTL for ethylbenzene. Similarly, using recently observed attenuation rates for benzene of 0.0011 to 0.003 day^{-1} (Parsons ES, 1995b and 1995c), it will take from 5 to 12 years to reach the SSTL for benzene in groundwater at Pumphouse #2. These durations are approximations and not site-specific. Site-specific attenuation rates will be calculated following the next groundwater sampling event. However, for long-term monitoring cost estimation purposes, attenuation rates calculated at an Ellsworth AFB JP-4 spill site will be used (Parsons ES, 1995c). Based on this calculated attenuation rate, it will take an estimated 12 years for benzene concentrations to approach the MDEQ criteria of 5 µg/L. However, risk-based site closure can be obtained in a shorter period of time (5 years) by demonstrating lack of contaminant migration and, more importantly, human health risk at the site.

Additionally, consideration should be given to the collection of a microcosm sample and the performance of a microcosm study for the laboratory determination of a site-specific biodegradation rate. A microcosm sample could be collected during a future monitoring event and submitted to a laboratory for analysis. The data collected from the microcosm study would supplement historical attenuation data at Pumphouse #2.

6.4 EVIDENCE OF CONTAMINANT BIODEGRADATION VIA MICROBIALLY CATALYZED REDOX REACTIONS

Historical and recent site data presented in the preceding sections suggest that BTEX concentrations are generally decreasing in soils and groundwater at Pumphouse #2. There is another line of evidence that more clearly indicates that reductions in contaminants are occurring via biodegradation in groundwater at Pumphouse #2. Analytical data quantifying concentrations of potential electron acceptors can be used as geochemical indicators of biodegradation (Salanitro, 1993; McAllister and Chiang, 1994; Wiedemeier *et al.*, 1995; Borden *et al.*, 1995). Reductions in the concentrations of chemical species that are used by microorganisms to facilitate the oxidation of BTEX compounds are an indication that contaminants are biodegrading. The amount of potential electron acceptors available to participate in contaminant biodegradation reactions can be used to estimate the total contaminant mass that can be biodegraded. Coupled with the site-specific attenuation rates that will be determined from long-term monitoring, this information can be used to predict how much and how quickly contaminant mass can be permanently removed from saturated soils and groundwater at Pumphouse #2.

6.4.1 Redox Couples in Biodegradation

Microorganisms obtain energy to replenish enzymatic systems and reproduce by oxidizing organic matter. Biodegradation of BTEX compounds is the result of a series of reduction/oxidation (redox) reactions that maintain the charge balance within the natural environment. Microorganisms facilitate the degradation of BTEX compounds by transferring electrons from the contaminants (electron donors) to available electron acceptors. Electron acceptors are elements or compounds that occur in relatively oxidized states and can participate in redox reactions involving BTEX compounds.

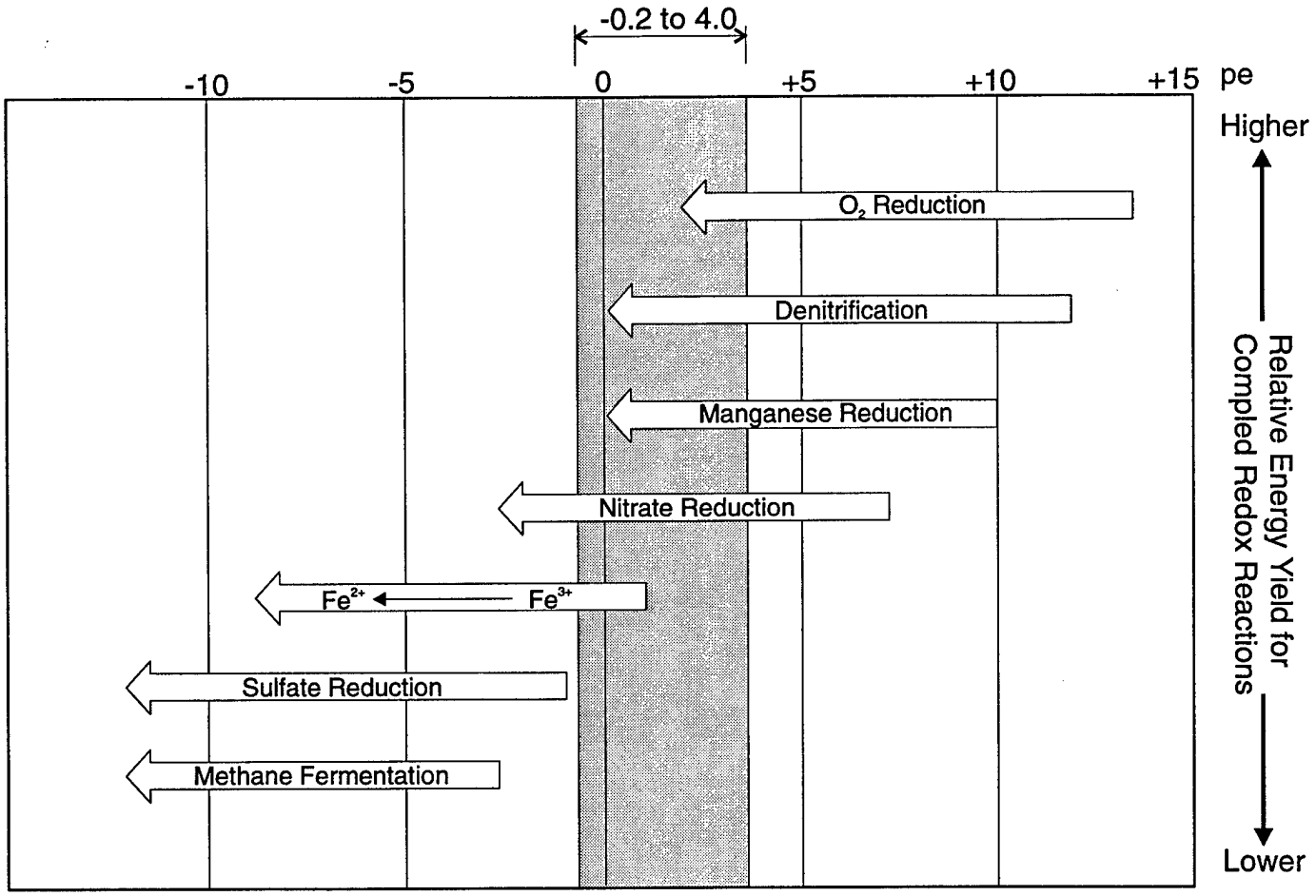
Electron acceptors that are present in saturated soil and groundwater at Pumphouse #2 are oxygen, manganese, sulfate, ferric iron, carbon dioxide, and possibly nitrate.

Microorganisms facilitate BTEX biodegradation to produce energy for their use. The amount of energy that is released when a reaction occurs or is required to drive the reaction to completion is quantified by the free energy of the reaction (Stumm and Morgan, 1981; Bouwer, 1994; Chapelle, 1993; Godsey, 1994; Mueller *et al.*, 1994). Microorganisms will only facilitate those redox reactions that will yield energy. Microorganisms are able to utilize electron transport systems and chemiosmosis to combine energetically favorable and unfavorable reactions to produce energy for life processes. By coupling the oxidation of BTEX compounds, which requires energy, to the reduction of other compounds (e.g., oxygen, nitrate, manganese, ferric iron, sulfate, and carbon dioxide), which yields energy, the overall reaction will yield energy. Detailed information on the redox reactions required to biodegrade each of the BTEX compounds is included in Appendix E. The reader is encouraged to review this information to more fully understand the chemical basis of biodegradation.

Figure 6.1 illustrates the sequence of microbially mediated redox processes based on the amount of free energy released for microbial use. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981; Godsey, 1994; Reinhard, 1994). As Figure 6.1 shows, oxygen reduction would be expected to occur first in an aerobic environment because oxygen reduction yields more energy than any other reaction (Bouwer, 1992; Chapelle, 1993). However, once the available oxygen is depleted and anaerobic conditions dominate the interior regions of the contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate, manganese, ferric iron, sulfate, and finally carbon dioxide. Each successive redox reaction provides less energy to the system, and each step down in redox energy yield would have to be paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

The expected sequence of redox processes is also a function of the oxidizing potential (E_h) of the groundwater. The oxidizing potential measures the relative tendency of a solution or chemical reaction to accept or transfer electrons. The oxidizing potential of the groundwater can be measured in the field. This measurement can be used as an indicator of which redox reactions may be operating at a site. This field measurement can also be expressed as pE, which is the hypothetical measure of the electron activity associated with a specific E_h. High pE means that the solution or redox couple has a relatively high oxidizing potential.

Microorganisms can only facilitate the biodegradation (oxidation) of BTEX compounds using redox couples that have a higher oxidizing potential than the contaminants. Appendix E includes tables that show that redox couples including oxygen, nitrate, manganese, ferric iron, sulfate, and carbon dioxide all have higher oxidizing potentials than the redox couples including BTEX compounds. This is why these electron acceptors can be used to oxidize BTEX compounds. The reduction of highly oxidized species results in an overall decrease in the oxidizing potential of the groundwater. As shown in Figure 6.1, the reduction of oxygen and nitrate will reduce the oxidizing potential of groundwater levels at which manganese and ferric iron (Fe^{3+})



Notes

Range of E_h (expressed as pe) measured at Pumphouse #2

1. These reactions would be expected to occur in sequence if the system is moving toward equilibrium.

2. These redox processes occur in order of their energy-yielding potential (provided microorganisms are available to mediate a specific reaction). Reduction of a highly oxidized species decreases the pe of the system.

3. The pe of the system determines which electron acceptors are available for COC oxidation.

4. Redox sequence is paralleled by an ecological succession of biological mediators.

Adapted from Stumm and Morgan, 1981.

FIGURE 6.1

SEQUENCE OF MICROBIALLY MEDIATED REDOX PROCESSES

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reduction can occur. As each chemical species that can be used to oxidize the contaminants is exhausted, microorganisms are forced to use other available electron acceptors with lower oxidizing capacities. When sufficiently negative pE levels have been developed as a result of these redox reactions, sulfate reduction and methanogenesis can occur almost simultaneously (Stumm and Morgan, 1981).

6.4.2 Dissolved Oxygen Concentrations

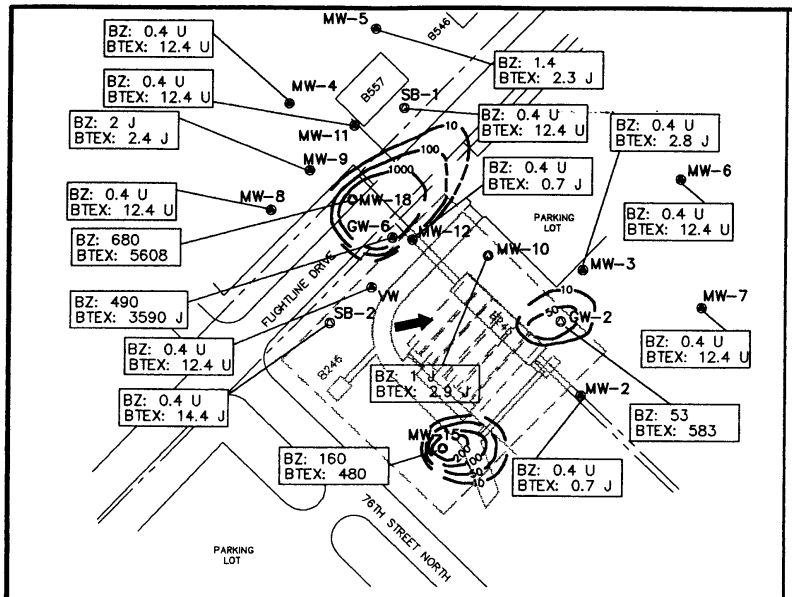
Almost all types of fuel hydrocarbons can be biodegraded under aerobic conditions (Borden, 1994). Mineralization of fuel hydrocarbons to carbon dioxide and water under aerobic conditions involves the use of oxygen as a cosubstrate during the initial stages of metabolism, and as a terminal electron acceptor during the later stages of metabolism for energy production (Higgins and Gilbert, 1978; Gibson and Subramanian, 1984; Young, 1984). The reduction of molecular oxygen during the oxidation of BTEX compounds yields a significant amount of free energy to the system that microorganisms can utilize. Dissolved oxygen (DO) concentrations were measured at groundwater monitoring wells at Pumphouse #2 in November 1994. Figure 6.2 presents results of DO sampling by sampling location.

The isoconcentration contours presented in Figure 6.2 show that there is a correlation between areas of BTEX contamination in groundwater and areas of depleted DO. The low concentrations of DO in contaminated groundwater indicate that oxygen is functioning as an electron acceptor during microbially-mediated degradation of fuel hydrocarbons at Pumphouse #2. DO concentrations measured in groundwater samples collected from sampling locations within the suspected source areas and immediately downgradient from the suspected source areas ranged from about 4.6 mg/L to below 0.1 mg/L. In comparison, background concentrations of DO at this site were as high as 7.4 mg/L.

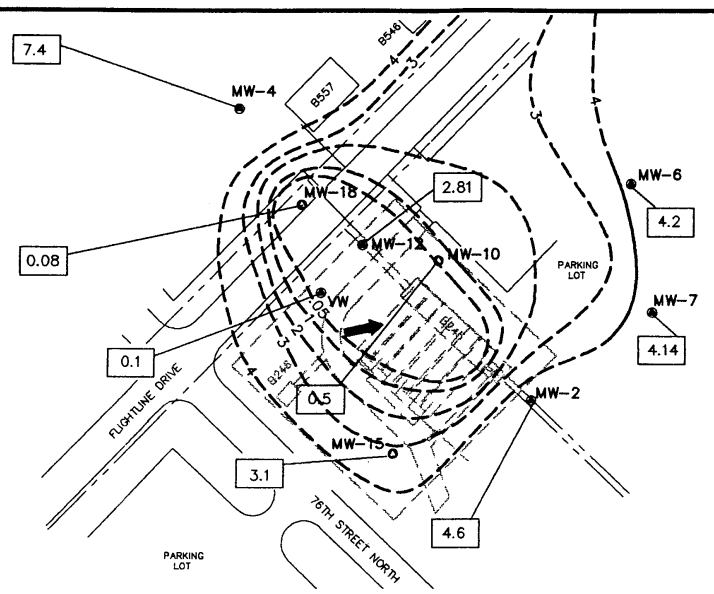
Concentrations of DO measured in all three source areas are significantly to somewhat reduced relative to background concentrations. When the reduction of DO is considerable, anaerobic conditions develop and the oxidizing potential of the groundwater is subsequently lowered. These events will bring about a change in the types of microorganisms that facilitate degradation of BTEX. Anaerobic microorganisms will then utilize alternate electron acceptors in the oxidation of BTEX compounds.

6.4.3 Dissolved Nitrate and Nitrite Concentrations

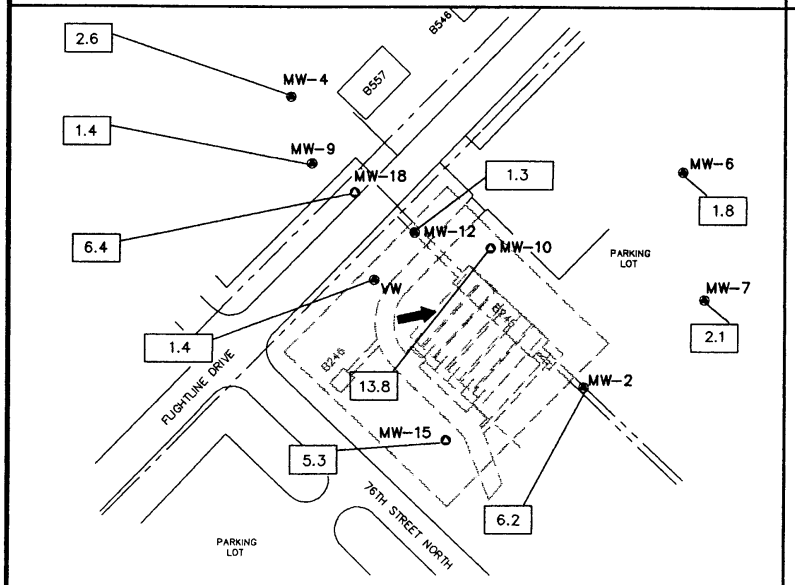
Once anaerobic conditions prevail in groundwater, nitrate can be used as an electron acceptor by facultative anaerobic microorganisms to mineralize BTEX compounds via either denitrification or nitrate reduction processes. Denitrification is the most energetically favorable of the anaerobic redox reactions likely to be involved in the oxidation of the contaminants (Appendix E). The process of denitrification proceeds through several intermediate steps, including nitrite production. The end product of nitrate reduction is ammonium (NH_4^+). Nitrate reduction may take precedence over denitrification as the groundwater at Pumphouse #2 becomes more reducing. As conditions become more reducing, nitrate is used as an electron acceptor via nitrate reduction.



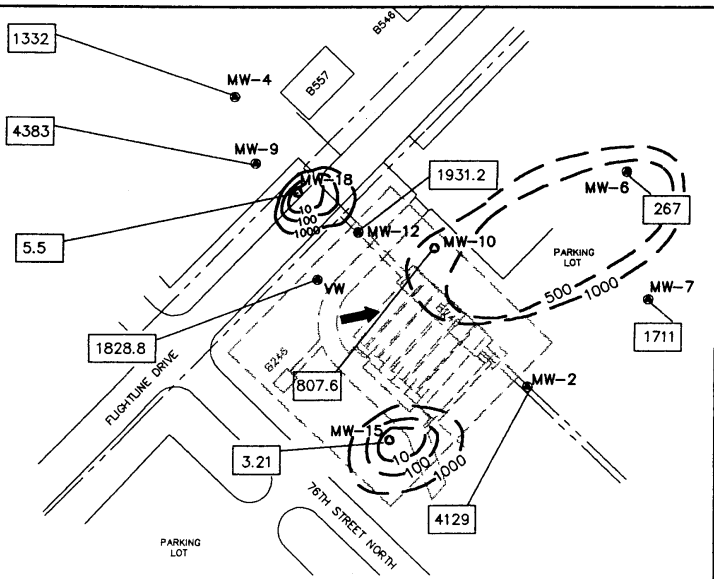
BENZENE AND TOTAL BTEX (?g/L)



DISSOLVED OXYGEN (mg/L)



NITRATE (mg/L)
NO ISOCONCENTRATION TRENDS OBSERVED



SULFATE (mg/L)

LEGEND

- GROUNDWATER MONITORING WELL (INSTALLED 1994)
- GROUNDWATER MONITORING WELL (INSTALLED 1993)
- TEMPORARY GROUNDWATER MONITORING WELL (INSTALLED 1994)
- U — ANALYTE NOT DETECTED ABOVE METHOD DETECTION LIMIT
- J — ESTIMATED VALUE
- B546 — BUILDING
- FENCE LINE
- UNDERGROUND FUEL PIPELINE
- GROUNDWATER FLOW DIRECTION
- 100 — LINE OF ESTIMATED EQUAL CHEMICAL CONCENTRATION (?g/L) (DASHED WHERE INFERRED)
- B246 — LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF THE DEMOLITION EFFORTS CONDUCTED IN MAY/JUNE 1995

0 50 100 200
FEET

FIGURE 6.2

ISOPLETH MAPS FOR BTEX AND OXIDIZED ELECTRON ACCEPTORS IN GROUNDWATER (NOVEMBER 1994)

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Pumphouse #2, Malmstrom AFB, Montana

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Concentrations of both nitrate and nitrite were measured at groundwater monitoring wells in November 1994. Figures 6.2 and 6.3 present the analytical data for the oxidized nitrate and reduced nitrite, respectively. Figure 6.2 shows that there is no apparent depletion of nitrate near or downgradient from the source areas relative to measured background concentrations. Although denitrification does not appear to be occurring, it is important to note that nitrite production was observed in samples collected from MW-18 and MW-9 (Figure 6.3). Additionally, measured E_h (pE) levels at the site suggest that the oxidizing potential of the groundwater has been reduced sufficiently so that denitrification and possibly nitrate reduction can occur (Figure 6.1).

6.4.4 Dissolved Manganese Concentration

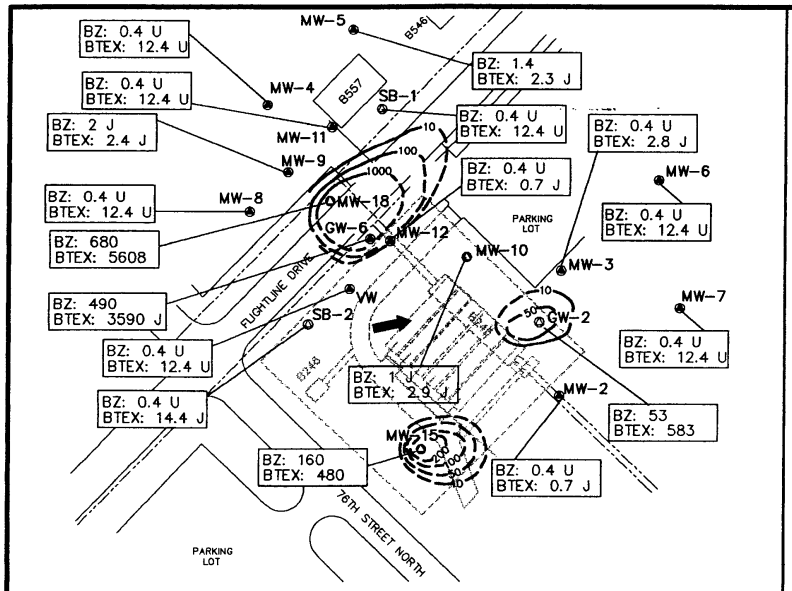
Manganese also can be used as an electron acceptor to facilitate the oxidation of BTEX compounds under anaerobic and slightly reducing conditions. In fact, as Figure 6.1 shows, manganese reduction can be microbially facilitated in groundwater conditions similar to those required to support denitrification. The reduction of manganese to oxidize BTEX compounds yields essentially as much free energy to the system as aerobic respiration. Under anaerobic and slightly reducing conditions, manganese reduction is the second most energetically favorable redox reaction that can be used to biodegrade BTEX compounds.

Groundwater samples were collected at Pumphouse #2 and analyzed for reduced forms of manganese. Elevated concentrations of reduced manganese were detected in samples collected from MW-18 and MW-2 (Figure 6.3). MW-18 is located in the source area associated with the JP-4 transfer lines. Although regions of elevated concentrations of reduced species of manganese are not as pronounced as those for DO, it does appear that microbes capable of manganese reduction are present and active in contaminated saturated media at Pumphouse #2.

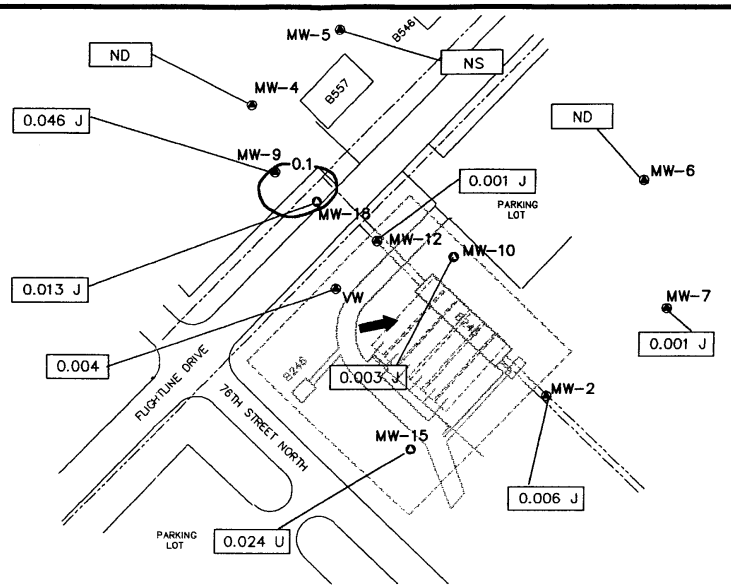
6.4.5 Ferrous Iron Concentrations

Although relatively little is known about the anaerobic metabolic pathways involving the reduction of ferric iron (Fe^{3+}), this process has been shown to be a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). Elevated concentrations of ferrous iron (Fe^{2+}) are often found in anaerobic groundwater systems. Concentrations of dissolved ferrous iron once were attributed to the spontaneous and reversible reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as BTEX. However, recent evidence suggests that the reduction of ferric iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires mediation by microorganisms with the appropriate enzymatic capabilities. The reduction of ferric iron results in the formation of ferrous iron.

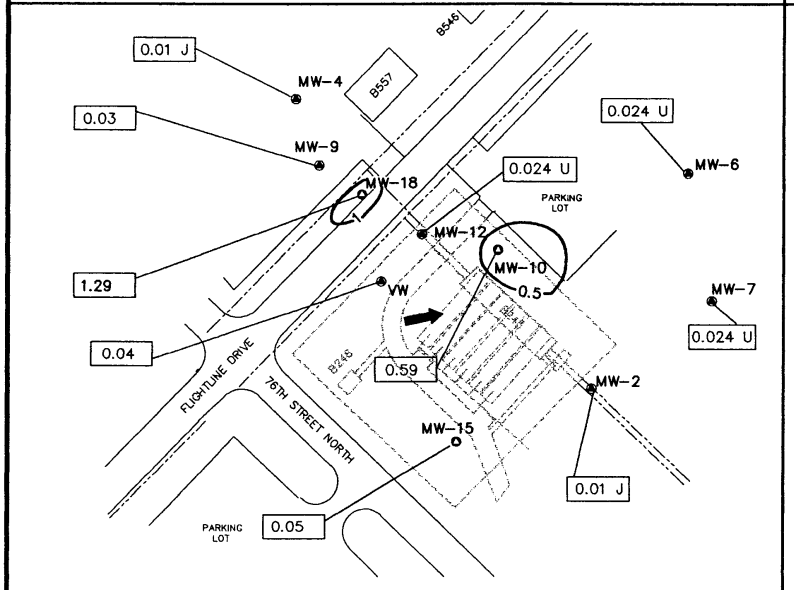
To determine if ferric iron is being used as an electron acceptor at Pumphouse #2, ferrous iron concentrations were measured at groundwater monitoring wells in November 1994. Figure 6.3 presents the analytical results for ferrous iron in



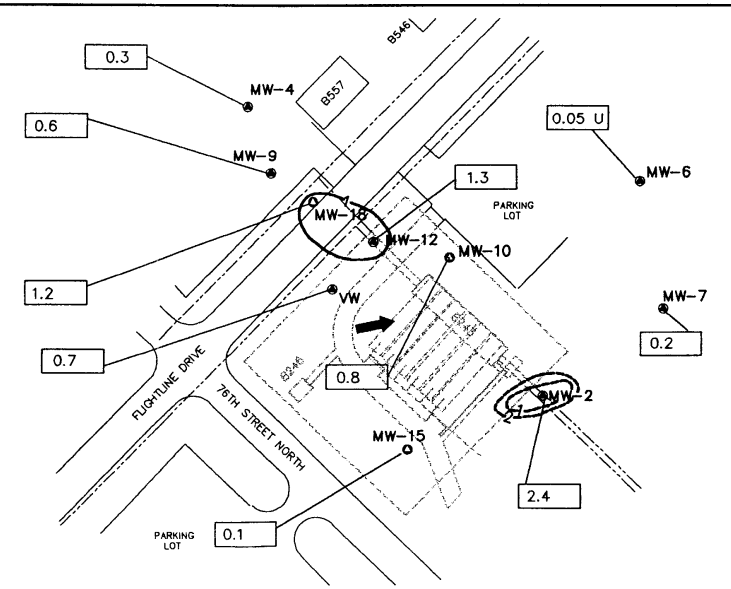
BENZENE AND TOTAL BTEX (µg/L)



NITRITE (mg/L)



FERROUS IRON (mg/L)



MANGANESE (mg/L)

LEGEND

- GROUNDWATER MONITORING WELL (INSTALLED 1994)
- GROUNDWATER MONITORING WELL (INSTALLED 1993)
- TEMPORARY GROUNDWATER MONITORING WELL (INSTALLED 1994)
- U — ANALYTE NOT DETECTED ABOVE METHOD DETECTION LIMIT
- J — ESTIMATED VALUE
- B546 — BUILDING
- FENCE LINE
- UNDERGROUND FUEL PIPELINE
- GROUNDWATER FLOW DIRECTION
- 100 — LINE OF ESTIMATED EQUAL CHEMICAL CONCENTRATION (µg/L) (DASHED WHERE INFERRED)
- B246 — LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF THE DEMOLITION EFFORTS CONDUCTED IN MAY/JUNE 1995

N

0 50 100 200
FEET

FIGURE 6.3

ISOPLETH MAPS FOR BTEX AND BYPRODUCTS OF ELECTRON ACCEPTOR REDUCTION IN GROUNDWATER (NOVEMBER 1994)

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Pumphouse #2, Malmstrom AFB, Montana

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groundwater at the site. Areas characterized by elevated concentrations of BTEX correspond well with areas of elevated concentrations of ferrous iron relative to measured background concentrations. Ferrous iron was measured near or below the detection limit in background well MW-4 and most wells located outside the areas affected by fuel contamination. Concentrations of ferrous iron measured in groundwater monitoring wells MW-18 and MW-10 were 1.29 and 0.59 mg/L, respectively. As discussed above, MW-18 is in the suspected source area associated with the JP-4 transfer lines. MW-10 appears to be near the leading edge of the dissolved BTEX plume emanating from the location of the former USTs. Elevated ferrous iron detected at MW-10 may be the result of upgradient iron reduction and groundwater transport of Fe^{+2} toward MW-10. The correlation between elevated total dissolved BTEX and elevated ferrous iron concentrations suggests that iron-reducing microorganisms are using ferric iron to oxidize the contaminants. Background levels of ferrous iron at MW-4 and MW-2 were at or below the 0.01 mg/L detection limit. These geochemical data suggest that iron-reducing microorganisms are present in the groundwater at the site, and that these microorganisms are using ferric iron to facilitate BTEX metabolism.

6.4.6 Sulfate and Sulfide Concentrations

Sulfate may be used as an electron acceptor during microbial degradation of fuel hydrocarbons under anaerobic and highly reduced conditions (Grbic-Galic, 1990). This redox reaction is commonly called sulfate reduction. Sulfate is reduced to sulfide during the oxidation of BTEX compounds. To investigate the potential for sulfate reduction at Pumphouse #2, total sulfate concentrations were measured at groundwater wells in November 1994.

Sulfate concentrations observed in suspected source areas appear to be reduced as much as three orders of magnitude relative to background concentrations. A groundwater sample collected from upgradient well MW- 4 had 1,332 mg/L of sulfate, while samples collected from MW-18, MW-15 and MW-10 had sulfate concentrations of 5.5 mg/L, 3.2 mg/L, and 808 mg/L, respectively. This is strong evidence that microbial populations present in groundwater and saturated media at Pumphouse #2 are metabolizing fuel hydrocarbons under sulfate-reducing conditions.

Elevated concentrations of hydrogen sulfide were not detected in groundwater samples collected from monitoring wells exhibiting elevated concentrations of BTEX compounds and depleted sulfate. This indicates that complete reduction of sulfate may not be occurring, and that other oxidized states of sulfur (thiosulfate, sulfur dioxide, and elemental sulfur) may be present in site groundwater. These other forms of sulfur were not quantitatively investigated at Pumphouse #2.

The measured E_h of site groundwater is slightly higher than redox conditions typically associated with sulfate-reducing groundwater environments. However, it is quite likely that the platinum electrode probes used to measure E_h are not sensitive to the sulfate/sulfide redox couple. Many authors have noted that measured E_h data cannot be used alone to reliably predict the electron acceptors that may be operating at a site (e.g., Stumm and Morgan, 1991; Godsey, 1994; Lovely *et al.*, 1994).

6.4.7 Methane and Carbon Dioxide Concentrations

On the basis of free energy yield and oxidizing potential, the carbon dioxide-methane (CO_2-CH_4) redox couple also could be used to oxidize fuel hydrocarbon compounds to carbon dioxide and water once the groundwater is sufficiently reducing. To attain these reducing levels, other highly oxidizing chemical species such as oxygen, nitrate, manganese, and sulfate must be reduced. These electron acceptors have been shown to be depleted at Pumphouse #2 and thus the carbon dioxide-methane couple could be active at the site. This redox reaction is called methanogenesis or methane fermentation. Methanogenesis yields the least free energy to the system in comparison to other chemical species (Figure 6.1 and Appendix E). The presence of methane in groundwater at elevated concentrations relative to background concentrations is a good indicator of methane fermentation.

To determine if methanogenesis is an active process at Pumphouse #2, five samples were collected and analyzed for the presence of methane. Elevated concentrations of methane were detected at two locations at the site, indicating that methanogenesis is and active destructive attenuation process at this site. MW-18 and MW-15 had 2.2 and 0.66 mg/L of methane, respectively. The other three wells sampled (MW-4, MW-7, and MW-12) did not contain measurable concentrations of methane. As with the other electron indicators, the areas of elevated methane correspond with areas of known groundwater and subsurface soil contamination at the site.

6.5 THEORETICAL ASSIMILATIVE CAPACITY ESTIMATES

The preceding discussions have been devoted to determining if geochemical data indicate BTEX compounds are biodegrading at Pumphouse #2. Analytical data on reduced and oxidized chemical species indicate that indigenous microorganisms are facilitating the oxidation of BTEX compounds by reducing certain electron acceptors to generate free energy for cell maintenance and production. The question of how much contaminant mass can be biodegraded must be addressed to assess the full potential for long-term natural chemical attenuation at the site.

Mass-balance relationships can be used to determine how much contaminant mass can be degraded by each of the redox reactions that the microorganisms might use to make free energy available for cell maintenance and production. The stoichiometric relationship between the contaminant and the electron acceptor can be used to estimate the expressed assimilative capacity of the groundwater. Based on the redox reactions operating at Pumphouse #2 (Section 6.4), it is possible to estimate how much contaminant mass can be assimilated or oxidized by available electron acceptors at the site. This analysis will provide the basis for determining the potential for continued natural chemical attenuation of BTEX contamination in saturated media at the site.

Appendix E presents the coupled redox reactions that represent the biodegradation of each of the BTEX compounds. These tables also present the stoichiometric mass ratios of electron acceptors needed to oxidize each of the BTEX compounds. These stoichiometric mass ratios can be used to estimate the assimilative capacity of the groundwater at Pumphouse #2. This is accomplished by first estimating the initial mass of each electron acceptor available in the groundwater. Data on these chemical species

were collected at sampling background location MW-4 upgradient from the site. Contaminant mass is divided by the mass of electron acceptors required to mineralize each of the fuel hydrocarbon compounds to estimate the intrinsic capacity of the groundwater to biodegrade each of the fuel hydrocarbon compounds.

Estimates of the background concentrations of all of the electron acceptors that may be involved in the biodegradation each of the BTEX compounds are listed in Table 6.2. The production of nitrite was not included in this estimate, as solid evidence of nitrate reduction is not apparent in site data collected during the 1994 risk-based investigation. These concentrations are used to calculate the available or expressed assimilative capacity of each electron acceptor participating in the degradation of BTEX at the site based on the mass stoichiometric relationships presented in detail in Appendix E. Table 6.2 also presents the highest concentrations of ferrous iron, manganese, and methane measured at the site. These concentrations are used to "back-calculate" the expressed assimilative capacity that is attributable to ferric iron reduction, manganese reduction, and methanogenesis, respectively. On the basis of these calculations, the groundwater at Pumphouse #2 has the intrinsic capacity to oxidize a concentration of approximately 291,521 µg/L of total BTEX per pore-volume exchange of groundwater (i.e., one unit pore volume of saturated soil at the site has the potential to reduce groundwater with a total BTEX concentration 291,521 µg/L to 0 µg/L).

The maximum measured concentrations of total BTEX in both 1993 and 1994 are well below the theoretical assimilative capacity of the groundwater at Pumphouse #2. This estimate represents an upper-bound value of the expressed assimilative capacity of the saturated soil and groundwater for BTEX compounds per pore-volume exchange. This means that contaminant mass in the source area has been in contact with more than sufficient electron mass to facilitate complete degradation of the entire dissolved mass of BTEX contamination. However, it appears that only a fraction of the actual electron acceptor mass contained in groundwater is being used by microorganisms to facilitate BTEX biodegradation. The total reservoir of electron acceptors is likely not immediately available to the microorganisms because of mass transfer, kinetic, and other biological and chemical limitations.

In summary, BTEX compounds do not and should not exert a significant demand on the total expressed assimilative capacity available at Pumphouse #2. There is sufficient electron acceptor mass available at Pumphouse #2 to completely degrade the maximum measured concentrations of BTEX compounds. However, site data demonstrate that only a portion of the total assimilative capacity is available for biodegradation reactions at any given time, possibly due to kinetic, equilibrium, and mass transfer limitations.

6.6 PREDICTING CHEMICAL FATE OVER TIME

Understanding the effects of natural physical, chemical, and biological processes influencing concentrations of site contaminants is an important step in determining potential long-term risks associated with chemical migration in the environment. The behavior of BTEX compounds under the influence of these processes must be estimated to predict the extent that any chemical could migrate and to assess the effects on chemical persistence, mass, concentration, and toxicity over time at the site. If destructive and nondestructive attenuation processes can minimize and/or isolate the

TABLE 6.2
ESTIMATE OF ASSIMILATIVE CAPACITY OF SATURATED SOIL AND GROUNDWATER
ENGINERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Electron Acceptor	Background Concentration (µg/L)	Initial BTEX Assimilative Capacity[a/] (µg/L)
Oxygen	7400	2410
Manganese[b/]	1200	114
Ferric iron[b/]	1290	60
Sulfate	1332000	288937
Methane[b/]	2200	2857
	Total	291521
	1993 Maximum	8860
	1994 Maximum	5608
	Observed Mass Loss	3252
	# Source Area Flushes [c/]	1
	Calculated % Utilized [d/]	1.1

[a/] Calculated based on the ratio of the total mass of electron acceptor required to oxidize a given mass of total BTEX (Appendix E).

[b/] This represents the reduced form of the electron acceptor. Assimilative capacity is expressed only as an estimate. Does not represent actual total reservoir of electron acceptor.

[c/] Number of source-area pore-volume exchanges between September 1993 to November 1994 (conservatively assumes groundwater not flowing).

[d/] Percent of total assimilative capacity utilized per liter of groundwater to reduce observed 1993 concentrations to observed 1994 concentrations at MW-18. Based on volume of groundwater flushing through source area from September 1993 until November 1994 (Appendix E).

site contaminants, remedial action may not be warranted because contamination may not pose a risk to potential receptors. The focus of this final section is to summarize how BTEX compounds will be transported and transformed over time in soils and groundwater based on site data.

6.6.1 Leaching Effects

Defining how COCs partition from soils and dissolve in groundwater based on site specific conditions can provide valuable information for predicting the nature of future groundwater and surface water quality impacts. Benzene and ethylbenzene were detected in soil samples collected during the 1994 investigation at concentrations in excess of leaching criteria SSTLs calculated using site-specific data (Table 5.2). Residual contamination in near-surface soils could potentially provide a migration pathway to surface water. Proposed remedial actions should address sediment/shallow soil contamination at the site (Section 8). Soils that are not addressed by remedial actions at the site may act as a long-term source of groundwater contamination.

6.6.2 Advective Effects

Limited groundwater flow appears to be governing the transport of dissolved BTEX contamination at Pumphouse #2. The low permeability of the glacial till and discontinuous nature of the groundwater appear to be minimizing dissolved contaminant transport in the subsurface at the site (Section 6.2.1.4). Dissolved BTEX contamination in the source areas near MW-15, GW-2, and MW-18 and GW-6 does not appear to have migrated downgradient. However, dissolved contamination maybe migrating along Flightline Drive in the more permeable road base fill material.

6.6.3 Biodegradation Effects

Based on 1994 electron acceptor data, the BTEX compounds appear to be biodegrading in saturated soils and groundwater at Pumphouse #2. The removal of COC mass via destructive contaminant attenuation processes will change the concentrations of BTEX in the affected media over time (and distance, if contamination is actually migrating at the site). This information is important to accurately estimate potential risks to onsite and offsite receptors. Site-specific attenuation rates can be developed to predict the persistence of COCs in groundwater over time. Long term monitoring of groundwater parameters at the site will establish these rates.

6.7 CONCLUSIONS

This section focused on explaining how and why BTEX compounds in saturated soil and groundwater at Pumphouse #2 are attenuating as a result of naturally occurring destructive and nondestructive attenuation mechanisms. The important findings of this section are summarized as follow:

- Active remedial efforts will be necessary to minimize risks associated with shallow soil/sediment contamination near MW-18 and GW-6.

- Additional groundwater monitoring will be required to determine site-specific attenuation rates.

- Consideration should be given to the performance of a microcosm study for the determination of a site-specific biodegradation rate if several years of long-term monitoring data yields inconclusive results.

- Migration of dissolved contaminants appears to be and is expected to continue to be restricted by the low permeability of the glacial till underlying Pumphouse #2.

- Electron acceptor isopleth maps suggest that BTEX compounds are biodegrading in saturated soils and groundwater at Pumphouse #2 via oxygen reduction, manganese reduction, ferric iron reduction, sulfate reduction, and methanogenesis.

- Expressed assimilative capacity estimates indicate that the available electron acceptor mass in groundwater underlying Pumphouse #2 is sufficient to maintain biodegradation of dissolved BTEX until concentrations are below state-promulgated groundwater standards.

SECTION 7

PILOT TESTING OF SOURCE-REDUCTION TECHNOLOGIES

Section 6 of this EE/CA shows that both destructive and nondestructive attenuation processes should be effective at minimizing contaminant migration and reducing contaminant mass over time at the Pumphouse #2 site. Other source reduction technologies were evaluated at Pumphouse #2 as part of this project in the event that engineered source removal is required to protect human health and the environment or to reduce the total time and cost of remediation. *In situ* bioventing and biosparging pilot tests were completed at Pumphouse #2 to determine the effectiveness of these two low-cost remedial techniques on treating site related contamination. A 1-year-long bioventing pilot-scale test was conducted at Pumphouse #2 by ES/Parsons ES in 1993 and 1994 as part of a separate AFCEE remedial technology testing program. Detailed results of initial bioventing pilot testing at Pumphouse #2 can be found in the *Interim Pilot Test Results Report for PS-3 (Pumphouses 2 and 3) and PS-4 (Bulk POL Storage Area) Malmstrom AFB, Montana* (ES, 1993). A biosparging pilot test also was conducted at this site by Parsons ES in November 1994 during the risk-based site investigation. One-year soil sampling results from the bioventing system test and results from the biosparging test at Pumphouse #2 are summarized in the following sections. Test data are presented in tabular form in Appendix F.

7.1 *IN SITU* BIOVENTING PILOT TESTING

7.1.1 Bioventing Well and Vapor Monitoring Point Installation

Vapor monitoring points MPA, MPB, and MPC were installed by ES on September 30 through October 2, 1993. The air injection vent well (VW) was installed at the site on August 15, 1993, by HDR during RFI field investigation activities. Figure 7.1 shows the locations of the VW, MPA, MPB, and MPC. Figure 7.2 is a hydrogeologic cross-section showing the relationships of the screened intervals to subsurface soil intervals. Boring logs and well construction diagrams for the bioventing system are included in Appendix B.

One 4-inch-diameter PVC VW was installed in contaminated source area soils. The VW is screened from 5 to 10 feet bgs through the sandy clay interval and into the top of the glacial till at the site. Groundwater was encountered in the VW at approximately 4.05 feet bgs in the fall of 1994. During air injection, the groundwater in and near the vent well was depressed by the injection air pressure. This groundwater depression allowed increasing quantities of air to be transferred in the capillary fringe. As the groundwater table dropped due to seasonal variations, the vadose zone became available for bioventing.

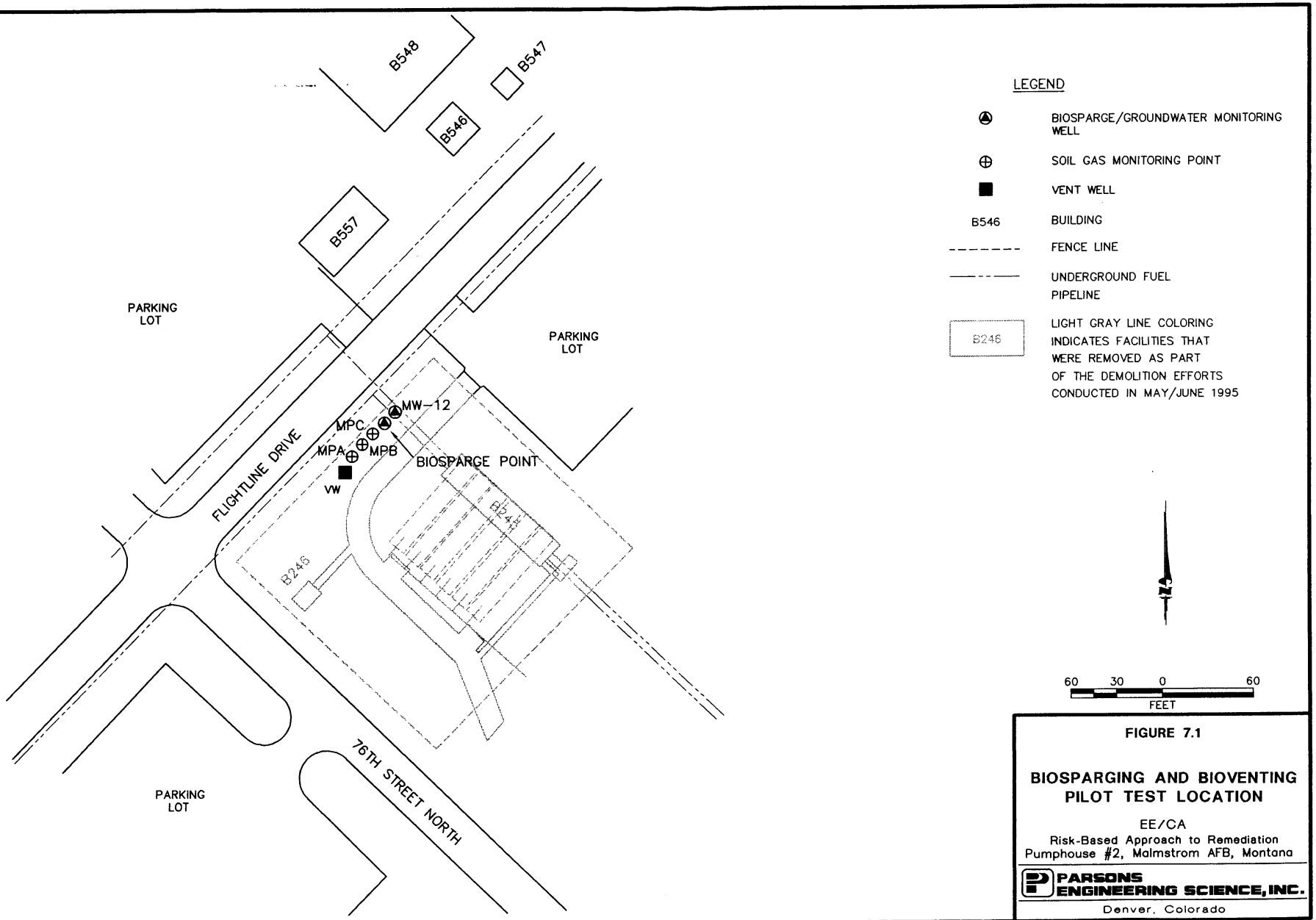


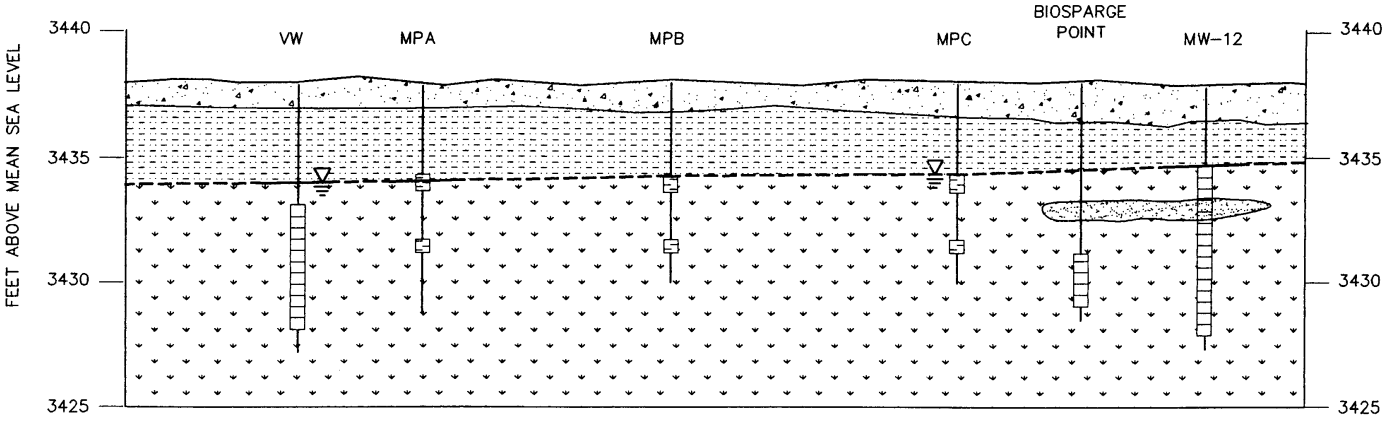
FIGURE 7.1

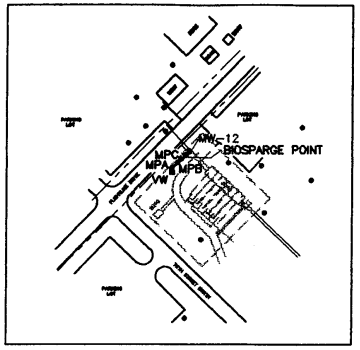
BIOSPARGING AND BIOVENTING PILOT TEST LOCATION

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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Denver, Colorado

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SCALE:
HORIZ. 1"=5'
VERT. 1"=5'

5 0 5
FEET
VERTICAL EXAGGERATION = 0X

LEGEND

- GROUNDWATER SURFACE (DASHED WHERE INFERRED)
- GEOLOGIC CONTACT (DASHED WHERE INFERRED)
- SCREENED INTERVAL
- MONITORING POINT SCREENED INTERVAL
- GLACIAL TILL
- GRAVEL
- BACKFILL MATERIAL
- SANDY/CLAY

FIGURE 7.2

HYDROGEOLOGIC CROSS-SECTION ADJACENT TO BIOVENTING AND BIOSPARGING PILOT TEST AREAS

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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The three soil vapor monitoring points (MPA, MPB, and MPC) are screened in the unsaturated and saturated zones using 6-inch-long sections of 1-inch-diameter well screen centered at depths of approximately 4.0 and 6.5 feet bgs. The deeper interval was below the groundwater surface at the time of installation in October 1993. These points were installed in anticipation of the groundwater elevation decreasing over the course of the test, thus allowing the points to be used in future sampling events. The shallow screened intervals were above the groundwater surface at the time of installation; however, during testing in November 1994, all but one of the screens were below the groundwater surface. Thermocouples were installed at both depths at MPA to measure soil temperatures.

7.1.2 Respiration Testing

In situ respiration testing was performed at Pumphouse #2 to determine oxygen utilization rates and potential biodegradation rates. Testing was performed by injecting a mixture of air (oxygen) and approximately 1.5 percent helium (inert tracer gas) into three screened monitoring point intervals (MPA-4, MPB-4, and MPC-4) for a 23-hour period. Oxygen loss and other changes in soil gas composition over time were then measured at these intervals and all other MP intervals that had elevated oxygen levels following the air permeability test. Oxygen, TVH, carbon dioxide, and helium were measured for a period of approximately 5.5 hours following air injection. The measured oxygen losses were then used to calculate biological oxygen utilization rates.

Because helium is a conservative, inert gas, the change in helium concentrations over time can be useful in determining the effectiveness of the bentonite seals between screened intervals. Because the observed helium loss was negligible at Pumphouse #2, and because helium will diffuse approximately three times faster than oxygen due to oxygen's greater molecular weight, the measured oxygen loss at the site was the result of bacterial respiration and not due to faulty monitoring point construction.

Oxygen loss occurred at high rates, ranging from 0.046 percent per minute at MPB-4 to 0.057 percent per minute at MPC-4. At MPC-4, the oxygen dropped from 20.5 percent to 1.0 percent in 330 minutes, or approximately 5.5 hours. Oxygen utilization rates are summarized in Table 7.1.

Based on these oxygen utilization rates, an estimated 2,240 to 2,780 milligrams (mg) of fuel per kilogram (kg) of soil can be degraded each year at this site. This conservative estimate is based on an average air-filled porosity of approximately 0.024 liter per kg of soil, and a ratio of 3.5 mg of oxygen consumed for every 1 mg of fuel biodegraded (ES, 1993). Actual degradation rates may exceed these estimates.

7.1.3 Air Permeability Testing

An air permeability test was conducted at Pumphouse #2 according to AFCEE's protocol document procedures (Hinchee *et al.*, 1992). Air was injected into the VW for 22.5 hours at a rate of approximately 17.5 standard cubic feet per minute (scfm) and an average pressure of 4 pounds per square inch (psi). The pressure measured at the monitoring points increased at an irregular rate throughout the period of air

TABLE 7.1

OXYGEN UTILIZATION RATES DURING INITIAL BIOVENTING PILOT TESTING

ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Location	O_2 Loss[a/] (%)	Test Duration[b/] (min)	O_2 Utilization Rate (%/min)
MPA-4	17.0	330	0.049
MPB-4	15.5	340	0.046
MPC-4	19.5	330	0.058

[a/] Actual measured oxygen loss.
[b/] Elapsed time from beginning of test to time when minimum oxygen concentration was measured.

TABLE 7.2

OXYGEN INFLUENCE IN SUBSURFACE DURING INITIAL BIOVENTING PILOT TESTING

ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

MP	Distance From VW (ft)	Depth (ft bgs)	Initial O_2 (%)	Permeability Test O_2[a/] (%)
A	5	4	0.5	NS[b/]
B	15	4	1.7	16.8
C	25	4	0.6	11.0

[a/] Reading taken at the end of 22.5-hour air permeability test.
[b/] NS = not sampled.

injection. Due to this varied pressure response, the HyperVentilate® method of determining air permeability was selected. A soil gas permeability value of 18 darcys was calculated for this site. A radius of pressure influence of at least 25 feet was observed at the 4.0-foot depth (ES, 1993). Pressure response was observed at the deeper monitoring points but was the result of increased groundwater pore pressures in adjacent soils. The upper 6 feet of these soils has exhibited relatively high permeability due to the presence of sand lenses which distribute air flow in the sandy-clay soils. Test data and associated calculations are presented in Appendix F.

The depth and radius of oxygen increase in the subsurface resulting from air injection into the VW during pilot testing is the primary design parameter for full-scale bioventing systems. Optimization of full-scale, multiple VW systems requires pilot testing to determine the volume of soil that can be oxygenated at a given flow rate and VW screen configuration.

Table 7.2 presents the change in soil gas oxygen levels that occurred during the 22.5-hour air permeability test. This period of air injection produced changes in soil gas oxygen levels at two of the three shallow monitoring intervals. Soil gas oxygen levels could not be measured in the three deeper intervals because they were below the groundwater surface. Based on measured changes in oxygen levels, it is anticipated that the radius of influence for a long-term bioventing system at this site will exceed 25 feet at all depths above the groundwater surface.

7.1.4 Pilot-Test Results

After initial pilot testing was completed, a rotary-vane blower was installed at the site, and long-term testing began. The pilot-scale system at Pumphouse #2 operated for approximately 11 months. One month prior to the final sampling event, the blower was turned off so that the subsurface could reach equilibrium. Final 12-month soil and soil gas samples were collected during the risk-based site investigation in October 1994 to determine the long-term effectiveness of the bioventing system. Soil gas samples were collected on October 19, 1994, and soil samples were collected on October 23, 1994. Table 7.3 presents the tabulated results of this sampling event. Throughout the pilot test area, BTEX concentrations in both soil and soil gas decreased appreciably. In several samples, BTEX levels decreased to below MDLs. Treatability testing indicates that *in situ* bioventing is a feasible and cost-effective method of remediating shallow hydrocarbon contaminated soils within the source area at Pumphouse #2.

7.2 BIOSPARGING TEST

Biosparging was evaluated as a potential remedial technology for *in situ* treatment of dissolved fuel hydrocarbons in the saturated zone at Pumphouse #2. Injecting air into contaminated groundwater serves two purposes: volatilizing BTEX compounds from groundwater, and supplying oxygen to groundwater to enhance biodegradation of less volatile compounds.

TABLE 7.3
INITIAL AND 1-YEAR SOIL AND SOIL GAS ANALYTICAL RESULTS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Analyte (Units)[a/]	Sample Location - Depth (feet below ground surface)					
	MPA-4		MPB-4		MPC-4	
Soil Gas Hydrocarbons	Initial[b/]	1-Year[c/]	Initial	1-Year	Initial	1-Year
TVH (ppmv)	5,400	NS[d/]	6,900	65	14,000	NS
Benzene (ppmv)	< 0.61	NS	< 0.69	< 0.002	19	NS
Toluene (ppmv)	< 0.61	NS	< 0.69	< 0.002	< 0.57	NS
Ethylbenzene (ppmv)	9	NS	5.2	0.150	13	NS
Xylenes (ppmv)	11	NS	9.8	0.280	15	NS
	MPA-2		MPB-3.5		MPC-5.5	
Soil Hydrocarbons	Initial[e/]	1-Year[f/]	Initial	1-Year	Initial	1-Year
TRPH (mg/kg)	300	146	270	33.5	150	74.4
Benzene (mg/kg)	< 0.65	< 0.05	< 0.64	< 0.05	< 0.31	< 0.05
Toluene (mg/kg)	0.71	< 0.05	< 0.64	0.12	1.1	0.057
Ethylbenzene (mg/kg)	1.2	< 0.05	2.2	0.55	1.5	0.067
Xylenes (mg/kg)	3.6	< 0.1	3.1	0.29	4.4	< 0.1
Moisture (%)	23	NA[g/]	22	NA	20	NA

[a/] TVH= total volatile hydrocarbons; ppmv=parts per million, volume per volume; TRPH=total recoverable petroleum hydrocarbons; mg/kg=milligrams per kilogram.

[b/] Initial soil gas samples collected on 10/3/93.

[c/] 1-Year soil gas samples collected on 10/19/94.

[d/] NS = Not sampled.

[e/] Initial soil samples collected on 10/2/93.

[f/] 1-Year soil samples collected on 10/23/94.

[g/] NA = Not analyzed.

The depth and radius of DO increase in groundwater resulting from air injection into the sparging point during pilot testing is the primary design parameter for full-scale biosparging systems. Optimization of full-scale, multiple sparging point systems requires pilot testing to determine the areal extent of groundwater that can be oxygenated at a given flow rate and sparging point screen configuration. The following sections summarize the biosparging test procedures and results, and assesses the applicability of this technology for *in situ* source reduction at Pumphouse #2.

7.2.1 Biosparging Well Installation

The 1-inch-diameter PVC biosparging well installed at the site was screened below the water table from 6.5 to 8.5 feet bgs. Newly installed groundwater monitoring well MW-12 and the existing bioventing VW were used to measure changes in groundwater DO concentrations and water levels. Figure 7.1 shows the locations of the VW, MW-12, and BS-1. Figure 7.2 provides a hydrogeologic cross section showing the relationships between the screened intervals and the groundwater surface. Boring logs and well construction diagrams are included in Appendix B.

7.2.2 Biosparging Test Procedures

One biosparging pilot test was performed at Pumphouse #2 during the period from October 13 to October 16, 1994, to determine the feasibility of reducing dissolved fuel contamination in source area groundwater. Initial groundwater levels and DO concentrations were measured at the VW and MW-12 prior to injecting air into groundwater through BS-1. After initial measurements were recorded, air was injected at varying flow rates and pressures for approximately 3 days. Air injection rates varied from 12 to 17.5 scfm (Table 7.4) with an average rate of approximately 14 scfm and an average injection pressure of approximately 2.5 psi.

During the period of air injection, groundwater levels, DO concentrations, injection pressure, and flow rate were periodically measured and recorded. These parameters

were measured at the injection blower, MW-12, and the VW. At the conclusion of the test, DO concentrations were also measured in the deep (6.5 feet bgs) monitoring points of the bioventing system at Pumphouse #2 (refer to Figure 7.1).

7.2.3 Biosparging Test Results

7.2.3.1 Radius of DO and Water Level Influence

Changes in groundwater DO concentrations were used to determine the effective radius of influence of the single biosparging point. Measured increases in water levels (mounding) were another indicator used to help determine the radius of influence. The biosparging test results are summarized in Table 7.4.

The maximum DO increase was measured at MW-12, located 9.3 feet northeast of BS-1. At MW-12, the DO concentration increased from 2.8 to 7.2 mg/L at 5 feet bgs (approximately 3 feet below the groundwater surface). At the VW, located 36 feet southwest of BS-1, DO increased from 0.1 to 4.1 mg/L. During the course of the test,

TABLE 7.4

BIOSPARGING PILOT-TEST RESULTS

ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

DATE	TIME	INJECTION PRESSURE (psi) (measured at blower)	INJECTION FLOWRATE (SCFM) (measured at blower)	DISSOLVED OXYGEN (mg/L)					GROUNDWATER ELEVATION (Ft. BTOC.)	
				MW-12	VW	MPA	MPB	MPC	MW-12	VW
11/13/94 [a/]	11:30	NS [b/]	NS	NS	NS	NS	NS	NS	NS	4.29
	15:30	NS	NS	2.81	NS	NS	NS	NS	3.11	NS
	16:30	NS	NS	NS	0.1	NS	NS	NS	NS	NS
11/14/94	10:00	1	NS	7.20	0.85	NS	NS	NS	4.90	5.83
	17:44	NS	NS	7.00	1.10	NS	NS	NS	NS	NS
11/15/94	08:53	NS	NS	7.10	5.50	NS	NS	NS	2.70	4.17
	16:52	NS	11.99	6.50	4.10	NS	NS	NS	2.70	4.13
11/16/94	08:41	1.6	17.44	5.00	3.20	NS	NS	NS	2.58	6.38
	16:30	0.9	17.44	5.20	1.60	4.40	0.50	1.15	2.56	4.01

a/ Initial conditions; Biosparging air injection was started at 17:40 on 11/13/94.

[b/] NS = Not sampled.

bubbles were observed in MW-12, indicating adequate oxygen distribution in shallow groundwater.

The uniformity of oxygen distribution cannot be determined from two monitoring points. Pilot testing indicates that sparging is a potentially effective method for increasing DO in groundwater at Pumphouse #2, thus promoting *in situ* biodegradation of fuel hydrocarbons.

7.2.3.2 Potential Air Emissions

The long-term potential for air emissions into the atmosphere from full-scale biosparging operations at this site is low. Emissions would be minimal because of the low air injection rates required and because vapors released into the vadose zone would move slowly upward from the biosparging wells. These vapors would be biodegraded as they slowly move through oxygenated vadose soils which primarily consist of sandy clays. Soil flux measurements (Section 4.4.3) taken at a location adjacent to BS-1 during the biosparging test confirm that BTEX and TVH vapor flux to the atmosphere did not measurably increase during biosparging.

7.2.3.3 Technology Assessment

The value of air sparging as a remediation tool is one of the most controversial topics in the remediation industry. Advocates of this technology cite case studies where volatile organics are removed and dissolved oxygen transferred to the groundwater in relatively short time frames (Brown, 1991a and b; Marley, 1990). Despite many apparent successful applications of this technology, a number of independent researchers have concluded that the use of fully-screened monitoring wells for monitoring sparging efficiency has significantly biased groundwater DO and VOC data. They point out that the monitoring wells may intersect a single channel of air which turns the well into an *in situ* air stripping column, adding DO to the water and stripping VOCs from the well. Independent researchers have also conducted large pilot tests and shown that injected air generally follows preferential channels and is not uniformly distributed, even in sandy aquifer material (Johnson, 1993). Studies on DO distribution have yielded similar results, with uneven DO distribution measured over long-term pilot testing (Johnson, 1994). In these pilot tests DO increased initially and then gradually declined over a 110-day test. This decline was likely the result of increased channeling, which reduces mass transfer of oxygen as smaller channels combine into larger, less efficient channels. Pulsing of air sparging systems has been suggested as a method of maintaining smaller channels and minimizing mass transfer (Johnson, 1994). On the basis of the pilot data gathered at Pumphouse #2 and air sparging research to date, Parsons ES believes that the pulsed operation of air sparging systems can increase DO near the sparge points and provide oxygen to the capillary fringe and vadose zone to enhance natural biodegradation. It is, however, doubtful that air sparging can remove large quantities of volatiles from the groundwater, given mass transfer limitations. Additionally, the application of biosparging to the heterogeneous shallow groundwater at the Pumphouse #2 site is inappropriate, given the likelihood that groundwater is found only in isolated area. The ability to efficiently distribute oxygen in the subsurface is doubtful and will not be pursued as a possible remedial alternative for dissolved contamination at the site.

SECTION 8

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

Sections 6 and 7 provided scientific documentation of natural attenuation processes and the potential benefits of excavation and *ex situ* treatment and/or bioventing in accelerating the remediation of the source area. An initial screening of remedial approaches and technologies was completed, and several of these were identified for possible use at Pumphouse #2. A complete review of the initial screening process is included in Appendix G. Two remedial alternatives were developed using various combinations of natural chemical attenuation, land and groundwater use controls, long-term monitoring, and active source reduction technologies. The objectives of Section 8 are to summarize the alternatives developed in Appendix G, to review the primary evaluation criteria used to compare these alternatives, and to complete a more detailed comparative analysis of each alternative in an effort to identify the most logical approach for remediating Pumphouse #2. Each alternative is more fully described in terms of its effectiveness, technical and administrative implementability, and cost. Following this evaluation, an implementation plan for the recommended alternative is presented in Section 9.

8.1 SUMMARY OF CANDIDATE REMEDIAL ALTERNATIVES

Based on the initial screening summarized in Appendix G, several remedial approaches and technologies were retained for the development of remedial alternatives. These technologies were selected to provide a range of passive to more active response actions, all of which can achieve risk-based closure of Pumphouse #2. As a secondary goal, each alternative will also eventually lower groundwater contaminant concentrations to levels that meet groundwater quality standards. State standards will be met in similar time frames but at different costs under each alternative. The following remedial approaches and technologies were retained for evaluation:

- Long-term groundwater monitoring;
- Limited land use controls;
- Groundwater use controls;
- Public education;
- Intrinsic remediation of soil and groundwater contamination;

- Source area sediment excavation;
- *Ex situ* sediment treatment in a landfarm; and
- Air injection bioventing in the source area.

The primary objective of source reduction technologies would be to more rapidly remove BTEX contamination from sediments and subsurface soils at Pumphouse #2. Speeding the removal of subsurface soil BTEX contamination may only decrease the length of time that will be required to bring the entire site into compliance with groundwater quality standards. Subsurface soil BTEX removal actions are not required at Pumphouse #2 to protect human health and the environment. Removal of contaminated sediments in the ditches at the site is required to protect groundwater quality and reduce the risk associated with incidental dermal contact with contaminated groundwater. As shown in Section 5, maximum contaminant concentrations of sediment samples currently exceed SSTLs that would prevent contamination of groundwater. The SSTLs are calculated to prevent groundwater contamination from reaching concentrations that would pose a human health risk through incidental dermal contact. Detected subsurface concentrations, however, were lower and do not present a risk to human health and groundwater quality under an industrial use scenario.

The greatest concentrations of BTEX in both groundwater and vadose zone soils exist in the vicinity of former fuel transfer lines that ran to and from the former location of the pumphouse. These fuel transfer lines were grouted in place when the site facilities were demolished in May and June 1995. Comparison of 1993 and 1994 groundwater sampling results for this source area indicate that natural processes may be reducing BTEX concentrations. Contaminant partitioning calculations imbedded in the development of SSTLs that are protective of groundwater quality indicate that sediment contamination will be a continuing source of groundwater contamination.

Because natural chemical attenuation has been effectively reducing dissolved BTEX compounds in the shallow groundwater and limiting downgradient migration, this ongoing remediation process can only be enhanced through a reduction of the continuing sources of contamination at Pumphouse #2. One candidate *in situ* source reduction technologies (bioventing), and one *ex situ* treatment technology (sediment excavation with landfarming) have been retained for additional analysis. Two candidate remedial alternatives were developed and are described in the following sections.

8.1.1 Alternative 1- Natural Chemical Attenuation, Long-Term Monitoring, Land and Groundwater Use Controls, Public Education, and Limited Sediment Excavation and *Ex Situ* Treatment

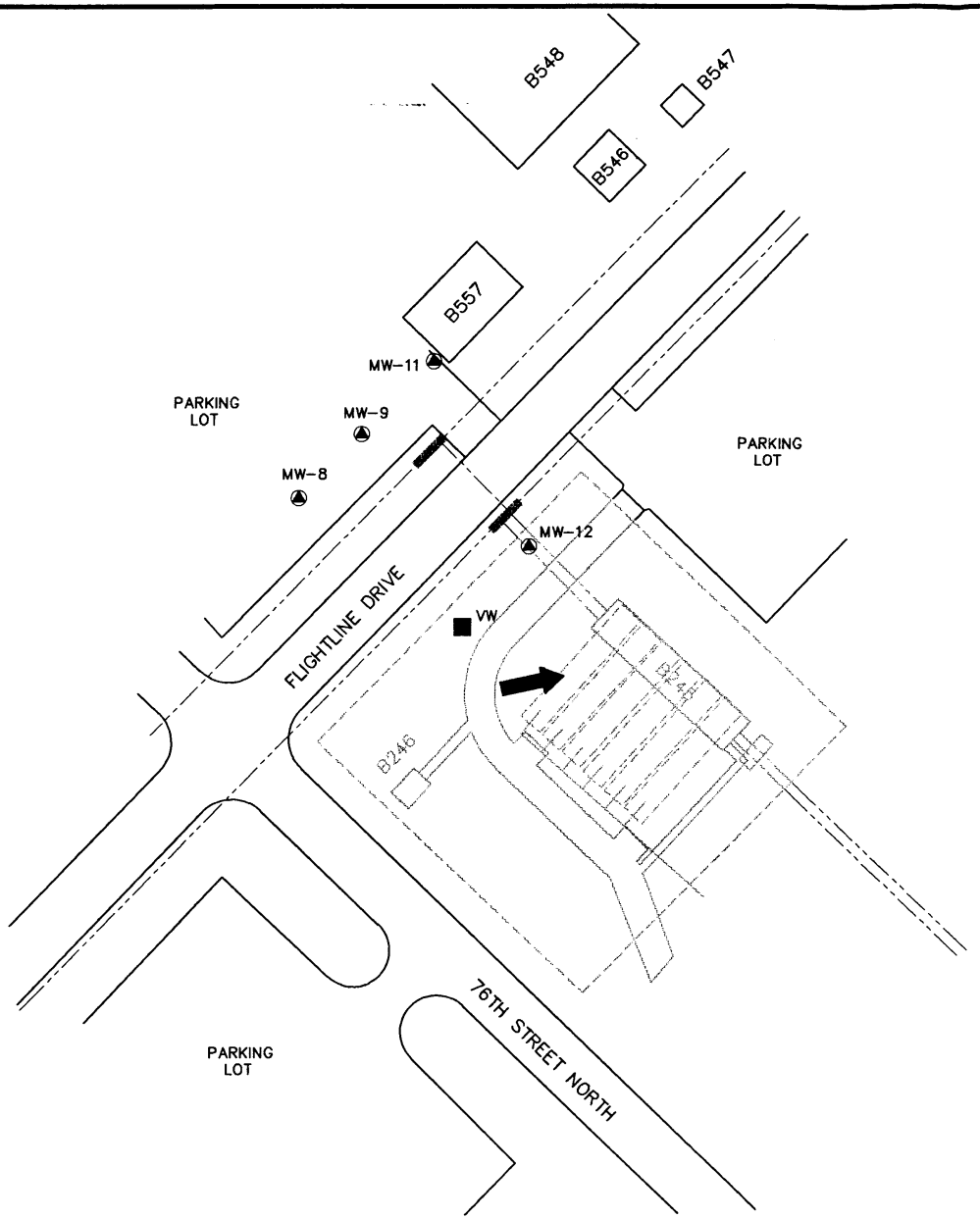
Goal of Alternative 1: Risk-based site closure in approximately 5 years and attainment of state promulgated groundwater quality standards in approximately 12 years.

Section 6 presents significant evidence that groundwater contaminants are being remediated by naturally occurring physical, chemical, and biological processes. On the basis of 1994 and 1995 subsurface soil sampling results (presented in Section 4 and evaluated in Section 5), BTEX concentrations in subsurface soils are already below levels that are protective of human health and the environment as a result of natural leaching and biodegradation. Ditch sediment samples, however, had concentrations of the BTEX compounds that could pose an indirect risk to human health. As a result, this alternative proposes limited excavation and treatment of contaminated sediments in the drainage ditches on both sides of Flightline Drive. The locations of the proposed excavations are shown on Figure 8.1. Groundwater data collected in 1994 clearly indicate a decrease in BTEX concentrations as groundwater moves away from the site. Aside from excavation and treatment of sediments, no further active remedial actions are required at Pumphouse #2 to protect human health and the environment.

Section 6 provided an evaluation of natural chemical attenuation processes operating at the site; a simple analytical natural chemical attenuation calculations was used to simulate the effects of these processes on contaminant mass and mobility over time. The calculation performed for this site predict that all concentrations of groundwater contaminants will be below state groundwater quality standards by the year 2008. Contaminantion is predicted to begin attenuating at an increased rate once source soils (i.e., contaminated sediments) are removed. No further plume migration is anticipated due to the discontinuous nature of water bearing strata and the natural processes occurring at the site. As discussed in Section 6, little historical groundwater data is available for the site. As a result, annual groundwater monitoring will be a key element in quantifying the progress of natural chemical attenuation at Pumphouse #2. Annual groundwater monitoring results will be evaluated to better quantify how natural chemical attenuation is reducing potential risks to human health and the environment at the site. Once it can be demonstrated that contaminants are not migrating and concentrations are declining, risk-based closure with appropriate land use and groundwater use controls can be achieved. It is anticipated that it will take approximately 5 years to gather the necessary data for a risk-based closure.

Once contaminated sediments are removed and treated, this site will be considered suitable for a variety of industrial uses. Land use (i.e., excavation) restrictions and groundwater use restrictions would be put in place until all subsurface soils and shallow groundwater at the site meet state standards. Limitations on land and groundwater use would not pose additional restrictions on current or planned future land uses in this uninhabited industrial area.

This alternative would include annual monitoring of groundwater to verify and document that natural chemical attenuation and the discontinuous hydrogeology are either decreasing the size of the contaminant plume or preventing it from significantly enlarging. The progress of natural chemical attenuation would be monitored using the existing network of monitoring wells. POA wells would be used to ensure that no groundwater BTEX concentrations exceeding groundwater quality standards migrate from the area of established groundwater use restrictions. Additional details on the frequency and types of groundwater analysis recommended to confirm natural chemical



LEGEND

- BIOVENTING VENT WELL (INSTALLED 1994)
- BIOVENTING VENT WELL (INSTALLED 1993)
- GROUNDWATER FLOW DIRECTION
- B546 BUILDING
- FENCE LINE
- UNDERGROUND FUEL PIPELINE
- B246 LIGHT GRAY LINE COLORING INDICATES FACILITIES THAT WERE REMOVED AS PART OF THE DEMOLITION EFFORTS CONDUCTED IN MAY/JUNE 1995
- AREA OF PROPOSED SEDIMENT EXCAVATION

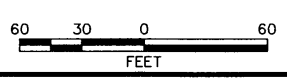


FIGURE 8.1

BIOVENTING VENT WELL LOCATIONS

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

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Denver, Colorado

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attenuation and to verify the eligibility of the site for risk-based closure are presented in the long-term monitoring plan included in Section 10.

8.1.2 Alternative 2: Natural Chemical Attenuation, Long-Term Monitoring, Land and Groundwater Use Controls, Public Education, Bioventing in Source Area, and Limited Sediment Excavation and *Ex Situ* Treatment

Goal of Alternative 2 - Risk-based site closure in approximately 5 years and state promulgated groundwater quality standards in approximately 15 years.

Alternative 2 is similar to Alternative 1 except for the addition of several bioventing air injection wells in the secondary source area. Bioventing would be employed to lower BTEX concentrations in unsaturated soils in the secondary source area. This action is not required to protect human health and the environment under current land use assumption for Pumphouse #2; it is included as a method to more rapidly reduce contaminant mass in the source area. Time to achieve both risk-based closure and state groundwater standards is not appreciably reduced.

An *in situ* pilot-scale bioventing test was performed by ES/Parsons ES at Pumphouse #2 in 1993 and 1994. The results of this test are summarized in Section 7.1. As the results indicate, bioventing will effectively remove BTEX from unsaturated soils at Pumphouse #2. Four 4-inch diameter air injection wells were installed in the source area during the risk-based field investigation in 1994. Under this alternative, air lines would be run to these wells, and air flow to the wells would be optimized to maximize subsurface biodegradation while minimizing contaminant volatilization. Soil gas flux testing would be performed during system startup to assure that no contaminant vapors are migrating from the subsurface. Figure 8.1 presents the locations of existing bioventing air injection wells that would be used for full-scale bioventing at Pumphouse #2.

Land use and groundwater use controls for Alternative 2 would be identical to Alternative 1. Additional site access would be required to maintain the bioventing system. Long-term groundwater monitoring also would be the same as Alternative 1, except that additional long-term soil gas monitoring and respiration testing would also be required for the full-scale bioventing system to document the amount of VOCs being removed from the vadose zone and to ensure optimal system performance.

8.2 REVIEW OF SCREENING AND EVALUATION CRITERIA

The evaluation criteria used to identify appropriate remedial alternatives for soil and groundwater contamination at Pumphouse #2 were adapted from those recommended by EPA (1988) for selecting remedial actions for Superfund sites [Office of Solid Waste and Emergency Response (OSWER) Directive 9355.3-01]. These criteria include (1) anticipated effectiveness in meeting target cleanup criteria, (2) technical and administrative implementability, and (3) relative cost. An initial screening of remedial technologies was conducted using the three broad evaluation criteria (Appendix G). The following sections briefly describe the scope and purpose of each criterion.

8.2.1 Effectiveness

Each remedial technology/approach or remedial alternative (which can be a combination of approaches and technologies) was evaluated to determine how effectively it can attain the desired degree of cleanup. The remedial alternatives proposed for this site are designed to complete a risk-based closure of Pumphouse #2. Both alternatives proposed for Pumphouse #2 also would eventually remediate groundwater to state standards; however, this is not the primary goal of the remedial action at Pumphouse #2. Sections 5 and 6 provide the rationale for why a risk-based closure is appropriate for the site, given the current and planned industrial land uses and the potential for exposure of receptors to site-related contamination. Remedial technologies that could not cost-effectively attain the desired level of remediation were eliminated from further consideration.

Remedial technologies and approaches retained for detailed evaluation are evaluated in terms of the expected effectiveness of each technology to attain the desired degree of risk reduction at Pumphouse #2, based on site-specific characterization and treatability data. The ability to minimize potential adverse impacts on surrounding facilities and operations and other environmental resources is considered. Time to implementation and time until protection is achieved are described. Potential adverse impacts that could be realized during implementation, the cost of necessary mitigation measures, and the potential for residual risks remaining following remedial action also are considered qualitatively. Potential residual risks that may exist following remedy implementation are described. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, also is evaluated.

8.2.2 Implementability

The technical feasibility, applicability, and reliability of each remedial technology were used initially as broad criteria to narrow the list of potentially applicable remedial approaches for the site. Technologies retained for detailed evaluation were evaluated in terms of engineering implementability, reliability, constructability, and technical feasibility. Potential effects due to unanticipated site conditions or significant changes in site conditions were considered. The ability to monitor performance and public perception is discussed. Any prohibition of onsite activities that would be required to ensure successful implementation is described.

8.2.3 Cost

Relative cost of various remedial technologies was used as an initial screening tool (Appendix G). More detailed cost estimates were prepared for each remedial alternative retained for comparative analysis. The cost includes operation and maintenance costs, distributed over the time required for implementation. Present worth cost estimates were prepared in accordance with OSWER Directive 9355.3-01.

8.3 DETAILED EVALUATION OF REMEDIAL ALTERNATIVES

In this section, each of the candidate alternatives is evaluated using the more detailed criteria described in the previous section. Each alternative is more fully described in terms of its effectiveness, technical and administrative implementability, and cost.

8.3.1 Alternative 1- Natural Chemical Attenuation, Long-Term Monitoring, Land and Groundwater Use Controls, Public Education, and Limited Sediment Excavation and *Ex Situ* Treatment

8.3.1.1 Effectiveness

Soil and groundwater sampling performed at Pumphouse #2 in 1994 indicates that concentrations of BTEX in subsurface soils are below levels that would cause a risk to human health and the environment under a industrial land use scenario. Sampling of ditch sediments, however, indicates that surface sediments found in the bottom of drainage ditches along Flightline Drive may pose an indirect potential risk to onsite workers. Benzene concentrations detected in groundwater may pose a carcinogenic risk to onsite workers. As part of this alternative, contaminated sediments will be physically removed from the site and treated at an existing on-Base landfarm. This remedial action will eliminate the risk posed by contaminated sediments at Pumphouse #2. Groundwater use and excavation would be restricted at the site under this alternative. These restrictions would be put in place to eliminate the risk associated with incidental contact with contaminated groundwater.

Groundwater BTEX concentrations will decrease slowly over time through natural chemical attenuation processes as plume migration is retarded by hydrogeological conditions. Based on the natural chemical attenuation estimate presented in Section 6, state-promulgated groundwater quality standards should be attained in approximately 12 years. The assimilative capacity of the saturated media and the site-specific biodegradation rates will be sufficient to transform BTEX compounds into carbon dioxide and water, and to limit migration of the plumes. It should be noted that the discontinuous hydrogeology at the site is also a predominant mechanism responsible for the containment of the plume at the site.

Long-term groundwater monitoring is recommended under Alternative 1 as a method of measuring the effectiveness of natural chemical attenuation and demonstrating the eligibility of the site for risk-based closure. Annual sampling also is required to collect additional historical data for the site. Little historical data is available for the site, only three wells at the site have been samples more than once. Annual sampling data will be evaluated to quantify the progress of natural chemical attenuation in reducing potential human health risk at the site. A network of groundwater monitoring wells would be sampled annually to monitor plume migration. This network will consist of ten wells and is discussed in detail in Section 10 of the EE/CA, the long-term monitoring plan. Annual groundwater sampling is recommended, given the limited contaminant migration that has been observed to date and low groundwater velocity. When 3 years of consecutive measurements indicate that contamination has stabilized or decreasing, a petition would be filed with MDEQ

to have the site closed. Contamination should stabilize and begin decreasing at an increased rate as soon as source soils (i.e., contaminated sediments) are removed. It is estimated that significant decreases will be documented within 5 years of sediment removal. Based on contaminant concentration data collected over a total of 7 years, closure of the site should be obtained in approximately 2001.

Groundwater samples collected during the annual analytical program would be analyzed for BTEX using EPA Method SW8020. Analytical data on selected geochemical indicators of biodegradation such as DO and sulfate would be collected to assess the progress of intrinsic remediation. Once started, annual analytical groundwater monitoring would continue until risk-based closure is achieved. After closure is achieved, sampling would be performed, as required, to monitor for the attainment of MDEQ standards. It is estimated that risk-based closure can be achieved at Pumphouse #2 in 5 years under this alternative. Based on conservative analytical calculations, state groundwater standards will be met at the site in approximately 12 years. For the purpose of cost estimation, 12 years of annual groundwater sampling has been assumed for Alternative 1.

A complete long-term monitoring plan is provided in Section 10 to assist the Base in implementing long-term groundwater monitoring. Parsons ES has been retained to complete the first year of groundwater monitoring at Pumphouse #2. Every year, groundwater sampling data would be used to revise the analytical calculations to quantify to what extent natural chemical attenuation and site hydrogeology are preventing the contaminant plume from spreading. In the event that remediation is not progressing and the contaminants at Pumphouse #2 is not being contained, the following contingency actions are recommended:

- Resample all downgradient wells to confirm initial results;
- Evaluate the results of the most recent groundwater sampling event to determine if there is a trend indicating more rapid contaminant migration due to a lack of natural chemical attenuation or misinterpretation of site hydrogeology;
- Complete a risk analysis to determine if the levels of groundwater contamination present a risk given actual site and downgradient land use at the time of sampling; and
- If a significant risk exists, reevaluate more active methods of remediation and implement the most effective risk reduction method. This could include initiation of the active *in situ* remediation methods described for Alternatives 2.

Groundwater use controls are an important component of this alternative. The current restrictions to site access (Base perimeter fencing) provide a limited measure of protection against unauthorized site access and groundwater contact. All persons having access to the Base have access to the site, including residents of on-Base housing. The present (uninhabited) land use and nonuse of groundwater have effectively eliminated potential exposure pathways involving groundwater at this site. As a part of this EE/CA, the Air Force proposes well permit restrictions to prevent

withdrawal of groundwater from the shallow aquifer for drinking water applications within 1,000 feet of the plume centerline until such time as site-related contaminants decrease below state groundwater cleanup standards. Although shallow groundwater at the site is not considered suitable for pumping, perched groundwater use restrictions should be a component of any future land use change or property exchange. This strategy will not interfere with the current and intended use of the site and affected natural resources. In the unlikely event that the site is ever released from government ownership and rezoned for unrestricted residential use, groundwater use restrictions must be kept in place and enforced until groundwater quality standards are achieved.

Land use restrictions would be put in place at Pumphouse #2 until contaminant concentrations in subsurface soils decrease to levels equal to or below state standards. This reduction will occur primarily through natural biodegradation and contaminant leaching. Fuel residuals will gradually biodegrade as atmospheric oxygen diffuses into the shallow contaminated soils. Precipitation percolating through vadose zone soils will leach contaminants out of the soil matrix and into groundwater where natural chemical attenuation will eliminate them. This process may take a significant amount of time to lower contaminant levels to state standards. It is proposed that the area of greatest soil contamination, sediments in the bottom of drainage ditches at the site, be actively remediated by excavation and *ex situ* treatment. This action would eliminate any risk from near surface (0 to 2 feet bgs) soils at the site as well as remove the most contaminated soils from the site.

Land use restrictions would take the form of restrictions on excavation and other subsurface disturbances. Fencing may also be placed around the site to eliminate the possibility of unauthorized excavation. If new construction or maintenance activities require that excavation be performed at the site, all parties involved must be notified of potential health hazards caused by exposure to contaminated subsurface soil and groundwater. No restrictions on surface activities will be required.

Soil excavation of sediments from the bottom of drainage ditches at the site would be required. Two sediments samples (SED-6 and SED-9) one from either side of Flightline Drive, had high concentrations of BTEX. Sediment samples from approximately 30 feet up- and downgradient from both locations did not have detectable concentrations of BTEX. This indicates that sediment contamination is isolated to small areas near where transfer lines teed into larger fuel supply and return pipelines which parallel Flightline Drive. The transfer lines and supply and return pipelines have been removed from service (abandoned by grouting in place) and are no longer a potential source of contamination.

It is anticipated that approximately 12 cubic yards (cy) of soil would need to be removed from each ditch. This volume corresponds to an excavation 4 feet deep by 4 feet wide by 20 feet long in each drainage ditch. Actual extent of excavation would be determined based on field observations (visual observation and headspace readings) during excavation activities. All apparent contamination will be removed during this activity. If the extent of contamination is far greater than expected, analytical samples will be collected from the contaminated soil remaining in place. The contamination remaining in place will then be evaluated to determine if it poses an unacceptable risk

to human health and the environment. After removal, contaminated sediments would be taken to an existing on-Base landfarm for treatment. Clean fill will be used to replace contaminated soil removed from the excavations.

8.3.1.2 Technical and Administrative Implementability

Alternative 1 is technically simple and would be easy to implement. Three additional POA monitoring wells are required to monitor the area downgradient of the current plume. One of these wells would be a typical groundwater monitoring well located approximately 180 feet downgradient of the source area at Pumphouse #2. The remaining two wells would be shallow monitoring points installed by hand in the drainage ditches downgradient of the site. These points would be used to detect and evaluate any contaminant migration along the utility corridors under the ditches. Long-term groundwater sampling is a standard procedure involving minimal worker exposure to contaminated media. Equipment reliability and maintainability are not issues under Alternative 1 because no remediation equipment would be used on the site. The reliability of natural chemical attenuation to reduce BTEX concentrations and the ability of site hydrogeology to limit plume migration would be reevaluated every year. Required sediment excavation can easily be accomplished with a backhoe and dump truck. Subsurface utilities, however, may make it necessary to perform some of the excavation by hand. Appropriate personal protective equipment would be used by excavation workers. Contaminated soils would be treated in an existing land farm currently operated by the base. No new treatment technology or equipment would need to be implemented.

Administrative implementation of this alternative would require that Malmstrom AFB personnel communicate plans regarding the future use of the Base and Pumphouse #2 to the public and MDEQ. Any proposed change in land use that differs from industrial use, or any proposed groundwater pumping within 1,000 feet of the current plume centerline, should be carefully evaluated Any future construction or maintenance activities in this area should be planned to minimize excavations (i.e., disturbance greater than 2 feet bgs) and should protect the network of long-term monitoring wells. Wells should remain locked and protected against tampering or vandalism.

The public perception of Alternative 1 is expected to be positive. This alternative is protective of human health and the environment, although contaminants would remain onsite at concentrations that will MDEQ soil and groundwater standards for a period of time. Public education would be a prominent part of this alternative and would focus on site-specific risk analysis and cost savings. After ditch sediments are removed from the site no human risk related to surface activities at the site will exist. Contaminant reductions that are compatible with existing and future land use would be achieved at minimum taxpayer expense. Consistent long-term monitoring would provide verification of natural chemical attenuation effectiveness and ensure that site conditions do not change over time.

8.3.1.3 Cost

The costs associated with Alternative 1 are presented in Table 8.1. Detailed cost calculations are presented in Appendix G. There is no remediation equipment to be operated or maintained under this alternative. Capital costs include the installation of three additional POA groundwater monitoring wells and excavation of contaminated sediments. Annual costs include groundwater monitoring and site management (to be provided by Malmstrom AFB), which would include evaluation of annual monitoring data and continued liaison with MDEQ and the public and participation in future land use planning. Operation and maintenance of the landfarm for the treatment of excavated sediments is not included since these sediments would be treated at an existing facility that is currently operating. Based on the assumption that 5 years of natural chemical attenuation and long-term monitoring will be required to ensure attainment of risk-based closure, the present-worth cost of Alternative 1 is estimated to be $176,180. These costs are most sensitive to unexpected delays in attaining closure. For example, if 15 years of annual long-term monitoring is required, the present-worth cost of this alternative would increase to $221,500.

TABLE 8.1

COST ESTIMATE FOR ALTERNATIVE 1

ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Tasks	Capital Costs
Drilling and installation of 3 POA wells	$ 8,400
Excavation and treatment of 24 cy of contaminated sediments	$ 12,500
Installation of perimeter fencing	$ 7,200
Site Management and Monitoring Tasks	**Annual Costs**
Conduct annual groundwater sampling at monitoring wells in accordance with the Long-Term Monitoring Plan (12 years)	$ 9,050
Public Education/Liaison (12 years) (assumes 160 man-hours/year)	$ 9,600
Present Worth of Alternative 1 [a/]	$176,180

[a/] Based on an annual discount factor of 7 percent.

8.3.2 Alternative 2 - Natural Chemical Attenuation, Long-Term Monitoring, Land and Groundwater Use Controls, Public Education, Bioventing in Source Area, and Limited Sediment Excavation and *Ex Situ* Treatment

8.3.2.1 Effectiveness

The effectiveness of Alternative 2 in containing or reducing the contaminant plume at Pumphouse #2 would rely primarily on natural chemical attenuation and hydrogeology. Natural chemical attenuation would be the only remedial action prescribed for the remediation of dissolved contamination in groundwater at Pumphouse #2 under this alternative. The enhanced reduction of contaminant mass and toxicity in the secondary source area is a potential advantage of Alternative 2. An analytical model of natural chemical attenuation for this site predicts that Pumphouse #2 would be eligible for risk-based closure in 5 years and groundwater and soil cleanup criteria could be achieved in approximately 12 years.

The land and groundwater use controls for this alternative would be identical to those described for Alternative 1. The installation and operation of a bioventing systems would require additional site access. The long-term groundwater monitoring proposed for Alternative 2 is identical to Alternative 1, except that the bioventing systems would require weekly system checks and more frequent monitoring to determine the effective radius of oxygenation and VOC removal for bioventing. Long-term groundwater monitoring requirements would be the same as Alternative 1. Annual groundwater analytical sampling for 12 years is included in the cost estimate for this alternative. Finally, contaminated sediments would be excavated and treated as described in Alternative 1 to be protective of human health and the environment.

Bioventing would be employed at Pumphouse #2 under this alternative to accelerate remediation of unsaturated contaminated soils. This remedial action is not required to protect human health and the environment or groundwater quality; it is only included as a potential technology to reduce contaminant mass in subsurface soils in a shorter period of time. Natural processes (leaching, biodegradation, volatilization) will eventually lower contaminant concentrations in subsurface soils to acceptable levels; however, this could take a considerable amount of time. Bioventing should speed this process. Based on the results of the pilot-scale bioventing test already performed at Pumphouse #2, bioventing would efficiently and cost effectively remediate BTEX contamination in unsaturated soils. An average BTEX removal efficiency of 93 percent was seen at the end of 1-year of pilot-scale bioventing system operation. This was based on initial and 1-year sampling results for three locations within the treatment area (Table 7.3).

8.3.2.2 Technical and Administrative Implementability

Alternative 2 would require installation of three additional POA wells as described in Alternative 1. Four additional 4-inch diameter bioventing air injection wells were installed at Pumphouse #2 during the site investigation in 1994. These four wells and one other well from the previous pilot-scale bioventing test will be used for full-scale bioventing at Pumphouse #2.

An air injection blower would be installed at the site, and air lines would be trenched to each injection well. Electrical service is available at power poles on either side of Flightline Drive, and the new bioventing blower would be placed in a shed onsite. All equipment required for bioventing can be installed at Pumphouse #2 with a minimal degree of difficulty; however, installation of an air line to injection wells on the northwest side of Flightline Drive would require trenching of asphalt.

As with Alternative 1, additional drilling would be required for three new downgradient monitoring wells. These new POA wells and the existing groundwater monitoring well network would be used to for analytical calculation verification sampling and field screening for electron acceptors to document natural chemical attenuation.

The general reliability and maintainability of bioventing systems is high. These are simple mechanical systems. Motors are sealed and do not require lubrication. Air filters provide protection for the air pumps. Filters generally require replacement every 90 to 180 days. Weekly system checks are recommended, and operating data such as injection pressure and flow rate would be manually recorded. It is estimated that the system will be operational for 2 years to remediate the source area soils to the maximum extent possible.

Administrative implementation of this alternative is similar to Alternative 1 and would require that Malmstrom AFB personnel communicate with the public and MDEQ regarding the future use of the site (i.e., continued industrial zoning), with appropriate lease restrictions, be upheld to prevent unnecessary exposure of humans to contaminated groundwater and soil. Any future site development plans should protect the bioventing system, the underground piping associated with the system, and the network of long-term monitoring wells. Wells should remain locked and protected against damage.

The public perception of Alternative 2 is expected to be positive. This alternative would be protective of human health and the environment and could achieve contaminants reductions at a relatively low expense. Although bioventing is expected to more rapidly reduce BTEX concentrations in soils the source area, it would have minimum influence on the reduction of dissolved contamination at the site. There is no real advantage to Alternative 2 over Alternative 1 unless future land use requires more rapid BTEX reduction in source area soils. Because the site is expected to be vacant and zoned for industrial use, this situation may never arise. As with Alternative 1, public education would be a prominent part of this alternative and would focus on site-specific risk analysis and cost savings. No human risk related to surface activities will exist at the site once ditch sediments are removed and contaminant reductions that are compatible with existing and future land use would be achieved at minimum taxpayer expense. Consistent long-term monitoring would provide verification of natural chemical attenuation effectiveness and ensure that site conditions do not change over time.

8.3.2.3 Cost

The costs associated with Alternative 2 are presented in Table 8.2 Detailed cost calculations are presented in Appendix G. Capital costs include the cost of drilling and installation of additional wells, excavation and treatment of contaminated sediments, and installation of a bioventing injection blower and associated piping. Two years of bioventing operation and monitoring have been included as annual costs. Annual costs also would include groundwater monitoring and site management (provided by Malmstrom AFB), which would include public education and continued liaison with MDEQ and participation in future land use planning. Using these assumptions, the present worth cost of Alternative 2 is $218,731. As with Alternative 1, these costs are most sensitive to unexpected delays in attaining site closure. For example, if 5 years of bioventing and 15 years of long-term monitoring is required, the present-worth cost of this alternative would increase to $254,290.

TABLE 8.2

COST ESTIMATE FOR ALTERNATIVE 2

ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Tasks	Capital Costs
Drilling and installation of 3 POA wells	$ 8,400
Excavation and treatment of 24 cy of contaminated sediments	$ 12,500
Installation of fencing	$ 7,200
Installation of bioventing blower and piping	$ 31,690
Site Management and Monitoring Costs	**Annual Costs**
Conduct annual groundwater sampling at monitoring wells in accordance with the Long-Term Monitoring Plan (12 years)	$ 9,050
Public Education/Liaison (12 years) (assumes 160 man-hours/year)	$ 9,600
Operation, maintenance and monitoring of bioventing system (2 years)	$ 6,000
Present Worth of Alternative 2 [a/]	$218,730

[a/] Based on an annual inflation factor of 7 percent

8.4 CONSIDERATION OF ACTIVE GROUNDWATER TREATMENT

As detailed in Appendix G, several different active groundwater treatment technologies were considered for application at Pumphouse #2. None of the remedial technologies were retained after the screening process; therefore, active groundwater treatment is not part of any of the remedial alternatives proposed for Pumphouse #2. Active treatment systems were not carried through a more in-depth evaluation because discontinuous shallow hydrogeology at Pumphouse #2 would make all active treatment techniques ineffective. Perched groundwater is isolated in gravel and sand lenses and is migrating at a slow rate (approximately 22 feet per year). In some areas of the site, shallow groundwater was not encountered at all during site investigation activities. Because groundwater is discontinuous, a typical pump-and-treat system would not be effective in capturing groundwater at the site. Semipermeable reactive barrier walls or slurry walls also would not be effective due to the low groundwater velocity at the site. Finally, it is believed that a portion of the groundwater at the site is flowing through more permeable soils near utility corridors (i.e., bedding sand and backfill) paralleling Flightline Drive. Natural chemical attenuation is the only alternative for the treatment of this groundwater because utility interferences preclude effective utilization of any kind of intrusive remedial technology.

8.5 RECOMMENDED ALTERNATIVE

Alternative 1 (natural chemical attenuation, long-term monitoring, land and groundwater use controls, public education, and limited sediment excavation and *ex situ* treatment) is recommended for remediation of Pumphouse #2 based on its expected effectiveness in attaining a risk-based site closure, and eventually state-promulgated groundwater and soil standards; its relative simplicity with respect to technical and administrative implementation; and its low overall cost. Table 8.3 provides a summary of the evaluation process for each alternative.

Significant evidence exists that discontinuous hydrogeologic conditions at Pumphouse #2 will limit the migration of the dissolved contaminant plume. The plume is not expected to migrate downgradient from the source area. Despite the fact that Pumphouse #2 was an active fueling facility for many years, the dissolved plume has not migrated an appreciable distance downgradient of the source area at Pumphouse #2. Two wells approximately 60 feet downgradient from the source area did not have detectable concentrations of BTEX in 1994. The site should qualify for a risk-based closure in approximately 5 years when the natural chemical attenuation of contaminants at the site can be accurately quantified. Given the current and projected industrial land use at Pumphouse #2 and Malmstrom AFB in general, excavation of contaminated ditch sediments is the only active remediation required at the site to protect human health or the natural environment. Long-term groundwater monitoring will be used to verify natural chemical attenuation and plume containment to ensure that contaminants do not migrate beyond the POA or Base boundary. Limitations on groundwater pumping and land use at this site should not impose a restriction on future land use or operations. Sections 9 and 10 provide additional details on the recommended implementation of this alternative.

TABLE 8.3
SUMMARY OF REMEDIAL ALTERNATIVE EVALUATION
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1			$176,180
-Natural Chemical Attenuation -Long-Term Monitoring -Land and Groundwater Use Controls -Public Education -Sediment Excavation and *Ex Situ* Treatment	Contaminant mass, volume, and toxicity would gradually be reduced by natural chemical attenuation. Risk-based closure would be attained in approximately 5 years.	Technically simple and easy to implement. Long-term groundwater monitoring for 5 years is required. Land and groundwater use restrictions need to be implemented. These would not interfere with any current or future planned land use. Requires public education.	
Alternative 2			$218,730
-Natural Chemical Attenuation -Long-Term Monitoring -Land and Groundwater Use Controls -Public Education -Sediment Excavation and *Ex Situ* treatment -Source Area Bioventing	Similar to Alternative 1, with the addition of bioventing increase contaminant removal rates and degradation in source area soils. Risk-based closure would be attained in approximately 5 years. Pilot testing indicates bioventing would significantly remove BTEX compounds from unsaturated soils in 2 years.	Long-term groundwater monitoring for 5 years is expected. The bioventing system is expected to operate for 2 years. This system will require weekly monitoring. Groundwater and land use restrictions would be the same as Alternative 1. Neutral to slightly positive public perception. Requires public education	

SECTION 9

IMPLEMENTATION OF RECOMMENDED REMEDIAL ACTION

This section provides an implementation plan for the recommended remedial action Alternative 1 (natural chemical attenuation, long-term groundwater monitoring, land and groundwater use controls, public education, and limited sediment excavation and *ex situ* treatment) at Pumphouse #2. This section reviews the scope and schedule of remediation activities, discusses possible contingencies if this remedial approach does not prevent offsite migration of contaminants, and summarizes costs by fiscal year.

9.1 SCOPE OF REMEDIAL ACTIVITIES

The recommended remedial action alternative will be implemented over a 5-year period to ensure that Pumphouse #2 will obtain a risk-based closure approved by MDEQ. The following sequence of events is proposed to fully implement this remedial action.

9.1.1 Review and Approval of Engineering Evaluation/Cost Analysis

Approval of this EE/CA is within the authority Malmstrom AFB personnel, MDEQ, and AFCEE. This group of environmental professionals was responsible for review of the draft EE/CA and eventual implementation of the approved remedial actions. Draft copies of this document were distributed to each of the above organizations for review and comment.

Following the review period, a project presentation was provided by Parsons ES and AFCEE on 25 July 1996 at Malmstrom AFB. The purpose of this presentation was to describe the major findings of this risk-based remediation project, to answer any questions, and to receive feedback and discuss any unresolved issues that surfaced during document review. This direct interface between the document preparers and the group charged with EE/CA implementation was essential for final EE/CA preparation and a smooth transition into remedial actions. On 16 August 1996, Mr. Daryl Reed of MDEQ provided a letter to Mr. T. Dan Duff of Malmstrom AFB which approved the EE/CA document and general remedial recommendations.

9.1.2 Implementation of Long-Term Groundwater Monitoring

Section 10 of this EE/CA provides a complete long-term monitoring plan (LTMP) for Pumphouse #2. Long-term groundwater monitoring is essential for verification of natural chemical attenuation progress and confirmation that the local hydrogeology and natural biodegradation is retarding plume migration. Prior to implementation of long-

term monitoring, a total of 9 additional groundwater monitoring wells were installed at the site. Three of these wells were installed downgradient from Pumphouse #2 and will serve as POA wells. If groundwater contaminants attributable to activities at Pumphouse #2 are detected in these wells, contingency actions outlined in Section 9.3 would be implemented. Several of the original groundwater monitoring wells could not be located by Malmstrom AFB personnel in December 1995. These wells were either destroyed during UST removal or covered with backfill. Since these wells could not be located, they were replaced by Parsons ES and used to establish a new long-term monitoring baseline.

Careful implementation of the LTMP is a key component of this EE/CA. The proposed remedial alternative for this site calls for annual groundwater sampling at ten groundwater monitoring wells at the site. Wells will be purged in accordance with the SAP presented in Appendix H and then sampled for BTEX and electron acceptors. Details on annual sampling and analysis are discussed in the LTMP for Pumphouse #2 (Section 10). After three consecutive years of annual sampling indicate that the plume is not migrating and contaminant concentrations are decreasing, a petition will be filed with MDEQ for risk-based closure of the site. It is estimated that plume stability and contaminant degradation can be adequately documented in approximately 5 years. Because the calculations are conservative and the site hydrogeology is difficult to characterize, the actual time required for the plume to stabilize may be significantly less than predicted. Additional details for annual sampling can be found in the LTMP in Section 10 and the SAP in Appendix H.

Annual groundwater monitoring is recommended to begin upon approval of the EE/CA and LTMP. Annual monitoring is considered appropriate given the limited contaminant migration observed to date. Parsons ES completed the first annual sampling event in October of 1996 and the results have been incorporated into this report. Results of annual groundwater monitoring will be provided to Malmstrom AFB, MDEQ, and AFCEE to update all parties involved on remediation progress and to provide new information for pending land use decisions, as necessary.

9.1.3 Sediment Excavation or *In Situ* Bioventing

As discussed in Section 8.3.3.1, approximately 12 cy of contaminated sediments were recommended for removal from each side of Flightline Drive as part of the implementation of this activity. Due to the high density of underground utilities in the proposed excavation area, the Base and MDEQ have concluded that the excavation activities could result in a safety risk to workers, possible utility damage and that it will be difficult to remove all of the contaminated soil without reconstructing some of the utilities. On 18 October 1996, Mr. T. Dan Duff notified Parsons ES of the decision to delay soil excavation at the site. In light of this decision it is important that Malmstrom AFB insure that future utility excavations adjacent to Flightline Drive be completed using proper respiratory protection and ambient air monitoring to safeguard site workers.

In the event that excavation of contaminated soil is completed during future utility upgrades, the following procedure is recommended. Excavations should be centered

over the connections of fuel supply and return pipelines paralleling Flightline Drive and transfer lines running toward the former location of the pumphouse (one connection on each side of the street). Excavation of the soil should be performed with a backhoe wherever possible and with hand tools when required by underground utility interferences. It is anticipated that the excavations would be approximately 4 feet deep by 4 feet wide by 20 feet long. The actual total extents of the two excavations should be determined in the field based on field screening (i.e., headspace analysis) of grab samples collected from the sides and bottoms of the excavations. Excavation should continue until all apparent contamination has been removed (i.e., headspace reading of <200 ppm). If the extent of contamination is much greater than anticipated (i.e., more than 30 feet long or 4 feet deep), laboratory samples should be collected from the contaminated soils left in place. These samples should be analyzed for BTEX using EPA Method 8020 and screened to determine the risk resulting from leaving the contamination in place in the ditches. If remaining soil pose an unacceptable risk, more extensive excavation and treatment should be performed. After soil removal, the excavations should be backfilled with clean fill from elsewhere on Base or from an outside supplier. Excavated materials should be taken to an existing landfarm operating at Malmstrom AFB. Soil should be treated until it meets MDEQ soil standards, at which time it can be used as fill where appropriate.

Malmstrom AFB is also considering replacing the soil excavation option with a less intrusive bioventing system. Although bioventing would require a longer timeframe to achieve significant BTEX reductions (1-2 years), this system could be installed directly above the underground utilities with minimum risk to site workers or chance of utility damage. The bioventing option would be more costly (approx. $50,000 vs $12,500) and would require one to two years of operation and monitoring. The primary advantage of bioventing would be the relatively low risk of installation while still reducing soil BTEX levels, reducing future leaching to groundwater and total remediation time.

If a decision is made to pursue the *in situ* bioventing option, the Air Force will prepare a separate work plan describing this soil remedy in greater detail. Briefly, the system would consist of a 10- to 15-foot section of horizontal vent well screen placed on each side of Flightline Drive in the center of each contaminated soil area. Low rates of air injection would be used to stimulate aerobic biodegradation of fuel residuals. Additional details on bioventing performance at Pumphouse 2 are found in Section 7.

9.1.4 Verification of Current and Future Land and Groundwater Use Controls

An important element of the recommended remedial action at Pumphouse #2 is groundwater use controls. On the basis of the exposure pathway analysis (Section 5), the site will be acceptable for continued industrial use if contaminated sediments remain undisturbed. Any excavation in contaminated soils along Flightline Drive should be completed using proper respiratory protection and ambient air monitoring. It is assumed that future land use will not require extraction and ingestion of site groundwater. It is recommended that access to the site be restricted by installing a perimeter fence around the former location of the pumphouse and USTs. This action

will prohibit unauthorized site access and ground disturbance. Additionally, any future lease or new land use of this land must stipulate that shallow groundwater will not be extracted within 1,000 feet of the plume centerline until BTEX concentrations have been reduced below state groundwater quality standards. Excavation in the plume area also should only be performed by workers who have been briefed on the nature of onsite contamination and trained in proper use of personal protective equipment. These minor restrictions will eliminate potential exposure of onsite workers to contaminated soil and groundwater.

9.2 IMPLEMENTATION SCHEDULE

Figure 9.1 is a proposed schedule for implementation of the EE/CA at Pumphouse #2. It is important that annual groundwater monitoring be completed during September or October of each year to minimize sampling variability due to seasonal groundwater fluctuations.

9.3 CONTINGENCY PLAN

Should natural chemical attenuation and site hydrogeology fail to retard plume migration and the eventual achievement of risk-based closure at Pumphouse #2, there should be no impact on the land redevelopment plans for this area. No new land use has been proposed for Pumphouse #2 or the surrounding area. For the foreseeable future, Pumphouse #2 will continue to be vacant land zoned for industrial use. Groundwater extraction in this area is not anticipated so long as alternate water supplies exist. In the event that shallow groundwater from this site must be extracted for potable uses, and state groundwater standards have not yet been achieved, the following contingency actions are available:

- The results of the most recent groundwater sampling event will be evaluated to determine if there is a trend indicating that natural chemical attenuation is not proceeding at the rates predicted in Section 6.

- A risk analysis will be completed to determine if levels of groundwater contamination present an actual risk based on the intended use of the groundwater.

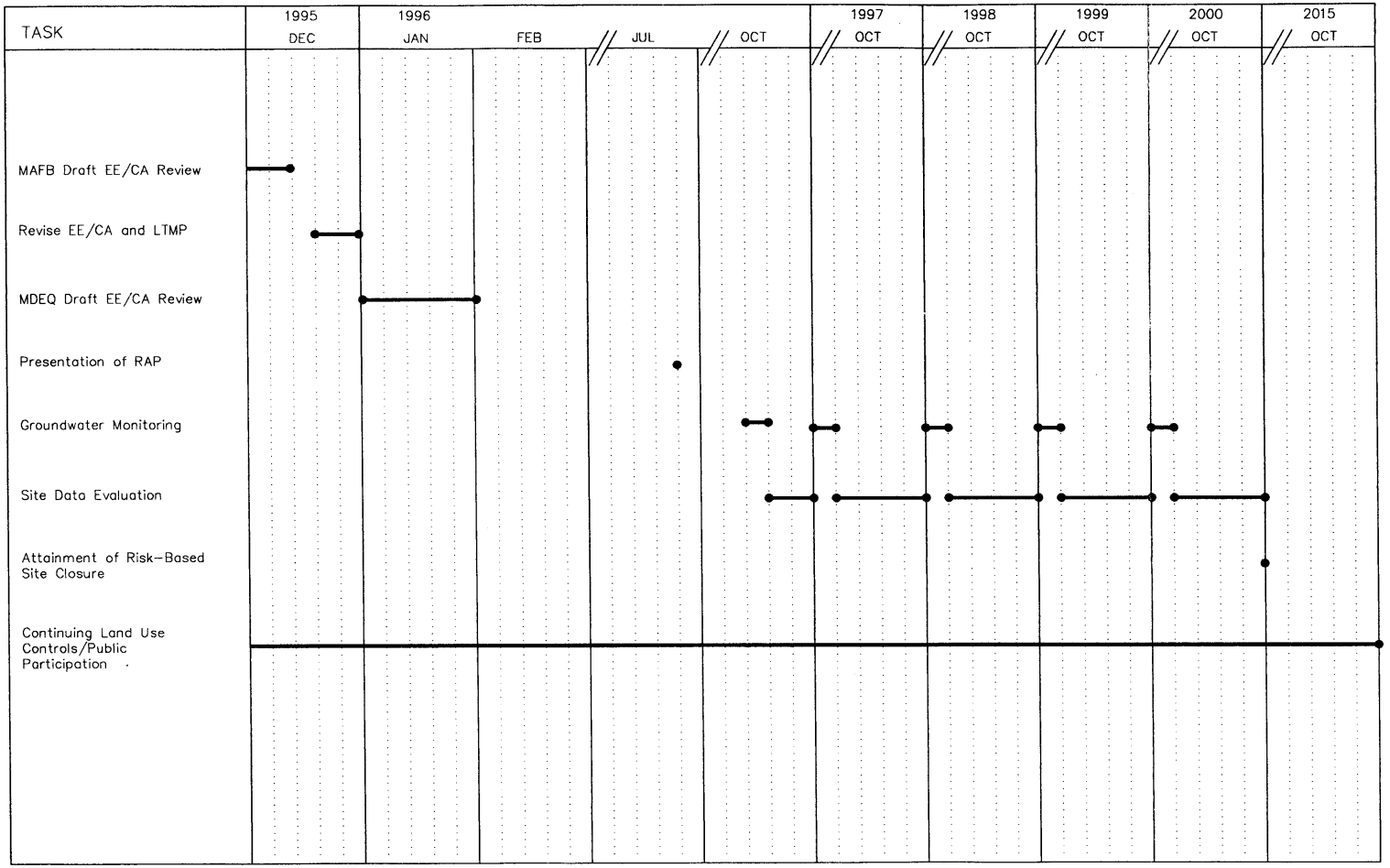
- If significant risk exists, more active methods of remediation will be evaluated. This could include possible initiation of point-of-use treatment systems, such as granular activated carbon (GAC) filtration, which could provide the most economical treatment of dilute contaminants.

Once again, failure of natural chemical attenuation of achieve risk-based closure will not impact the approved use of this area as an industrial area, unless groundwater must be extracted for long-term potable industrial uses or soils must be excavated.

Contingency plans also would be required if the plume begins to migrate toward the east-northeast at concentrations exceeding MDEQ cleanup criteria. A total of five POA wells have been installed downgradient from the site to verify that contaminants do not migrate further than predicted by the calculations presented in Section 6. Two of the

FIGURE 9.1

IMPLEMENTATION OF PROPOSED ACTIONS
LONG-TERM MONITORING PLAN
PUMPHOUSE #2, MALMSTROM AFB, MONTANA



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POA wells were installed by hand along the drainage ditches parallel to Flightline Drive. Since these sampling points were installed by hand, drilling costs are not included in Table 9.1. Because groundwater velocity at Pumphouse #2 is low, contaminants are not predicted to migrate to within approximately 0.5 mile of the nearest downgradient Base boundary. If COCs are detected in any of the POA wells, or annual groundwater sampling indicates a significant change in the direction of plume migration, the following contingency actions are available:

- All downgradient POA wells will be resampled to determine the extent of plume migration and to locate the center of highest plume concentrations.
- The results of the most recent groundwater sampling event will be evaluated to determine if there is a trend indicating that natural chemical attenuation is not proceeding at the rates predicted in Section 6 or that site hydrogeology is not adequately retarding the migration of contaminants.
- A risk analysis will be completed to determine if BTEX concentrations approaching the POA well present a risk based on the actual intended use of the groundwater.
- If significant risk exists, or if contaminant concentrations exceeding state groundwater cleanup criteria could migrate beyond the area of exposure control, more active methods of remediation will be evaluated.

9.4 COST OF IMPLEMENTATION

A summary of the estimated present-worth cost of implementing the recommended remedial alternative is provided in Section 8.3.1.3. Table 9.1 provides a cost estimate, based on expenditures during the next five fiscal years, to assist the Air Force in budgeting for Pumphouse #2 remedial actions. As discussed in Section 8.3.1.3, this cost estimate is most sensitive to the number of years assumed for long-term monitoring.

TABLE 9.1

ESTIMATED COST BY FISCAL YEAR[a/]

ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Task	FY97	FY98	FY99	FY00	FY01[d/]
Annual Groundwater Sampling[c/]	$9,050	$9,500	$9,970	$10,480	$11,000
Soil Excavation and Treatment	$12,500[b/]				
Drilling and Installation of Three POA Wells	$8,400[b/]				
Installation of Perimeter Fencing	$7,200				
Site Management (By MAFB)[c/] (160 hours/year)	$9,600	$10,080	$10,580	$11,120	$11,670
Fiscal Year Totals	$46,750	$19,580	$20,550	$21,600	$22,670

a/ Estimates for execution of 5 years of long-term monitoring.

b/ This activity has been delayed by a mutual agreement between Malmstrom AFB and MDEQ. If bioventing is used in lieu of soil excavation, the installation and first year of operation would be approximately $50,000.

c/ Assumes a 5 percent annual inflation rate.

d/ Total groundwater sampling costs for FY02 through FY08 = $80,000.
Total site management costs for FY02 through FY08 = $99,700.

SECTION 10

LONG-TERM MONITORING PLAN

10.1 OVERVIEW

In keeping with the requirements of the recommended remedial action for Pumphouse #2 (natural chemical attenuation, long-term monitoring [LTM], land and groundwater use controls, public education, and limited sediment excavation and *ex situ* treatment), a LTMP has been developed. This LTMP includes a proposed groundwater monitoring network, sampling and analysis strategies for groundwater, and an evaluation of land use controls. A schedule for implementation of the actions described in the plan is presented in Figure 9.1. The purpose of LTMP is to confirm the effectiveness of natural processes at reducing contaminant concentration, mass, mobility, and toxicity in affected media. This plan also will assess site conditions over time and the need for additional remediation.

As part of LTM, contaminant behavior in groundwater over time will be monitored to verify that the proposed remedial action is sufficient to protect human health and the environment. The areal extent of contamination will be monitored for increases in concentration and spatial distribution of contaminants during the course of the proposed remediation. In the event that data collected under this LTM program indicate that natural physical, chemical, and biological processes are insufficient to contain and reduce contaminants at Pumphouse #2, contingency actions will be implemented to augment the effects of the proposed remedial action.

10.2 GROUNDWATER MONITORING NETWORKS

A total of 10 wells will be used to monitor dissolved contaminant removal and migration at the site over time. These wells are located within, upgradient from, downgradient from, and at the leading edge of the dissolved contamination to ensure that natural chemical attenuation processes are occurring at rates sufficient to remove contaminant mass and minimize contaminant transport in groundwater. The locations of all wells to be used for long-term monitoring are illustrated in Figure 10.1.

Five POA groundwater monitoring wells (MW-6, MW-7, MW-13, MW-14, and MW-16) are located at varying distances downgradient from the existing leading edge of contamination (i.e., downgradient from any detected concentrations of BTEX). The POA wells will be used to delineate the maximum downgradient extent of groundwater contamination. Two of the wells were placed by hand in the drainage ditches downgradient from the site. These two monitoring wells will be used to detect and monitor any potential preferential flow along the utility corridors adjacent to the

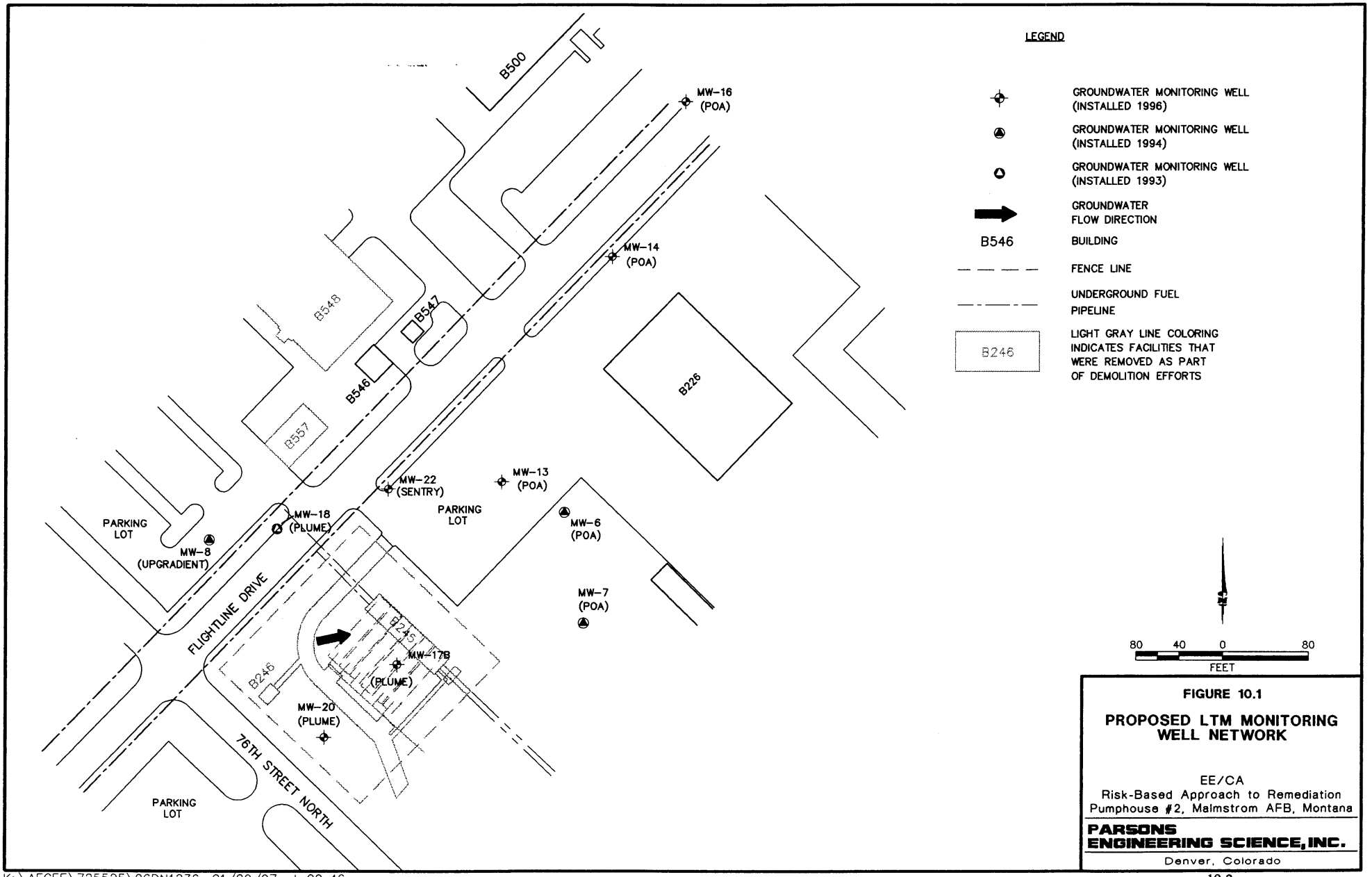


FIGURE 10.1

PROPOSED LTM MONITORING WELL NETWORK

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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ditches. According to an assessment of site hydrogeology and natural chemical attenuation occurring at the site, site-related contaminants should never be measured at concentrations exceeding state groundwater standards in the POA wells. This will demonstrate plume containment and stability to facilitate a risk-based closure at the site.

10.2.1 Upgradient and Plume Wells

One existing well (MW-8), which is upgradient from and outside the influence of the potential contaminant sources, will be monitored to evaluate background conditions. Three additional wells located within or at the lateral edge of the dissolved contaminant plume area will be monitored to evaluate the rates of contaminant removal as a result of natural chemical attenuation. Three of the plume wells (MW-17B, MW-18, and MW-20) are located in known source areas. Groundwater monitoring wells MW-10, MW-12 and MW-15 could not be located in October 1996; and were therefore replaced with wells MW-19, MW-21, and MW-20, respectively. Upgradient and plume wells will be sampled and analyzed for the parameters listed in Table 10.1 to verify the effectiveness of the proposed remedial action.

10.2.2 Sentry Well

One sentry well will be used to evaluate the migration of the leading edge of the dissolved contaminant plume. The sentry well (MW-22) is located in the leading edge of the contaminant plume. This well will be used to verify that natural chemical attenuation is reducing contaminant concentrations at the site. Future increases in contaminant concentrations in MW-22 would be indicative of contaminant migration from upgradient contaminant sources (i.e., pipeline junctions adjacent to Flightline Drive). Such increases in contaminant concentrations would result in the enactment of the contingency actions described in Section 9.3. The sentry well will be monitored for parameters listed in Table 10.2.

10.2.3 Point-of-Action Wells

Two existing wells (MW-6 and MW-7) and three new wells (MW-13, MW-14, and MW-16) were installed as POAs downgradient from the current contaminant plume. These wells also will be monitored to ensure that the contaminant plume is behaving according to conservative predictions. The POA wells will be monitored for parameters listed in Table 10.2. The detection of site-related contaminants at levels exceeding state groundwater quality standards at any of the POA wells will trigger the need to evaluate possible contingency actions. The exact scope of contingency actions will be established when concentrations of site-related contaminants exceeding groundwater standards appear in collected samples from any of the POA wells. These actions could include, but may not be limited to, the following:

- Additional investigation efforts to reevaluate results obtained during initial investigation activities;

TABLE 10.1

GROUNDWATER MONITORING ANALYTICAL PROTOCOL FOR UPGRADIENT, PLUME, AND SENTRY WELLS

ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site -Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Aromatic hydrocarbons (BTEX)	SW8020 (Gas Chromatography/ Mass Spectrometry method)	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	BTEX compounds (benzene, toluene, ethylbenzene, and total xylenes) have been identified as either groundwater COCs or compounds that can affect biodegradation of groundwater COCs	Annually	Collect water samples in a 40 milliliter volatile organic analysis vial with zero headspace; cool to 4°C; add hydrochloric acid to pH $\leq$2	See Table 2.1	See Table 2.1	Fixed-base
Redox potential	Direct-reading meter (Orion Model 290A with Orion Combination Redox 9678BN probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of ground water influences and is influenced by biologically mediated reactions: can be used as an indicator of the terminal electron acceptor process involved in COC biodegradation	Annually	Measure directly using a flow-through cell with probe portals. Probe should be standardized against Zobel solution	NA[a/]	0.0 pe units	Field
Dissolved oxygen	Direct-reading meter (YSI Model 50B with YSI 5739 probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Reduced concentrations of dissolved oxygen indicate that microorganisms are facilitating oxygen reduction to biodegrade COCs	Annually	Measure directly using flow-through cell with probe portals. Probe should be calibrated with zero dissolved oxygen solution	NA	0.5 mg/L	Field
Manganese (Mn^{+2})	Colorimetric HACH 8034	Field only	Elevated concentrations of reduced forms of manganese indicate that microorganisms are facilitating manganese reduction to biodegrade COCs	Annually	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	0.01 mg/L	0.05 mg/L	Field

TABLE 10.1 (Continued)

GROUNDWATER MONITORING ANALYTICAL PROTOCOL FOR UPGRADIENT, PLUME, AND SENTRY WELLS

ENGINEERING EVALUATION\COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site -Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Ferrous iron (Fe^{2+})	Colorimetric HACH 8146	Field only	Elevated ferrous iron concentrations indicate that microorganisms are facilitating ferric iron reduction to biodegrade COCs	Annually	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	0.01 mg/L	0.024 mg/L	Field
Sulfate (SO_4^{2-})	Colorimetric HACH 8051	Field only	Reduced concentrations of sulfate indicate that microorganisms are facilitating sulfate reduction to biodegrade COCs	Annually	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	0.01 mg/L	0.01 mg/L	Field
pH	Direct-reading meter (Orion Model 140)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Aerobic and anaerobic processes are pH-sensitive	Annually	Measure directly using a contained flow-through cell with probe portals. Probe should be calibrated using at least three pH standards	NA	0.00 pH units	Field
Temperature	Direct-reading meter	Field only	Metabolism rates for microorganisms depend on temperature	Annually	Measure directly using a contained flow-through cell with probe portals	NA	1.0 °C	Field
Conductivity	Direct-reading meter (Orion Model 140 with Conductivity Cell 014050)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	General water quality parameter used as a marker to verify that site samples are obtained from the same ground water system	Annually	Measure directly using a contained flow-through cell with probe portals. Probe is factory calibrated	NA	0.02 µmhos/cm	Field

[a] NA = not applicable

TABLE 10.2

GROUNDWATER MONITORING ANALYTICAL PROTOCOL FOR POINT-OF-ACTION WELLS

ENGINEERING EVALUATION\COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site-Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Aromatic hydrocarbons (BTEX)	SW8020 (Gas Chromatography/ Mass Spectrometry method SW8020	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	BTEX compounds have been identified as groundwater COCs or compounds of interest which may affect COC degradation	Annually	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤2	See Table 2.1	See Table 2.1	Fixed-base
Redox potential	Direct-reading meter (Orion Model 290A with Orion Combination Redox 9678BN probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of ground water influences and is influenced by biologically mediated reactions: can be used as an indicator of the terminal electron acceptor process involved in COC biodegradation	Annually	Measure directly using a flow-through cell with probe portals. Probe should be standardized against Zobel solution	NA[a/]	0.0 pe units	Field
Dissolved oxygen	Direct-reading meter (YSI Model 50B with YSI 5739 probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Reduced concentrations of dissolved oxygen indicate that microorganisms are facilitating oxygen reduction to biodegrade COCs	Annually	Measure directly using flow-through cell with probe portals. Probe should be calibrated with zero dissolved oxygen solution	NA	0.5 mg/L	Field
pH	Direct-reading meter (Orion Model 140)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Aerobic and anaerobic processes are pH-sensitive	Annually	Measure directly using a contained flow-through cell with probe portals. Probe should be calibrated using at least three pH standards	NA	0.00 pH units	Field

TABLE 10.2 (Concluded)

GROUNDWATER MONITORING ANALYTICAL PROTOCOL FOR POINT-OF-ACTION WELLS

ENGINEERING EVALUATION\COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site-Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Temperature	Direct-reading meter	Field only	Metabolism rates for microorganisms depend on temperature	Annually	Measure directly using a contained flow-through cell with probe portals	NA	1.0 °C	Field
Conductivity	Direct-reading meter (Orion Model 140 with Conductivity Cell 014050)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	General water quality parameter used as a marker to verify that site samples are obtained from the same ground water system	Annually	Measure directly using a contained flow-through cell with probe portals. Probe is factory calibrated	NA	0.02 µmhos/cm	Field

NA = not applicable

- Additional investigation efforts to reevaluate results obtained during initial investigation activities;

- Reevaluation of model results to determine if concentrations of contaminants that may pose a risk to human health or the environment have the potential to migrate beyond Base boundaries (approximately 0.5 mile downgradient from the leading edge current plume location); and

- Additional engineering evaluations to determine if more aggressive remedial efforts, such as groundwater interceptor trenches and groundwater treatment, are necessary and/or feasible.

10.2.4 Point-of-Compliance Wells

Due to the extreme distance (0.5 mile) between the leading edge of the current plume and the Base boundary, the slow groundwater velocity (22 feet per year), no point-of-compliance wells, per the legal definition, have been identified or proposed for LTM at this time.

10.3 GROUNDWATER SAMPLING

This LTMP includes a comprehensive groundwater SAP. The LTMP, when implemented in accordance with the SAP, will verify that contaminant concentrations above promulgated state groundwater standards are not migrating downgradient of any of the POA wells. The SAP for all sampling related to this LTMP is provided in Appendix H. POA wells will be sampled and analyzed periodically as described in Table 10.2 to verify that natural processes are effectively reducing contaminant concentrations, mass, mobility, and toxicity. Reductions in COC toxicity will be implied by concentration and mass reduction (e.g., as COCs are biodegraded to less toxic compounds such as carbon dioxide and water).

10.3.1 Implementation Requirements

All LTM groundwater monitoring wells will be sampled and analyzed in accordance with Tables 10.1 and 10.2, respectively, to determine progress toward and compliance with the proposed chemical-specific cleanup criteria for Pumphouse #2. All samples will be collected in accordance with the SAP presented in Appendix H. Additionally, QA/QC samples and procedures will be implemented as described in the SAP and the QAPP presented, respectively, in Appendices H and I.

10.3.2 Sampling Frequency

Each of the groundwater sampling points will be sampled annually. Sampling results will be evaluated after each event to document contaminant stability and reduction. After 3 years of sampling indicate contaminant stability and reduction, MDEQ will be petitioned for risk-based closure. The sampling frequency and duration will be reevaluated based on previous sampling results. If the sampling results contradict the calculated predictions (i.e., the plume is migrating more rapidly or contaminant reduction is not taking place), monitoring of all 10 wells in the LTM

network will continue until the site is demonstrated to be eligible for a risk-based closure or until contingency remedial actions are considered.

10.4 SUBSURFACE SOIL SAMPLING

No confirmatory subsurface soil sampling is currently prescribed for Pumphouse #2. Excavation and removal of the most contaminated soil near Flightline Drive is intended to remove all soils which are known to exceed SSTLs. At this time, the Base and MDEQ have agreed that excavation restrictions will be used to eliminate any risks associated with soils. No excavation is planned due to the risk of damaging underground utilities. Data from the 1995 UST removal, the 1994 risk-based site investigation, and the 1993 RFI investigation has been reviewed to determine if SSTLs are exceeded by subsurface soils at the site. Approximately 120 sample results from various locations and depths were available for this review. Based on this extensive soil sampling, only a narrow strip of soil on both sides of Flightline Drive contains BTEX concentrations in excess of SSTLs.

10.5 LAND USE CONTROLS VERIFICATION

Long-term site management responsibilities will include verification that any future land uses are consistent with the planned industrial use of the site. The monitoring program specified herein is designed to document plume stability and eventual contaminant mass removal. These data will be used to confirm that there is no need for additional exposure controls downgradient from Pumphouse #2 to minimize potential human health risks and unacceptable environmental impacts. At the former location of the pumphouse and in the immediate vicinity, land use controls should put in place that strictly limit excavation. Any excavation, particularly along Flightline Drive should be completed using proper respiratory protection and ambient air monitoring. This action will eliminate unacceptable onsite worker exposure to site related contaminants in shallow soil and groundwater. Any changes in activities conducted in areas impacted by Pumphouse #2 contamination will be documented.

Any future uses of the site should preclude use of impacted shallow groundwater as a source of potable water until such time that state groundwater standards have been attained at every monitoring point. In addition to future site use reviews, interim confirmation of land and groundwater use controls are proposed to include documenting the land zoning, types of potential onsite receptors, and the kinds of activities in which these potential receptors may engage at the site. For example, this EE/CA recommends that extensive soil excavation in the Pumphouse #2 area should be restricted to prevent worker contact with contaminated soil and groundwater. This confirmation step will be formally documented when the results of site annual analytical sampling events are prepared for review and assessment. Any significant changes in land use will be identified, and any modification of the recommended remedial alternative that may be required to protect human health and the environment will be identified and proposed for review and implementation, as necessary.

REFERENCES

Abdul, S.A., Gibson, T.L., and Rai, D.N. 1987. Statistical correlations for predicting the partition coefficient for nonpolar organic contaminants between aquifer organic carbon and water: *Hazardous Waste and Hazardous Materials*, vol. 4, no. 3, p. 211-222.

Altenschmidt, U. and Fuchs, G. 1991. Anaerobic degradation of toluene in denitrifying *Pseudomonas* sp.: Indication for toluene methylhydroxylation and benzoyl-CoA as central aromatic intermediate: *Arch. Microbial.*, vol. 156, p. 152-158.

Alvarez, P.J.J., and Vogel, T.M. 1991. Substrate interactions of benzene, toluene, and para-xylene during microbial degradation by pure cultures and mixed culture aquifer slurries: *Applied and Environmental Microbiology*, vol. 57, p. 2981-2985.

Atlas, R.M. 1981. Microbial degradation of petroleum hydrocarbons - an environmental perspective: *Microbiological Reviews*, vol. 45, no. 1, p. 180-209.

Atlas, R.M. 1984. *Petroleum Microbiology*: Macmillan Publishing Company, New York.

Atlas, R.M. 1988. *Microbiology - Fundamentals and Applications*: Macmillan Publishing Company, New York.

Arthur D. Little, Inc., 1987. The Installation Restoration Program Toxicology Guide. Volume 3. Prepared for Air Force Sytems Command, Wright-Patterson Air Force Base, Ohio, June 1987.

Baedecker, M.J., Siegel, D.I., Bennett, P.C., Cozzarelli, I.M. 1988. The fate and effects of crude oil in a shallow aquifer: I. The distribution of chemical species and geochemical facies, In: G.E. Mallard, and SE. Ragone, editors, U.S. Geological Survey Toxic Substances Hydrology Program, *Proceedings of the Technical Meeting,* Phoenix, Arizona, September 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-42320, p. 29-22.

Baedecker, M.J., and Cozzarelli, I.M. 1991. Geochemical modeling of organic degradation reactions in an Aquifer contaminated with Crude Oil: U.S. Geological Survey Water-Resources Investigations Report 91-4034. Reston, VA. p 627-632.

Bartha, R. 1986. Biotechnology of petroleum pollutant biodegradation: *Microbial Ecology*, vol. 12, p. 155-172.

Battelle, Columbus Division. 1988. Installation Restoration Program, Phase II, Confirmation/Quantification, Stage 1. November.

Bauman, B. 1991. Biodegradation research of the American Petroleum Institute. Presented at: *In Situ* Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation. San Diego, CA. March 19-21, 1991.

Beller, H.R. Reinhard, M., and Grbic-Galic, D. 1992. Metabolic byproducts of anaerobic toluene degradation by sulfate-reducing enrichment cultures: *Appl. Environ. Microbiol.*, vol. 58, p. 3192-3195.

Bohon, R.L., and Claussen, W.F. 1951. The solubility of aromatic hydrocarbons in water: *Journal of American Chemical Society*, vol. 73, no. 4, p.1571-1578.

Borden, R.C. 1991. Simulation of enhanced in situ biorestoration of petroleum hydrocarbons. In: *In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation. Eds.*, R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 529-534.

Borden, R.C. 1994. Natural Bioremediation of Hydrocarbon-Contaminated Ground Water: In: *Handbook of Bioremediation.* Lewis Publishers. Boca Raton, FL.

Borden, Robert C., Gomez, Carlos A., and Becker, Mark T. 1995. Geochemical indicators of intrinsic bioremediation. *Ground Water*, vol. 33, no. 2, p. 180-189.

Bouwer, E.J. 1992. Bioremediation of Subsurface Contaminants, In: Mitchell, R., ed.: *Environmental Microbiology.* Wiley-Liss, New York, New York.

Bouwer, E.J. 1994. Bioremediation of chlorinated solvents using alternate electron acceptors: In: *Handbook of Bioremediation.* Lewis Publishers. Boca Raton, FL.

Brown, R.A., Dey, J.C. and McFarland, W.E. 1991a. Integrated site remediation combining groundwater treatment, soil vapor extraction, and bioremediation, In: *In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation.* Eds., R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 444-449.

Brown, R.A., et al. 1991b. The use of aeration in environmental cleanups, Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection, and Restoration, Houston, Texas. p. 265-279.

Chapelle, F.H. 1993. *Ground-water Microbiology and Geochemistry.* John Wiley and Sons, Inc., New York, NY.

Chiang, C.Y., Salanitro, H.P., Chai, E.Y., Colthart, H.D., and Klein, C.L. 1989. Aerobic biodegradation of benzene, toluene, and xylene in a sandy aquifer - data analysis and computer modeling: *Ground Water*, vol. 27, no. 6, p. 823-834.

Davis, J.W., Klier, N.J., and Carpenter. 1994. Natural biological attenuation of benzene in ground water beneath a manufacturing facility: Ground Water, vol. 32, no. 2, p. 215-226.

Downey, D.C., and Hall, J.F. 1994. *Addendum One to Test Plan and Technical Protocol for a Field Treatability Test for Bioventing - Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential.* Prepared for the Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas.

Edwards, E.A., and Grbic-Galic, D. 1992. Complete mineralization of benzene by aquifer microorganisms under strictly anaerobic conditions: *Appl. Environ. Microbiol.*, vol. 58, p. 2663-2666.

Engineering-Science, Inc. 1993. Bioventing Pilot Test Final Report for PS-3 and PS-4, Malmstrom AFB, Montana. Prepared for the U.S. Air Force Center for Environmental Excellence. December.

Engineering-Science, Inc. 1994a. *Draft Work Plan for an Engineering Evaluation/Cost Analysis in Support of the Risk-Based Approach to Remediation at Pumphouse #2.* Prepared for Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas and Malmstrom Air Force Base, Great Falls, Montana. August.

Engineering-Science, Inc. 1994b. *Draft Intrinsic Remediation Engineering Evaluation/Cost Analysis for UST Site 870.* Prepared for Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas and Hill Air Force Base, Ogden, Utah. September.

Engineering-Science, Inc. 1994c. *Draft Intrinsic Remediation Engineering Evaluation/Cost Analysis for UST Site ST-29.* Prepared for Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas and Patrick Air Force Base, Florida. September.

Gibson, D.T., and Subramanian, V. 1984. Microbial degradation of aromatic hydrocarbons, In: *Microbial Degradation of Organic Compounds*, Ed., D.T. Gibson, Marcel Dekker, Inc., p. 181-252.

Godsy, E.M. 1994. Microbiological and geochemical degradation processes, In: *Symposium on Intrinsic Bioremediation in Ground Water.* Denver, CO. August 30 - September 1, 1994, p.35-40.

Grbic-Galic, D. 1989. Microbial degradation of homocyclic and heterocyclic aromatic hydrocarbons under conditions: *Dev. Ind. Microbiol.*, vol. 30, p. 237-253.

Grbic-Galic, D. 1990. Anaerobic microbial transformation of nonoxygenated aromatic and alicyclic compounds in soil, subsurface, and freshwater sediments, In: Bollag, J.M., and Stotzky, G., eds.: *Soil Biochemistry*: Marcel Dekker, Inc., New York, NY. p. 117-189.

Haag, F., Reinhard, M., and McCarty, P.L. 1991. Degradation of toluene and p-xylene in an anaerobic microcosms: Evidence for sulfate as a terminal electron acceptor: *Environ. Toxicol. Chem.*, vol. 10, p. 1379-1389.

HDR Engineering, Inc. 1994. Draft RCRA Facility Investigation Report, Malmstrom AFB, Montana. Prepared for U.S. Army Corps of Engineers, Missouri River Division, Omaha District, Omaha, Nebraska, Contract No. DACA45-92-C-0139. April.

Higgins, I.J., and Gilbert, P.D. 1978. The biodegradation of hydrocarbons, In: K.W.A. Chator and H.J. Somerville, editors, The Oil Industry and Microbial Ecosystems: Heyden and Sons, London, p. 80-114.

Hinchee, R.E., Ong, S.K., Miller, R.N., Downey, D.C., and Frandt, R. 1992. *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing.* Prepared for the Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas. January.

Howard, P.H. 1990. *Handbook of Environmental Fate and Exposure Data for Organic Chemicals*, Vol. II: Solvents. Lewis Publishers, Inc. Chelsea, Michigan. 546 pp.

Hutchins, S.R., and Wilson, J.T. 1991. Laboratory and field studies on BTEX biodegradation in a fuel-contaminated aquifer under denitrifying conditions, In: *In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation.* Eds. R.E. Hinchee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 157-172.

Isnard, S., and Lambert, S. 1988. Estimating bioconcentration factors from octanol-water partition coefficient and aqueous solubility: *Chemosphere*, vol. 17, no. 1, p. 21-34.

Jobson, A.F., Cook, F.D., and Westlake, D.W. 1972. Microbial utilization of crude oil. *Applied and Environmental Microbiology*, vol. 23, p. 1082-1089.

Johnson, P. 1994. Performance monitoring and pilot testing of in situ air sparging systems, Proceedings of the Third AFCEE Environmental Restoration Technology Transfer Symposium, San Antonio, Texas.

Johnson, R.L. 1993. Enhancing biodegradation with in situ air sparging: a conceptual model, In *Air Sparging for Site Remediation* (Robert E. Hichee, ed.), Lewis Publishers.

JRB Associates. 1985. Installation Restoration Program, Phase I-Records Search. January.

Leahy, J.G., and Colwell, R.R. 1990. Microbial degradation of hydrocarbons in the environment: *Microbiolgical Reviews*, vol. 53, no. 3, p. 305-315.

Lee, M.D. 1988. *Biorestoration of Aquifers Contaminated with Organic Compounds: CRC Critical Reviews in Environmental Control.* vol. 18. p. 29-89.

Litchfield, J.H., and Clark, L.C. 1973. Bacterial Activities in Ground Waters Containing Petroleum Products. American Petroleum Institute. Pub. No. 4211.

Lovley, D.R., and Phillips, E.J.P. 1988. Novel mode of microbial energy metabolism: organic carbon oxidation coupled to dissimilatory reduction of iron or manganese. *Applied and Environmental Microbiology*, vol. 56, no. 6, p. 1472-1480.

Lovley, D.R., Phillips, E.J.P., and Lonergan, D.J. 1991. Enzymatic versus noenzymatic mechanisms for Fe(III) reduction in aquatic sediments. *Environmental Science and Technology*, vol. 26, no. 6, p. 1062-1067.

Lovley, Derek R., Chapelle, Francis H., and Woodward, Joan C. 1994. Use of dissolved H_2 concentrations to determine distribution of microbially catalyzed redox reactions in anoxic groundwater. *Environmental Science and Technology*, vol. 28, no. 7, p. 1205-1210.

Lyman, W.J., Reehl, W.F., and Rosenblatt, T.A. 1992. *Handbook of Chemical Property Estimation Methods Environmental Behavior of Organic Compounds*. McGraw-Hill, Inc., New York, NY.

Mackay, D., and Shiu, W.Y. 1981. A critical review of Henry's Law Constants for chemicals of environmental interest: *Journal of Physical Chemistry* Reference Data, vol. 10, no. 4, p. 1175-1199.

Malmstrom Air Force Base. 1992. Base Commander's Summary.

Malone, D.R., Kao, C.M., and Borden, R.C. 1993. Dissolution and biorestoration of nonaqueous phase hydrocarbons - models development and laboratory evaluation: *Water Resources Research*, vol. 29, no. 7, p. 2003-2213.

Marley, M.C., Walsh, M.T., and Nangeroni, P.E. 1990. Case study on the application of air sparging as a complimentary technology to vapor extraction at a gasoline spill site in Rhode Island, Proceedings of HMRCI's 11th Annual National Conference and Exhibition, Washington, DC, p. 636-640.

Martel. 1987. Military Jet Fuels 1944-1987: AF Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio.

McAllister, Paul M., and Chiang, Chen Y. 1994. A practical approach to evaluating natural attenuation of contaminants in ground water. Presented at the USEPA Symposium on Intrinsic Bioremediation of Ground Water, Denver, CO.

MCS Environmental. 1995. Tank Closure Report, Fuel Tanks, Malmstrom AFB, Great Falls, Montana. September.

Micromedix, Inc. 1995. *Toxicology, Occupational Medicine and Environmental Series (Tomes) Plus Database*, Vol. 17. Denver, Colorado.

Montana Department of Health and Environmental Sciences (MDHES). 1994. *Clean-up Guidelines for Petroleum Releases Under the Montana Underground Storage Tank Program*. April.

Mueller, J.G., Chapman, P.J., Blattman, B.O., and Pritchard, P.H. 1990. Isolation and characterization of a fluoranthene-utilizing strain of Pseduomonas paucimobilis. *Applied and Environmental Microbiology*, vol. 56, p. 1079-1086.

Parker, K.S., R.C. Sims, and R.R. Dupont. 1990. Transformation of PAHs in soil systems, *Journal of Environmental Engineering*, Vol. 116, No. 3, pp. 632-640.

Parsons Engineering Science, Inc. 1994a. *Draft Intrinsic Remediation Engineering Evaluation/Cost Analysis for the Site FT-002.* Prepared for Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas and Plattsburgh Air Force Base, New York. November.

Parsons Engineering Science, Inc. 1994b. *Draft Intrinsic Remediation Engineering Evaluation/Cost Analysis for Site ST-41.* Prepared for Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas and Elmendorf Air Force Base, Alaska. November.

Parsons Engineering Science, Inc. 1995a. *Draft Remedial Action Option Evaluation in Support of Intrinsic Remediation for the Jet Fuel Transfer Line Southwest of Building 412 and the POL Yard.* Prepared for Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas and Wisconsin Air National Guard at Truax Field, Madison, Wisconsin. February.

Parsons Engineering Science, Inc. 1995b. *Draft Remedial Action Plan for the Risk-Based Remediation of the KC-135 Crash Site.* Prepared for Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas and Wurtsmith Air Force Base, Michigan. March.

Parsons Engineering Science, Inc. 1995c. *Draft Remedial Action Plan for the Risk-Based Remediation of Area D.* Prepared for Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks Air Force Base, San Antonio, Texas and Ellsworth Air Force Base, South Dakota. July.

Perry, J.J. 1977. Microbial metabolism of cyclic hydrocarbons and related compounds, *Critical Reviews in Microbiology*, vol., 5, p. 387-412.

Reinhard, M. 1994. In-Situ Bioremediation Technologies for Petroleum-Derived Hydrocarbons Based on Alternate Electron Acceptors (Other Than Molecular Oxygen), In: *Handbook of Bioremediation.* Lewis Publishers, Boca Raton, FL. 1994.

Reinhard, M., Goodman, N.L., and Barker, J.F. 1984. Occurrence and distribution of organic chemicals in two landfill leachate plumes: *Environ. Sci. Technol.*, vol. 18, no. 12, p. 953-961.

Salanitro, J.P. 1993. "The Role of Bioattenuation in the Management of Aromatic Hydrocarbon Plumes in Aquifers." *Ground Water Monitoring and Remediation*, Vol. 13, pp. 150-161.

Science Applications International Corporation (SAIC). 1991. Installation Restoration Program, Stage 2, Remedial Investigation/Feasibility Study Report. July.

Stieber, M., K. Böckle, P. Werner, and F.H. Frimmel. 1990. "Biodegradation of Polycyclic Aromatic Hydrocarbons (PAH) in the Subsurface." In F. Arend, M. Hinseveld, and W. J. Van den Brink (Eds.), *Contaminated Soil 1990*, pp. 473-479. Kluwer Academic Publishers, Netherlands.

Stumm, W. and Morgan, J.J. 1981. *Aquatic Chemistry*. John Wiley & Sons, New York, NY.

Thierrin, J., Davis, G.B., Barber, C., Patterson, B.M., Pribac, F., Power, T.R., and Lambert, M. 1992. Natural degradation rates of BTEX compounds and napthalene in a sulfate reducing ground water environment, In: *In-Situ* Bioremediation Symposium '92". Niagara-on-the-Lake, Ontario, Canada. September 20-24, 1992: In Press.

US Environmental Protection Agency (EPA). 1986. *Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber.* User's Guide Prepared by M.R. Klenbusch under EPA Contract No. 68-02-3889.

US Environmental Protection Agency. 1987. *A compendium of Superfund Field Operations Methods.* Office of Emergency and Remedial Response. EPA/540/P-87/001. (OSWER Directive 9355.0-14)

US Environmental Protection Agency. 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies (RI/FS) Under CERCLA.* OSWER Directive 9355.3-01.

US Environmental Protection Agency. 1989a. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A),* Interim Final, Publication EPA 540/1-89/002.

US Environmental Protection Agency. 1989b. *Risk Assessment Guidance for Superfund, Volume II, Environmental Evaluation Manual.* Interim Final, Office of Emergency and Remedial Response, Publication EPA 540/1-89/001.

US Environmental Protection Agency. 1991a. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals),* Interim, Publication 9285.7-01B.

US Environmental Protection Agency. 1991b. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives),* Interim Final, Publication 9285.7-01C.

US Environmental Protection Agency. 1991c. *Human Health Evaluation Manual, Supplemental Guidance: "Standard Default Exposure Factors."* Office of Solid Waste and Emergency Response Directive 9285.6-03.

US Environmental Protection Agency. 1992. *Guidelines for Exposure Assessment*; Notice, Federal Register, Vol. 57, No. 104 (Friday, May 29, 1992).

US Environmental Protection Agency. 1994a. *Soil Screening Guidance.* Office of Solid Waste and Emergency Response. Publication EPA/540/R-94/101.

US Environmental Protection Agency. 1994b. *The Hydrocarbon Spill Screening Model (HSSM) Volume 1: User's Guide.* Robert S. Kerr Environmental Research Laboratory. Ada, Oklahoma. April. Publicabtion EPA/600/R-94/039a.

Verschueren, K. 1983. *Handbook of Environmental Data on Organic Chemicals.* Van Nostrand Reinhold Co., New York, New York.

Weidemeier, T.H., Downey, D.C., Wilson, J.T., Kampbell, D.H., Miller, R.N., and Hansen, J.E. 1995. *Technical Protocol for Implementing the Intrinsic Remediation (Natural Attenuation) with Long-term Monitoring Option for Dissolved-phase Fuel Contamination in Ground Water.* Prepared by the Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas.

Wilson, B.H., Smith, G.B., and Rees, J.F. 1986. Biotransformations of Selected Alkylbenzenes and Halogenated Aliphatic Hydrocarbons in Methanogenic Aquifer Material: A Microcosm Study: *Environmental Science and Technology*, 20(10):997-1002.

Wilson, B.H., Bledsoe, B., and Kampbell, D. 1987. Biological processes occurring at an aviation gasoline spill site, In: R.C. Averett and D.M. McKnight editors, *Chemical Quality of Water and the Hydrologic Cycle.* Lewis Publishers, Chelsea, Michigan, p.125-137.

Wilson, B.H., Wilson, J.T., Kampbell, D.H., Bledsoe, B.E., and Armstrong, J.M. 1990. Biotransformation of Monoaromatic and Chlorinated Hydrocarbons at an Aviation Gasoline Spill Site: *Geomicrobiology Journal*, 8:225-240.

Woodward-Clyde Consultants. 1992. RCRA Facility Investigation Final Work Plan.

Young, L.Y. 1984. Anaerobic degradation of aromatic compounds, In: Gibson, D.R., ed.: *Microbial Degradation of Aromatic Compounds.* Marcel-Dekker, New York.

Zobell, C.E. 1946. Action of microorganisms on hydrocarbons: *Bacterial Review.* vol. 10, p. 1-49.

APPENDIX A

SAMPLE ANALYTICAL RESULTS

TABLE A.1
VALIDATED SOIL DATA FOR VOLATILE ORGANIC COMPOUNDS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-1	4-Nov-94	6.50 - 7.50	Benzene	0.52 U	µg/kg	SW8020
			Toluene	20	µg/kg	SW8020
			Ethylbenzene	5.2 U	µg/kg	SW8020
			Xylenes (Total)	2.6 J	µg/kg	SW8020
			1,3,5-Trimethylbenzene	5.2 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	5.2 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	5.2 U	µg/kg	SW8020
MW-2	4-Nov-94	5.50 - 6.50	Total Extractable Hydrocarbons	38 J	mg/kg	M8015
			Total Volatile Hydrocarbons	0.3 J	mg/kg	M8015
			Benzene	0.51 U	µg/kg	SW8020
			Toluene	19	µg/kg	SW8020
			Ethylbenzene	3.4 J	µg/kg	SW8020
			Xylenes (Total)	10	µg/kg	SW8020
			1,3,5-Trimethylbenzene	2.8 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	5.1	µg/kg	SW8020
			1,2,3-Trimethylbenzene	5.1 U	µg/kg	SW8020
MW-3	4-Nov-94	5.50 - 6.50	Benzene	63 U	µg/kg	SW8020
			Toluene	2,000	µg/kg	SW8020
			Ethylbenzene	9,100	µg/kg	SW8020
			Xylenes (Total)	16,000	µg/kg	SW8020
			1,3,5-Trimethylbenzene	12,000	µg/kg	SW8020
			1,2,4-Trimethylbenzene	18,000	µg/kg	SW8020
			1,2,3-Trimethylbenzene	5,200	µg/kg	SW8020
MW-3	4-Nov-94	8.50 - 9.50	Benzene	0.48 U	µg/kg	SW8020
			Toluene	4.8 U	µg/kg	SW8020
			Ethylbenzene	2.1 J	µg/kg	SW8020
			Xylenes (Total)	3.6 J	µg/kg	SW8020
			1,3,5-Trimethylbenzene	1.3 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	1.4 J	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.8 U	µg/kg	SW8020
MW-4	5-Nov-94	3.50 - 4.50	Benzene	0.5 J	µg/kg	SW8020
			Toluene	36	µg/kg	SW8020
			Ethylbenzene	0.6 J	µg/kg	SW8020
			Xylenes (Total)	3.2 J	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.8 U	µg/kg	SW8020

TABLE A.1
VALIDATED SOIL DATA FOR VOLATILE ORGANIC COMPOUNDS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-5	5-Nov-94	4.50 - 5.50	Benzene	2.1 J	µg/kg	SW8020
			Toluene	49	µg/kg	SW8020
			Ethylbenzene	0.7 J	µg/kg	SW8020
			Xylenes (Total)	2.9 J	µg/kg	SW8020
			1,3,5-Trimethylbenzene	5.3 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	5.3 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	5.3 U	µg/kg	SW8020
MW-6	5-Nov-94	3.50 - 4.50	Benzene	0.51 U	µg/kg	SW8020
			Toluene	6.8	µg/kg	SW8020
			Ethylbenzene	5.1 U	µg/kg	SW8020
			Xylenes (Total)	5.1 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	5.1 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	5.1 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	5.1 U	µg/kg	SW8020
MW-7	5-Nov-94	4.50 - 5.50	Total Extractable Hydrocarbons	12 U	mg/kg	M8015
			Total Volatile Hydrocarbons	0.12 U	mg/kg	M8015
			Benzene	0.48 U	µg/kg	SW8020
			Toluene	4.8 U	µg/kg	SW8020
			Ethylbenzene	4.8 U	µg/kg	SW8020
			Xylenes (Total)	4.8 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.8 U	µg/kg	SW8020
MW-8	9-Nov-94	4.50 - 5.50	Benzene	0.49 U	µg/kg	SW8020
			Toluene	4.9 U	µg/kg	SW8020
			Ethylbenzene	4.9 U	µg/kg	SW8020
			Xylenes (Total)	4.9 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.9 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.9 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.9 U	µg/kg	SW8020
MW-9	9-Nov-94	4.50 - 5.50	Total Extractable Hydrocarbons	12 U	mg/kg	M8015
			Total Volatile Hydrocarbons	0.6 J	mg/kg	M8015
			Benzene	1.4 J	µg/kg	SW8020
			Toluene	13	µg/kg	SW8020
			Ethylbenzene	0.7 J	µg/kg	SW8020
			Xylenes (Total)	4.8 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.8 U	µg/kg	SW8020

TABLE A.1
VALIDATED SOIL DATA FOR VOLATILE ORGANIC COMPOUNDS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-11	9-Nov-94	3.00 - 4.00	Benzene	0.47 U	µg/kg	SW8020
			Toluene	4.7 U	µg/kg	SW8020
			Ethylbenzene	4.7 U	µg/kg	SW8020
			Xylenes (Total)	4.7 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.7 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.7 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.7 U	µg/kg	SW8020
MW-12	10-Nov-94	4.50 - 5.50	Total Extractable Hydrocarbons	36 J	mg/kg	M8015
			Total Volatile Hydrocarbons	53	mg/kg	M8015
MW-12	10-Nov-94	6.00 - 7.00	Benzene	2.6 U	µg/kg	SW8020
			Toluene	7.1 J	µg/kg	SW8020
			Ethylbenzene	13 J	µg/kg	SW8020
			Xylenes (Total)	31	µg/kg	SW8020
			1,3,5-Trimethylbenzene	31	µg/kg	SW8020
			1,2,4-Trimethylbenzene	28	µg/kg	SW8020
			1,2,3-Trimethylbenzene	42	µg/kg	SW8020
MW-12	10-Nov-94	9.00 - 10.00	Benzene	0.47 U	µg/kg	SW8020
			Toluene	4.7 U	µg/kg	SW8020
			Ethylbenzene	4.7 U	µg/kg	SW8020
			Xylenes (Total)	4.7 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.7 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.7 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.7 U	µg/kg	SW8020
SB-1	22-Oct-94	4.50 - 5.50	Benzene	0.52 U	µg/kg	SW8020
			Toluene	1.4 J	µg/kg	SW8020
			Ethylbenzene	5.2 U	µg/kg	SW8020
			Xylenes (Total)	5.2 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	5.2 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	5.2 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	5.2 U	µg/kg	SW8020
SB-2	23-Oct-94	1.50 - 2.50	Benzene	0.48 U	µg/kg	SW8020
			Toluene	4.8 U	µg/kg	SW8020
			Ethylbenzene	4.8 U	µg/kg	SW8020
			Xylenes (Total)	4.8 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	0.8 J	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.8 U	µg/kg	SW8020

TABLE A.1
VALIDATED SOIL DATA FOR VOLATILE ORGANIC COMPOUNDS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
SB-2	23-Oct-94	3.50 - 4.50	Benzene	0.47 U	µg/kg	SW8020
			Toluene	4.7 U	µg/kg	SW8020
			Ethylbenzene	4.7 U	µg/kg	SW8020
			Xylenes (Total)	4.7 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	0.5 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	0.8 J	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.7 U	µg/kg	SW8020
BS	10-Nov-94	4.50 - 5.50	Benzene	0.5 U	µg/kg	SW8020
			Toluene	5 U	µg/kg	SW8020
			Ethylbenzene	1 J	µg/kg	SW8020
			Xylenes (Total)	4.2 J	µg/kg	SW8020
			1,3,5-Trimethylbenzene	1.5 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	3.1 J	µg/kg	SW8020
			1,2,3-Trimethylbenzene	5 U	µg/kg	SW8020
SB-23	24-Oct-96	0 - 0.25	Total Volatile Hydrocarbons	0.1 U	mg/kg	M8015
			Benzene	0.5 U	µg/kg	SW8020
			Toluene	0.5 U	µg/kg	SW8020
			Ethylbenzene	0.5 U	µg/kg	SW8020
			Xylenes (Total)	0.5 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	0.5 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	11	µg/kg	SW8020
			1,2,3-Trimethylbenzene	0.5 U	µg/kg	SW8020
SB-23	24-Oct-96	2 - 2.25	Total Volatile Hydrocarbons	1,700	mg/kg	M8015
			Benzene	247 U	µg/kg	SW8020
			Toluene	5,600	µg/kg	SW8020
			Ethylbenzene	10,000	µg/kg	SW8020
			Xylenes (Total)	38,000	µg/kg	SW8020
			1,3,5-Trimethylbenzene	19,000	µg/kg	SW8020
			1,2,4-Trimethylbenzene	37,000	µg/kg	SW8020
			1,2,3-Trimethylbenzene	28,000	µg/kg	SW8020
SB-24	24-Oct-96	0 - 0.25	Total Volatile Hydrocarbons	8.3	mg/kg	M8015
			Benzene	0.5 U	µg/kg	SW8020
			Toluene	1.7	µg/kg	SW8020
			Ethylbenzene	23	µg/kg	SW8020
			Xylenes (Total)	120	µg/kg	SW8020
			1,3,5-Trimethylbenzene	88	µg/kg	SW8020
			1,2,4-Trimethylbenzene	120	µg/kg	SW8020
			1,2,3-Trimethylbenzene	150 E	µg/kg	SW8020

TABLE A.1
VALIDATED SOIL DATA FOR VOLATILE ORGANIC COMPOUNDS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
SB-24	24-Oct-96	2 - 2.25	Total Volatile Hydrocarbons	1,500	mg/kg	M8015
			Benzene	258 U	µg/kg	SW8020
			Toluene	2,700	µg/kg	SW8020
			Ethylbenzene	5,400	µg/kg	SW8020
			Xylenes (Total)	20,000	µg/kg	SW8020
			1,3,5-Trimethylbenzene	14,000	µg/kg	SW8020
			1,2,4-Trimethylbenzene	22,000	µg/kg	SW8020
			1,2,3-Trimethylbenzene	25,000	µg/kg	SW8020
SB-25	24-Oct-96	0 - 0.25	Total Volatile Hydrocarbons	0.1 U	mg/kg	M8015
			Benzene	0.5 U	µg/kg	SW8020
			Toluene	0.5 U	µg/kg	SW8020
			Ethylbenzene	0.5 U	µg/kg	SW8020
			Xylenes (Total)	0.5 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	0.5 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	0.5 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	0.5 U	µg/kg	SW8020
SB-25	24-Oct-96	2 - 2.25	Total Volatile Hydrocarbons	0.1 U	mg/kg	M8015
			Benzene	2.6 U	µg/kg	SW8020
			Toluene	2.6 U	µg/kg	SW8020
			Ethylbenzene	13	µg/kg	SW8020
			Xylenes (Total)	39	µg/kg	SW8020
			1,3,5-Trimethylbenzene	32	µg/kg	SW8020
			1,2,4-Trimethylbenzene	60	µg/kg	SW8020
			1,2,3-Trimethylbenzene	2.6 U	µg/kg	SW8020
SB-26	24-Oct-96	0 - 0.25	Total Volatile Hydrocarbons	0.1 U	mg/kg	M8015
			Benzene	0.5 U	µg/kg	SW8020
			Toluene	0.5 U	µg/kg	SW8020
			Ethylbenzene	0.5 U	µg/kg	SW8020
			Xylenes (Total)	0.5 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	0.5 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	0.5 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	0.5 U	µg/kg	SW8020
SB-26	24-Oct-96	2 - 2.25	Total Volatile Hydrocarbons	2.6	mg/kg	M8015
			Benzene	2.6 U	µg/kg	SW8020
			Toluene	2.6 U	µg/kg	SW8020
			Ethylbenzene	13	µg/kg	SW8020
			Xylenes (Total)	39	µg/kg	SW8020
			1,3,5-Trimethylbenzene	32	µg/kg	SW8020
			1,2,4-Trimethylbenzene	60	µg/kg	SW8020
			1,2,3-Trimethylbenzene	2.6 U	µg/kg	SW8020

TABLE A.2
VALIDATED SOIL DATA FOR OTHER ANALYSIS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-9	9-Nov-94	2.50 - 3.50	Moisture, Percent	18.2	%	%MOIST
MW-9	9-Nov-94	5.50 - 6.50	Total Organic Carbon	0.42 J	%	E415.1
			pH	9.44	pH units	SW9045
MW-11	9-Nov-94	4.50 - 5.50	Moisture, Percent	16.4	%	%MOIST
			Total Organic Carbon	0.65	%	E415.1
			pH	9.38	pH units	SW9045
MW-12	10-Nov-94	1.50 - 2.50	Moisture, Percent	20.7	%	%MOIST
MW-12	10-Nov-94	4.50 - 5.50	Total Organic Carbon	0.24 J	%	E415.1
			pH	8.86	pH units	SW9045

TABLE A.3
VALIDATED SOIL GAS DATA
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
SG-1	21-Oct-94	3.00 - 3.50	Benzene	0.007 U	µg/L	TO3
			Toluene	0.027 J	µg/L	TO3
			Ethylbenzene	0.022 J	µg/L	TO3
			Xylenes (Total)	0.066 J	µg/L	TO3
			Petroleum Hydrocarbons	4.4	µg/L	TO3
SG-2	21-Oct-94	3.00 - 3.50	Benzene	0.011 U	µg/L	TO3
			Toluene	0.36	µg/L	TO3
			Ethylbenzene	0.22	µg/L	TO3
			Xylenes (Total)	0.44	µg/L	TO3
			Petroleum Hydrocarbons	42	µg/L	TO3
SG-3	21-Oct-94	3.00 - 3.50	Benzene	0.32	µg/L	TO3
			Toluene	0.27	µg/L	TO3
			Ethylbenzene	0.62	µg/L	TO3
			Xylenes (Total)	2.1	µg/L	TO3
			Petroleum Hydrocarbons	340	µg/L	TO3
SG-4	21-Oct-94	3.00 - 3.50	Benzene	290	µg/L	TO3
			Toluene	2.1 U	µg/L	TO3
			Ethylbenzene	110	µg/L	TO3
			Xylenes (Total)	410	µg/L	TO3
			Petroleum Hydrocarbons	120000	µg/L	TO3
SG-5	21-Oct-94	3.00 - 3.50	Benzene	0.94	µg/L	TO3
			Toluene	0.028 U	µg/L	TO3
			Ethylbenzene	2	µg/L	TO3
			Xylenes (Total)	8.4	µg/L	TO3
			Petroleum Hydrocarbons	580	µg/L	TO3

TABLE A.4
VALIDATED SOIL FLUX DATA
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
FLUX-1	16-Nov-94	0.00 - 0.00	Benzene	0.007 U	µg/L	TO3
			Toluene	0.008 U	µg/L	TO3
			Ethylbenzene	0.01 U	µg/L	TO3
			Xylenes (Total)	0.018 J	µg/L	TO3
			Petroleum Hydrocarbons	0.14 U	µg/L	TO3
FLUX-2	16-Nov-94	0.00 - 0.00	Benzene	0.007 U	µg/L	TO3
			Toluene	0.008 J	µg/L	TO3
			Ethylbenzene	0.01 U	µg/L	TO3
			Xylenes (Total)	0.079 J	µg/L	TO3
			Petroleum Hydrocarbons	0.14 U	µg/L	TO3
FLUX-3	16-Nov-94	0.00 - 0.00	Benzene	0.007 U	µg/L	TO3
			Toluene	0.019 J	µg/L	TO3
			Ethylbenzene	0.013 J	µg/L	TO3
			Xylenes (Total)	0.097 J	µg/L	TO3
			Petroleum Hydrocarbons	0.15 U	µg/L	TO3
FLUX-4	16-Nov-94	0.00 - 0.00	Benzene	0.007 U	µg/L	TO3
			Toluene	0.011 J	µg/L	TO3
			Ethylbenzene	0.009 J	µg/L	TO3
			Xylenes (Total)	0.088 J	µg/L	TO3
			Petroleum Hydrocarbons	0.39 J	µg/L	TO3
FLUX-5	16-Nov-94	0.00 - 0.00	Benzene	0.007 U	µg/L	TO3
			Toluene	0.008 J	µg/L	TO3
			Ethylbenzene	0.01 U	µg/L	TO3
			Xylenes (Total)	0.018 J	µg/L	TO3
			Petroleum Hydrocarbons	0.018 J	µg/L	TO3

TABLE A.5
FLUX CALCULATIONS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

ANALYTE	MEAS. CONC. mg/L		AREA m^2	FLOWRATE L/min	Erate(uncor.) mg/min m^2	temp(c)	temp(a)	C factor	Erate mg/min m^2	Remarks
FLUX 1										
benzene	0.007	0	0.164	5	0.213414634	5.9	5.8	1.013084867	0.21620714	MDL USED TO CALC. EMISSIONS
toluene	0.008	0	0.164	5	0.243902439				0.24709387	MDL USED TO CALC. EMISSIONS
ethylbenzene	0.01	0	0.164	5	0.304878049				0.30886734	MDL USED TO CALC. EMISSIONS
xylenes	0.018	1	0.164	5	0.548780488				0.55596121	ANALYTE DETECTED
tph	0.14	0	0.164	5	4.268292683				4.32414273	MDL USED TO CALC. EMISSIONS
FLUX 2										
benzene	0.007	0	0.164	5	0.213414634	6.3	5.9	1.053375743	0.2248058	MDL USED TO CALC. EMISSIONS
toluene	0.008	1	0.164	5	0.243902439				0.25692091	ANALYTE DETECTED
ethylbenzene	0.01	0	0.164	5	0.304878049				0.32115114	MDL USED TO CALC. EMISSIONS
xylenes	0.079	1	0.164	5	2.408536585				2.53709401	ANALYTE DETECTED
tph	0.14	0	0.164	5	4.268292683				4.49611597	MDL USED TO CALC. EMISSIONS
FLUX 3										
benzene	0.007	0	0.164	5	0.213414634	7.3	6.8	1.067159024	0.22774735	MDL USED TO CALC. EMISSIONS
toluene	0.019	1	0.164	5	0.579268293				0.61817139	ANALYTE DETECTED
ethylbenzene	0.013	1	0.164	5	0.396341463				0.42295937	ANALYTE DETECTED
xylenes	0.097	1	0.164	5	2.957317073				3.1559276	ANALYTE DETECTED
tph	0.15	0	0.164	5	4.573170732				4.88030042	MDL USED TO CALC. EMISSIONS
FLUX 4										
benzene	0.007	0	0.164	5	0.213414634	6.4	6	1.053375743	0.2248058	MDL USED TO CALC. EMISSIONS
toluene	0.011	1	0.164	5	0.335365854				0.35326626	ANALYTE DETECTED
ethylbenzene	0.009	1	0.164	5	0.274390244				0.28903603	ANALYTE DETECTED
xylenes	0.088	1	0.164	5	2.682926829				2.82613004	ANALYTE DETECTED
tph	0.39	1	0.164	5	11.8902439				12.5248945	ANALYTE DETECTED

TABLE A.5
FLUX CALCULATIONS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

ANALYTE	MEAS. CONC. mg/L		AREA m^2	FLOWRATE L/min	Erate(uncor.) mg/min m^2	temp(c)	temp(a)	C factor	Erate mg/min m^2	Remarks
FLUX 5										
benzene	0.007	0	0.164	5	0.213414634	6.6	6.2	1.053375743	0.2248058	MDL USED TO CALC. EMISSIONS
toluene	0.008	1	0.164	5	0.243902439				0.25692091	ANALYTE DETECTED
ethylbenzene	0.01	0	0.164	5	0.304878049				0.32115114	MDL USED TO CALC. EMISSIONS
xylenes	0.018	1	0.164	5	0.548780488				0.57807205	ANALYTE DETECTED
tph	0.18	1	0.164	5	5.487804878				5.78072054	ANALYTE DETECTED

TABLE A.6
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
NOVEMBER 1994
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-2	12-Nov-94	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	0.7 J	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	0.5 J	µg/L	E602
			1,2,4-Trimethylbenzene	1.9 J	µg/L	E602
			1,2,3-Trimethylbenzene	1.2 J	µg/L	E602
MW-3	17-Mar-95	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	1.9 J	µg/L	E602
			Ethylbenzene	0.9 J	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	3.2 J	µg/L	E602
			1,2,3-Trimethylbenzene	3.8 J	µg/L	E602
			1,2,3,4-Tetramethylbenzene	11	µg/L	E602
			Chlorobenzene	4 U	µg/L	E602
MW-4	11-Nov-94	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
			Total Extractable Hydrocarbons	0.5 U	mg/L	M8015
			Total Volatile Hydrocarbons	0.1 U	mg/L	M8015
MW-5	14-Nov-94	0.00 - 0.00	Benzene	1.4	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	0.9 J	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
MW-6	12-Nov-94	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602

TABLE A.6
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
NOVEMBER 1994
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-7	11-Nov-94	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
MW-8	17-Mar-95	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	4 U	µg/L	E602
			Chlorobenzene	4 U	µg/L	E602
MW-9	15-Nov-94	0.00 - 0.00	Benzene	2 J	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	0.4 J	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
MW-9	17-Mar-95	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	4 U	µg/L	E602
			Chlorobenzene	4 U	µg/L	E602
MW-10	14-Nov-94	0.00 - 0.00	Benzene	1 J	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	1.9 J	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	1.6 J	µg/L	E602
			1,2,4-Trimethylbenzene	3.3 J	µg/L	E602
			1,2,3-Trimethylbenzene	0.8 J	µg/L	E602
			Total Extractable Hydrocarbons	2.1 J	mg/L	M8015
			Total Volatile Hydrocarbons	0.4 J	mg/L	M8015

TABLE A.6
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
NOVEMBER 1994
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-11	17-Mar-95	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	4 U	µg/L	E602
			Chlorobenzene	4 U	µg/L	E602
MW-12	13-Nov-94	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	0.7 J	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	0.7 J	µg/L	E602
			1,2,4-Trimethylbenzene	1.6 J	µg/L	E602
			1,2,3-Trimethylbenzene	0.7 J	µg/L	E602
			Total Extractable Hydrocarbons	0.5 U	mg/L	M8015
			Total Volatile Hydrocarbons	0.1 U	mg/L	M8015
MW-12	17-Mar-95	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	0.8 J	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	0.6 J	µg/L	E602
			Chlorobenzene	4 U	µg/L	E602
MW-15	14-Nov-94	0.00 - 0.00	Benzene	160	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	50	µg/L	E602
			Xylenes (Total)	270	µg/L	E602
			1,3,5-Trimethylbenzene	34	µg/L	E602
			1,2,4-Trimethylbenzene	28	µg/L	E602
			1,2,3-Trimethylbenzene	41	µg/L	E602
MW-18	15-Nov-94	0.00 - 0.00	Benzene	680	µg/L	E602
			Toluene	18 J	µg/L	E602
			Ethylbenzene	710	µg/L	E602
			Xylenes (Total)	4200	µg/L	E602
			1,3,5-Trimethylbenzene	290	µg/L	E602
			1,2,4-Trimethylbenzene	760	µg/L	E602
			1,2,3-Trimethylbenzene	440	µg/L	E602
			Total Extractable Hydrocarbons	8.1	mg/L	M8015
			Total Volatile Hydrocarbons	23	mg/L	M8015

TABLE A.6
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
NOVEMBER 1994
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
GW-2	5-Nov-94	0.00 - 0.00	Benzene	53	µg/L	E602
			Toluene	95	µg/L	E602
			Ethylbenzene	105	µg/L	E602
			Xylenes (Total)	330	µg/L	E602
			1,3,5-Trimethylbenzene	50	µg/L	E602
			1,2,4-Trimethylbenzene	100	µg/L	E602
			1,2,3-Trimethylbenzene	75	µg/L	E602
GW-6	10-Nov-94	0.00 - 0.00	Benzene	490	µg/L	E602
			Toluene	20 J	µg/L	E602
			Ethylbenzene	580	µg/L	E602
			Xylenes (Total)	2500	µg/L	E602
			1,3,5-Trimethylbenzene	470	µg/L	E602
			1,2,4-Trimethylbenzene	1300	µg/L	E602
			1,2,3-Trimethylbenzene	670	µg/L	E602
SB-1	22-Oct-94	7.00 - 7.50	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
SB-2	23-Oct-94	6.00 - 6.50	Benzene	0.4 U	µg/L	E602
			Toluene	5.4	µg/L	E602
			Ethylbenzene	1.3 J	µg/L	E602
			Xylenes (Total)	7.7	µg/L	E602
			1,3,5-Trimethylbenzene	5.6	µg/L	E602
			1,2,4-Trimethylbenzene	8.5	µg/L	E602
			1,2,3-Trimethylbenzene	1.5 J	µg/L	E602
VW	13-Nov-94	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602

TABLE A.7
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
OCTOBER 1996
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-6	15-Oct-96	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	0.4 U	µg/L	E602
			Xylenes (Total)	0.4 U	µg/L	E602
			1,3,5-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,4-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	0.5 U	µg/L	E602
			Total Volatile Hydrocarbons	0.1 U	mg/L	M8015
MW-7	18-Oct-96	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	0.4 U	µg/L	E602
			Xylenes (Total)	0.4 U	µg/L	E602
			1,3,5-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,4-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	0.5 U	µg/L	E602
			Total Volatile Hydrocarbons	0.1 U	mg/L	M8015
MW-8	15-Oct-96	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	0.4 U	µg/L	E602
			Xylenes (Total)	0.4 U	µg/L	E602
			1,3,5-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,4-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	0.5 U	µg/L	E602
			Total Volatile Hydrocarbons	0.1 U	mg/L	M8015
MW-13	15-Oct-96	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	0.4 U	µg/L	E602
			Xylenes (Total)	0.4 U	µg/L	E602
			1,3,5-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,4-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	0.5 U	µg/L	E602
			Total Volatile Hydrocarbons	0.1 U	mg/L	M8015

TABLE A.7
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
OCTOBER 1996
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-14	15-Oct-96	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	0.4 U	µg/L	E602
			Xylenes (Total)	0.4 U	µg/L	E602
			1,3,5-Trimethylbenzene	1.1	µg/L	E602
			1,2,4-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	0.5 U	µg/L	E602
			Total Volatile Hydrocarbons	0.5	mg/L	M8015
MW-16	15-Oct-96	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	0.4 U	µg/L	E602
			Xylenes (Total)	0.4 U	µg/L	E602
			1,3,5-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,4-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	0.5 U	µg/L	E602
			Total Volatile Hydrocarbons	0.1 U	mg/L	M8015
MW-17A	15-Oct-96	0.00 - 0.00	Benzene	0.4	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	0.4 U	µg/L	E602
			Xylenes (Total)	0.4 U	µg/L	E602
			1,3,5-Trimethylbenzene	2.5	µg/L	E602
			1,2,4-Trimethylbenzene	1.5	µg/L	E602
			1,2,3-Trimethylbenzene	3.2	µg/L	E602
			1,2,3,4-Tetramethylbenzene	15	µg/L	E602
			Total Volatile Hydrocarbons	0.1	mg/L	M8015
MW-17B	15-Oct-96	0.00 - 0.00	Benzene	47	µg/L	E602
			Toluene	10	µg/L	E602
			Ethylbenzene	20	µg/L	E602
			Xylenes (Total)	330	µg/L	E602
			1,3,5-Trimethylbenzene	120	µg/L	E602
			1,2,4-Trimethylbenzene	120	µg/L	E602
			1,2,3-Trimethylbenzene	380	µg/L	E602
			1,2,3,4-Tetramethylbenzene	210	µg/L	E602
			Total Volatile Hydrocarbons	2.7	mg/L	M8015

TABLE A.7
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
OCTOBER 1996
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-18	15-Oct-96	0.00 - 0.00	Benzene	430	µg/L	E602
			Toluene	28	µg/L	E602
			Ethylbenzene	920	µg/L	E602
			Xylenes (Total)	4100	µg/L	E602
			1,3,5-Trimethylbenzene	190	µg/L	E602
			1,2,4-Trimethylbenzene	790	µg/L	E602
			1,2,3-Trimethylbenzene	530	µg/L	E602
			1,2,3,4-Tetramethylbenzene	120	µg/L	E602
			Total Volatile Hydrocarbons	18	mg/L	M8015
MW-19	23-Dec-96	0.00-0.00	Benzene	0.4 U	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	0.4 U	µg/L	E602
			Xylenes (Total)	0.4 U	µg/L	E602
			1,3,5-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,4-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	0.5 U	µg/L	E602
			Total Volatile Hydrocarbons	0.1 U	mg/L	M8015
MW-20	15-Oct-96	0.00 - 0.00	Benzene	180	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	300	µg/L	E602
			Xylenes (Total)	1900	µg/L	E602
			1,3,5-Trimethylbenzene	10 U	µg/L	E602
			1,2,4-Trimethylbenzene	120	µg/L	E602
			1,2,3-Trimethylbenzene	110	µg/L	E602
			1,2,3,4-Tetramethylbenzene	12.5 U	µg/L	E602
			Total Volatile Hydrocarbons	5.5	mg/L	M8015
MW-21	15-Oct-96	0.00 - 0.00	Benzene	0.4 U	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	0.4 U	µg/L	E602
			Xylenes (Total)	0.4 U	µg/L	E602
			1,3,5-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,4-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,3,4-Tetramethylbenzene	0.5 U	µg/L	E602
			Total Volatile Hydrocarbons	0.1 U	mg/L	M8015

TABLE A.7
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
OCTOBER 1996
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-22	15-Oct-96	0.00 - 0.00	Benzene	1.5	µg/L	E602
			Toluene	0.4 U	µg/L	E602
			Ethylbenzene	140	µg/L	E602
			Xylenes (Total)	280	µg/L	E602
			1,3,5-Trimethylbenzene	0.4 U	µg/L	E602
			1,2,4-Trimethylbenzene	290	µg/L	E602
			1,2,3-Trimethylbenzene	120	µg/L	E602
			1,2,3,4-Tetramethylbenzene	90	µg/L	E602
			Total Volatile Hydrocarbons	4	mg/L	M8015

TABLE A.8
VALIDATED GROUNDWATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-4	11-Nov-94	0.00 - 0.00	Naphthalene	10 U	µg/L	SW8270
MW-6MW-6	12-Nov-94	0.00 - 0.00	Naphthalene	10 U	µg/L	SW8270
MW-12	13-Nov-94	0.00 - 0.00	Naphthalene	10 U	µg/L	SW8270
MW-15	14-Nov-94	0.00 - 0.00	Naphthalene	10 U	µg/L	SW8270
VW	13-Nov-94	0.00 - 0.00	Naphthalene	10 U	µg/L	SW8270

TABLE A.9
VALIDATED GROUNDWATER DATA FOR
ELECTRON ACCEPTORS
NOVEMBER 1994
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-2	12-Nov-94	0.00 - 0.00	Dissolved Oxygen	4.6	mg/L	FDO
			Nitrate	6.2	mg/L	H8039
			Nitrite	0.006	mg/L	H8507
			Manganese	2.4	mg/L	H8149
			Sulfate	4129	mg/L	H8051
			Sulfide	0.01 U	mg/L	H2238
			Hydrogen Sulfide	0.024 U	mg/L	H8131
			Iron, Total	0.01 J	mg/L	H8008
			Iron, Ferrous	0.01 J	mg/L	H8146
			Carbon Dioxide	100	mg/L	H8223
MW-4	11-Nov-94	0.00 - 0.00	Dissolved Oxygen	7.4	mg/L	FDO
			Nitrate	2.6	mg/L	H8039
			Nitrite	0.005 U	mg/L	H8507
			Manganese	0.3	mg/L	H8149
			Sulfate	1332	mg/L	H8051
			Sulfide	0.01 U	mg/L	H2238
			Hydrogen Sulfide	0.024 U	mg/L	H8131
			Iron, Total	0.01 J	mg/L	H8008
			Iron, Ferrous	0.01 J	mg/L	H8146
			Carbon Dioxide	105	mg/L	H8223
MW-6	12-Nov-94	0.00 - 0.00	Dissolved Oxygen	4.2	mg/L	FDO
			Nitrate	1.8	mg/L	H8039
			Nitrite	0.005 U	mg/L	H8507
			Manganese	0.05 U	mg/L	H8149
			Sulfate	267	mg/L	H8051
			Sulfide	0.01 U	mg/L	H2238
			Hydrogen Sulfide	0.024 U	mg/L	H8131
			Iron, Total	0.024 U	mg/L	H8008
			Iron, Ferrous	0.024 U	mg/L	H8146
			Carbon Dioxide	80	mg/L	H8223
MW-7	11-Nov-94	0.00 - 0.00	Dissolved Oxygen	4.14	mg/L	FDO
			Nitrate	2.1	mg/L	H8039
			Nitrite	0.001 J	mg/L	H8507
			Manganese	0.2	mg/L	H8149
			Sulfate	1711	mg/L	H8051
			Sulfide	0.01 U	mg/L	H2238
			Hydrogen Sulfide	0.024 U	mg/L	H8131
			Iron, Total	0.024 U	mg/L	H8008
			Iron, Ferrous	0.024 U	mg/L	H8146
			Carbon Dioxide	100	mg/L	H8223

TABLE A.9
VALIDATED GROUNDWATER DATA FOR
ELECTRON ACCEPTORS
NOVEMBER 1994
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-9	15-Nov-94	0.00 - 0.00	Nitrate	1.4	mg/L	H8039
			Nitrite	0.046	mg/L	H8507
			Manganese	0.6	mg/L	H8149
			Sulfate	4383	mg/L	H8051
			Sulfide	0.01 U	mg/L	H2238
			Hydrogen Sulfide	0.024 U	mg/L	H8131
			Iron, Total	0.024 U	mg/L	H8008
			Iron, Ferrous	0.03	mg/L	H8146
			Carbon Dioxide	190	mg/L	H8223
MW-10	13-Nov-94	0.00 - 0.00	Dissolved Oxygen	0.5	mg/L	FDO
MW-10	14-Nov-94	0.00 - 0.00	Nitrate	13.8	mg/L	H8039
			Nitrite	0.003 J	mg/L	H8507
			Manganese	0.8	mg/L	H8149
			Sulfate	807.6	mg/L	H8051
			Sulfide	0.01 U	mg/L	H2238
			Hydrogen Sulfide	0.024 U	mg/L	H8131
			Iron, Total	0.83	mg/L	H8008
			Iron, Ferrous	0.59	mg/L	H8146
			Carbon Dioxide	210	mg/L	H8223
MW-12	13-Nov-94	0.00 - 0.00	Dissolved Oxygen	2.81	mg/L	FDO
			Nitrate	1.3	mg/L	H8039
			Nitrite	0.001 J	mg/L	H8507
			Manganese	1.3	mg/L	H8149
			Sulfate	1931.2	mg/L	H8051
			Sulfide	0.01 U	mg/L	H2238
			Hydrogen Sulfide	0.024 U	mg/L	H8131
			Iron, Total	0.16	mg/L	H8008
			Iron, Ferrous	0.024 U	mg/L	H8146
			Methane	0.001 U	mg/L	METHAN
			Carbon Dioxide	70	mg/L	H8223
			Carbon Dioxide	389	mg/L	CO2
MW-15	13-Nov-94	0.00 - 0.00	Dissolved Oxygen	3.1	mg/L	FDO
MW-15	14-Nov-94	0.00 - 0.00	Nitrate	5.3	mg/L	H8039
			Nitrite	0.005 U	mg/L	H8507
			Manganese	0.1	mg/L	H8149
			Sulfate	3.21	mg/L	H8051
			Sulfide	0.01 U	mg/L	H2238
			Hydrogen Sulfide	0.024 U	mg/L	H8131
			Iron, Total	0.05	mg/L	H8008
			Iron, Ferrous	0.05	mg/L	H8146
			Carbon Dioxide	190	mg/L	H8223

TABLE A.9
VALIDATED GROUNDWATER DATA FOR
ELECTRON ACCEPTORS
NOVEMBER 1994
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-18	13-Nov-94	0.00 - 0.00	Dissolved Oxygen	0.08	mg/L	FDO
MW-18	15-Nov-94	0.00 - 0.00	Nitrate	6.4	mg/L	H8039
			Nitrite	0.013	mg/L	H8507
			Manganese	1.2	mg/L	H8149
			Sulfate	5.5	mg/L	H8051
			Sulfide	0.01 U	mg/L	H2238
			Hydrogen Sulfide	0.024 U	mg/L	H8131
			Methane	2.2	mg/L	METHAN
			Iron, Total	1.54	mg/L	H8008
			Iron, Ferrous	1.29	mg/L	H8146
			Carbon Dioxide	220	mg/L	H8223
			Carbon Dioxide	711	mg/L	CO2
VW	13-Nov-94	0.00 - 0.00	Dissolved Oxygen	0.1	mg/L	FDO
			Nitrate	1.4	mg/L	H8039
			Nitrite	0.004 J	mg/L	H8507
			Manganese	0.7	mg/L	H8149
			Sulfate	1828.8	mg/L	H8051
			Sulfide	0.01 U	mg/L	H2238
			Hydrogen Sulfide	0.024 U	mg/L	H8131
			Iron, Total	0.05	mg/L	H8008
			Iron, Ferrous	0.04	mg/L	H8146
			Carbon Dioxide	80	mg/L	H8223

TABLE A.10
VALIDATED GROUNDWATER DATA FOR
ELECTRON ACCEPTORS
OCTOBER 1996
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-6	15-Oct-96	0.00 - 0.00	Dissolved Oxygen	0.76	mg/L	FDO
			Nitrate	76.5	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	0.1	mg/L	H8149
			Sulfate	321	mg/L	E300
			Hydrogen Sulfide	0.013	mg/L	H8131
			Iron, Total	0.02 J	mg/L	H8008
			Iron, Ferrous	0.01 J	mg/L	H8146
			Carbon Dioxide	35	mg/L	H8223
MW-7	18-Oct-96	0.00 - 0.00	Dissolved Oxygen	1.85	mg/L	FDO
			Nitrate	0.78	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	0.7	mg/L	H8149
			Sulfate	2390	mg/L	E300
			Hydrogen Sulfide	0.066	mg/L	H8131
			Iron, Total	0.08	mg/L	H8008
			Iron, Ferrous	0.07	mg/L	H8146
			Carbon Dioxide	70	mg/L	H8223
MW-8	15-Oct-96	0.00 - 0.00	Dissolved Oxygen	1.12	mg/L	FDO
			Nitrate	0.056 U	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	1.3	mg/L	H8149
			Sulfate	5540	mg/L	E300
			Hydrogen Sulfide	0.025	mg/L	H8131
			Iron, Total	0.04 J	mg/L	H8008
			Iron, Ferrous	0.05 U	mg/L	H8146
			Carbon Dioxide	110	mg/L	H8223
MW-13	15-Oct-96	0.00 - 0.00	Manganese	0 U	mg/L	H8149
			Iron, Total	0.04 J	mg/L	H8008
			Iron, Ferrous	0.07	mg/L	H8146
			Carbon Dioxide	18	mg/L	H8223
MW-14	15-Oct-96	0.00 - 0.00	Dissolved Oxygen	4.32	mg/L	FDO
			Nitrate	5.7	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	4	mg/L	H8149
			Sulfate	4960	mg/L	E300
			Hydrogen Sulfide	0.043	mg/L	H8131
			Iron, Total	0.02 J	mg/L	H8008
			Iron, Ferrous	0.05	mg/L	H8146
			Carbon Dioxide	150	mg/L	H8223

TABLE A.10
VALIDATED GROUNDWATER DATA FOR
ELECTRON ACCEPTORS
OCTOBER 1996
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-16	15-Oct-96	0.00 - 0.00	Dissolved Oxygen	2.98	mg/L	FDO
			Nitrate	2.6	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	0 U	mg/L	H8149
			Sulfate	267	mg/L	E300
			Hydrogen Sulfide	0.008	mg/L	H8131
			Iron, Total	0.02	mg/L	H8008
			Iron, Ferrous	0.02	mg/L	H8146
			Carbon Dioxide	35	mg/L	H8223
MW-17A	15-Oct-96	0.00 - 0.00	Dissolved Oxygen	0.64	mg/L	FDO
			Nitrate	0.056 U	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	20.5	mg/L	H8149
			Sulfate	2040	mg/L	E300
			Hydrogen Sulfide	0.022	mg/L	H8131
			Iron, Total	1.09	mg/L	H8008
			Iron, Ferrous	0.76	mg/L	H8146
			Carbon Dioxide	200	mg/L	H8223
MW-17B	15-Oct-96	0.00 - 0.00	Dissolved Oxygen	0.3	mg/L	FDO
			Nitrate	0.056 U	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	1.2	mg/L	H8149
			Sulfate	1110	mg/L	E300
			Hydrogen Sulfide	0.053	mg/L	H8131
			Iron, Total	0.77	mg/L	H8008
			Iron, Ferrous	0.44	mg/L	H8146
			Carbon Dioxide	30	mg/L	H8223
MW-18	15-Oct-96	0.00 - 0.00	Dissolved Oxygen	0.29	mg/L	FDO
			Nitrate	0.056 U	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	1.9	mg/L	H8149
			Sulfate	135	mg/L	E300
			Hydrogen Sulfide	0.039	mg/L	H8131
			Iron, Total	2.24	mg/L	H8008
			Iron, Ferrous	1.47	mg/L	H8146
			Carbon Dioxide	<100	mg/L	H8223
MW-19	15-Oct-96	0.00 - 0.00	Manganese	0.3	mg/L	H8149
			Iron, Total	0.54	mg/L	H8008
			Iron, Ferrous	0.36	mg/L	H8146
			Carbon Dioxide	35	mg/L	H8223

TABLE A.10
VALIDATED GROUNDWATER DATA FOR
ELECTRON ACCEPTORS
OCTOBER 1996
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-20	15-Oct-96	0.00 - 0.00	Dissolved Oxygen	3.66	mg/L	FDO
			Nitrate	0.056 U	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	0.8	mg/L	H8149
			Sulfate	2780	mg/L	E300
			Hydrogen Sulfide	0.029	mg/L	H8131
			Iron, Total	0.01	mg/L	H8008
			Iron, Ferrous	0.00 U	mg/L	H8146
			Carbon Dioxide	220	mg/L	H8223
MW-21	15-Oct-96	0.00 - 0.00	Dissolved Oxygen	1.29	mg/L	FDO
			Nitrate	0.056 U	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	1.52	mg/L	H8149
			Sulfate	1980	mg/L	E300
			Hydrogen Sulfide	0.032	mg/L	H8131
			Iron, Total	0.00 U	mg/L	H8008
			Iron, Ferrous	0.22	mg/L	H8146
			Carbon Dioxide	135	mg/L	H8223
MW-22	15-Oct-96	0.00 - 0.00	Dissolved Oxygen	2.8	mg/L	FDO
			Nitrate	0.056 U	mg/L	E300
			Nitrite	0.076 U	mg/L	E300
			Manganese	3.4	mg/L	H8149
			Sulfate	791	mg/L	E300
			Hydrogen Sulfide	0.027	mg/L	H8131
			Iron, Total	0.04	mg/L	H8008
			Iron, Ferrous	0.01 U	mg/L	H8146
			Carbon Dioxide	50	mg/L	H8223

TABLE A.11
VALIDATED GROUND WATER DATA FOR OTHER ANALYSIS
NOVEMBER 1994
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-2	12-Nov-94	0.00 - 0.00	pH	7.24	pH units	E150.1
			Electrical Conductivity	6.21	mmhos/cm	FCOND
			pH	7.1	pH units	FPH
			Redox potential	3.47	pE units	FREDOX
			Temperature	13.2	°C	FTEMP
			Alkalinity, Carbonate	1000	mg/L	H8221
MW-4	11-Nov-94	0.00 - 0.00	pH	7.34	pH units	E150.1
			Electrical Conductivity	2.47	mmhos/cm	FCOND
			pH	7.2	pH units	FPH
			Redox potential	3.76	pE units	FREDOX
			Temperature	12.2	°C	FTEMP
			Alkalinity, Carbonate	480	mg/L	H8221
MW-5	14-Nov-94	0.00 - 0.00	pH	7.39	pH units	E150.1
MW-6	12-Nov-94	0.00 - 0.00	pH	7.11	pH units	E150.1
			Electrical Conductivity	1.937	mmhos/cm	FCOND
			pH	6.86	pH units	FPH
			Redox potential	3.47	pE units	FREDOX
			Temperature	13	°C	FTEMP
			Alkalinity, Carbonate	600	mg/L	H8221
MW-7	11-Nov-94	0.00 - 0.00	pH	6.94	pH units	E150.1
			Electrical Conductivity	4.35	mmhos/cm	FCOND
			pH	7	pH units	FPH
			Redox potential	3.97	pE units	FREDOX
			Temperature	13.8	°C	FTEMP
			Alkalinity, Carbonate	580	mg/L	H8221
MW-9	15-Nov-94	0.00 - 0.00	pH	7.4	pH units	E150.1
			Alkalinity, Carbonate	600	mg/L	H8221
MW-10	13-Nov-94	0.00 - 0.00	Total Organic Carbon	38.5	mg/L	E415.1
			Electrical Conductivity	2.84	mmhos/cm	FCOND
			pH	7.1	pH units	FPH
			Redox potential	3.5	pE units	FREDOX
			Temperature	13.7	°C	FTEMP
MW-10	14-Nov-94	0.00 - 0.00	pH	7.05	pH units	E150.1
			Alkalinity, Carbonate	1600	mg/L	H8221
MW-12	13-Nov-94	0.00 - 0.00	pH	7.37	pH units	E150.1
			Total Organic Carbon	13.2	mg/L	E415.1
			Electrical Conductivity	3.93	mmhos/cm	FCOND
			pH	7.34	pH units	FPH
			Redox potential	3.52	pE units	FREDOX
			Temperature	17	°C	FTEMP
			Alkalinity, Carbonate	380	mg/L	H8221

TABLE A.11
VALIDATED GROUND WATER DATA FOR OTHER ANALYSIS
NOVEMBER 1994
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-15	13-Nov-94	0.00 - 0.00	Electrical Conductivity	1.842	mmhos/cm	FCOND
			pH	7.1	pH units	FPH
			Redox potential	3.72	pE units	FREDOX
			Temperature	11.8	°C	FTEMP
MW-15	14-Nov-94	0.00 - 0.00	pH	7.26	pH units	E150.1
			Alkalinity, Carbonate	1180	mg/L	H8221
MW-18	13-Nov-94	0.00 - 0.00	Total Organic Carbon	14.2	mg/L	E415.1
			Electrical Conductivity	1.24	mmhos/cm	FCOND
			pH	7.1	pH units	FPH
			Redox potential	-0.19	pE units	FREDOX
			Temperature	13.1	°C	FTEMP
MW-18	15-Nov-94	0.00 - 0.00	pH	7.36	pH units	E150.1
			Alkalinity, Carbonate	760	mg/L	H8221
VW	13-Nov-94	0.00 - 0.00	pH	7.23	pH units	E150.1
			Electrical Conductivity	3.75	mmhos/cm	FCOND
			pH	7.2	pH units	FPH
			Redox potential	2.86	pE units	FREDOX
			Temperature	16.6	°C	FTEMP
			Alkalinity, Carbonate	420	mg/L	H8221

TABLE A.12
VALIDATED GROUND WATER DATA FOR OTHER ANALYSES
OCTOBER 1996
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
MW-6	16-Oct-96	0.00 - 0.00	Temperature	15.5	°C	FTEMP
			Alkalinity, Carbonate	940	mg/L	E310
MW-7	17-Oct-96	0.00 - 0.00	Electrical Conductivity	4.21	mS/cm	FCOND
			pH	6.0	pH units	FPH
			Temperature	14.9	°C	FTEMP
			Alkalinity, Carbonate	760	mg/L	E310
MW-8	16-Oct-96	0.00 - 0.00	Temperature	16.4	°C	FTEMP
			Alkalinity, Carbonate	873	mg/L	E310
MW-13	13-Oct-96	0.00 - 0.00	Electrical Conductivity	5.48	mS/cm	FCOND
			pH	7.7	pH units	FPH
			Temperature	14	°C	FTEMP
MW-14	14-Oct-96	0.00 - 0.00	Electrical Conductivity	7.45	mS/cm	FCOND
			Temperature	14.9	°C	FTEMP
			Alkalinity, Carbonate	961	mg/L	E310
MW-16	14-Oct-96	0.00 - 0.00	Temperature	20.9	°C	FTEMP
			Electrical Conductivity	1.35	mS/cm	FCOND
			Alkalinity, Carbonate	438	mg/L	E310
MW-17A	12-Oct-96	0.00 - 0.00	Electrical Conductivity	3.67	mS/cm	FCOND
			pH	7	pH units	FPH
			Temperature	14.8	°C	FTEMP
			Alkalinity, Carbonate	839	mg/L	E310
MW-17B	12-Oct-96	0.00 - 0.00	Electrical Conductivity	2.88	mS/cm	FCOND
			pH	7.7	pH units	FPH
			Temperature	12	°C	FTEMP
			Alkalinity, Carbonate	474	mg/L	E310
MW-18	16-Oct-96	0.00 - 0.00	Temperature	15.5	°C	FTEMP
			Alkalinity, Carbonate	840	mg/L	E310
MW-19	14-Oct-96	0.00 - 0.00	Electrical Conductivity	6.15	mS/cm	FCOND
			pH	7.6	pH units	FPH
			Temperature	12.8	°C	FTEMP
MW-20	14-Oct-96	0.00 - 0.00	Electrical Conductivity	5.73	mS/cm	FCOND
			pH	7.5	pH units	FPH
			Alkalinity, Carbonate	1340	mg/L	E310
			Temperature	12.0	°C	FTEMP
MW-21	13-Oct-96	0.00 - 0.00	Electrical Conductivity	3.39	mS/cm	FCOND
			pH	7.2	pH units	FPH
			Temperature	16.7	°C	FTEMP
			Alkalinity, Carbonate	565	mg/L	E310
MW-22	14-Oct-96	0.00 - 0.00	Electrical Conductivity	2.25	mS/cm	FCOND
			Temperature	15.4	°C	FTEMP
			Alkalinity, Carbonate	615	mg/L	E310

TABLE A.13
VALIDATED SURFACE WATER DATA
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
SW-2	22-Oct-94	0.00 - 0.00	pH	8.26	pH units	E150.1
			Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	2.4 J	µg/L	E602
			1,2,4-Trimethylbenzene	0.6 J	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
SW-3	22-Oct-94	0.00 - 0.00	pH	8.14	pH units	E150.1
			Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
SW-4	22-Oct-94	0.00 - 0.00	pH	8.19	pH units	E150.1
			Total Organic Carbon	7.59 J	mg/L	E415.1
			Benzene	0.4 U	µg/L	E602
			Toluene	4 U	µg/L	E602
			Ethylbenzene	4 U	µg/L	E602
			Xylenes (Total)	4 U	µg/L	E602
			1,3,5-Trimethylbenzene	4 U	µg/L	E602
			1,2,4-Trimethylbenzene	4 U	µg/L	E602
			1,2,3-Trimethylbenzene	4 U	µg/L	E602
			Naphthalene	10 U	µg/L	SW8270

TABLE A.14
VALIDATED SEDIMENT DATA
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
SED-1	22-Oct-94	0.00 - .25	Benzene	0.49 U	µg/kg	SW8020
			Toluene	4.9 U	µg/kg	SW8020
			Ethylbenzene	4.9 U	µg/kg	SW8020
			Xylenes (Total)	4.9 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.9 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.9 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.9 U	µg/kg	SW8020
SED-2	10-Nov-94	0.00 - .25	Benzene	0.49 U	µg/kg	SW8020
			Toluene	4.9 U	µg/kg	SW8020
			Ethylbenzene	4.9 U	µg/kg	SW8020
			Xylenes (Total)	4.9 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.9 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.9 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.9 U	µg/kg	SW8020
SED-5	10-Nov-94	0.00 - .25	Benzene	0.5 U	µg/kg	SW8020
			Toluene	5 U	µg/kg	SW8020
			Ethylbenzene	5.7	µg/kg	SW8020
			Xylenes (Total)	21	µg/kg	SW8020
			1,3,5-Trimethylbenzene	27	µg/kg	SW8020
			1,2,4-Trimethylbenzene	14	µg/kg	SW8020
			1,2,3-Trimethylbenzene	65	µg/kg	SW8020
SED-6	10-Nov-94	0.00 - .25	Benzene	66 U	µg/kg	SW8020
			Toluene	9900	µg/kg	SW8020
			Ethylbenzene	3400	µg/kg	SW8020
			Xylenes (Total)	44000	µg/kg	SW8020
			1,3,5-Trimethylbenzene	65000	µg/kg	SW8020
			1,2,4-Trimethylbenzene	94000	µg/kg	SW8020
			1,2,3-Trimethylbenzene	65000	µg/kg	SW8020
SED-7	10-Nov-94	0.00 - .25	Benzene	0.5 U	µg/kg	SW8020
			Toluene	5 U	µg/kg	SW8020
			Ethylbenzene	5 U	µg/kg	SW8020
			Xylenes (Total)	5 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	5 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	5 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	5 U	µg/kg	SW8020
SED-8	10-Nov-94	0.00 - .25	Benzene	0.49 U	µg/kg	SW8020
			Toluene	4.9 U	µg/kg	SW8020
			Ethylbenzene	4.9 U	µg/kg	SW8020
			Xylenes (Total)	4.9 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.9 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.9 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.9 U	µg/kg	SW8020

TABLE A.14
VALIDATED SEDIMENT DATA
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Interval (ft bgs: begin-end)	Analyte	Result	Units	Anmcode
SED-9	10-Nov-94	0.00 - .25	Benzene	2300 J	µg/kg	SW8020
			Toluene	11000	µg/kg	SW8020
			Ethylbenzene	35000	µg/kg	SW8020
			Xylenes (Total)	210000	µg/kg	SW8020
			1,3,5-Trimethylbenzene	66000	µg/kg	SW8020
			1,2,4-Trimethylbenzene	150000	µg/kg	SW8020
			1,2,3-Trimethylbenzene	69000	µg/kg	SW8020
SED-10	10-Nov-94	0.00 - .25	Benzene	0.47 U	µg/kg	SW8020
			Toluene	4.7 U	µg/kg	SW8020
			Ethylbenzene	1.1 J	µg/kg	SW8020
			Xylenes (Total)	5.9	µg/kg	SW8020
			1,3,5-Trimethylbenzene	0.8 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	1.2 J	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.7 U	µg/kg	SW8020

TABLE A.15
SAMPLES ASSOCIATED WITH CONTAMINATED FIELD BLANKS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

			Associated Samples				
Field Blank	Blank Date	Analyte	Blank Concentration	Sample Location	Sample Date	Sample Matrix	Sample Depth
FB1	9-Nov-94	1,2,3-Trimethylbenzene	0.5 µg/L	MW-1	4-Nov-94	SOIL	6.50-7.50
				MW-2	4-Nov-94	SOIL	5.50-6.50
				MW-3	4-Nov-94	SOIL	5.50-6.50
				MW-3	4-Nov-94	SOIL	8.50-9.50
				MW-4	5-Nov-94	SOIL	3.50-4.50
				MW-5	5-Nov-94	SOIL	4.50-5.50
				MW-6	5-Nov-94	SOIL	3.50-4.50
				MW-7	5-Nov-94	SOIL	4.50-5.50
				MW-8	9-Nov-94	SOIL	4.50-5.50
				MW-9	9-Nov-94	SOIL	4.50-5.50
				MW-11	9-Nov-94	SOIL	3.00-4.00
				MW-12	10-Nov-94	SOIL	6.00-7.00
				MW-12	10-Nov-94	SOIL	9.00-10.00
				SB-1	22-Oct-94	SOIL	4.50-5.50
				SB-2	23-Oct-94	SOIL	1.50-2.50
				SB-2	23-Oct-94	SOIL	3.50-4.50
				BS	10-Nov-94	SOIL	4.50-5.50
				SED-1	22-Oct-94	SEDIMENT	0.00-.25
				SED-2	10-Nov-94	SEDIMENT	0.00-.25
				SED-5	10-Nov-94	SEDIMENT	0.00-.25
				SED-6	10-Nov-94	SEDIMENT	0.00-.25
				SED-7	10-Nov-94	SEDIMENT	0.00-.25
				SED-8	10-Nov-94	SEDIMENT	0.00-.25
				SED-9	10-Nov-94	SEDIMENT	0.00-.25
				SED-10	10-Nov-94	SEDIMENT	0.00-.25
EB3	10-Nov-94	Ethylbenzene	0.4 µg/L	MW-12	10-Nov-94	SOIL	6.00-7.00
				MW-12	10-Nov-94	SOIL	9.00-10.00

TABLE A.16
DATA VALIDATION QAULIFIER APPLICATION
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Depth	Matrix	Analytical Method	Analyte	Laboratory Flag	Method Blank Flag	PQL Flag	Field Flag	Final Report
MW-1	4-Nov-94	6.50-7.50	SOIL	SW8020	Xylenes (Total)	=		J		J
MW-2	4-Nov-94	5.50-6.50	SOIL	M8015	Total Extractable Hydrocarbons	=		J		J
				M8015	Total Volatile Hydrocarbons	=		J		J
				SW8020	1,3,5-Trimethylbenzene	=		J		J
				SW8020	Ethylbenzene	=		J		J
MW-3	4-Nov-94	8.50-9.50	SOIL	SW8020	1,2,3-Trimethylbenzene	=	U	J	U	U
				SW8020	1,2,4-Trimethylbenzene	=		J		J
				SW8020	1,3,5-Trimethylbenzene	=		J		J
				SW8020	Ethylbenzene	=		J		J
				SW8020	Toluene	=	U	J		U
				SW8020	Xylenes (Total)	=		J		J
MW-4	5-Nov-94	3.50-4.50	SOIL	SW8020	Benzene	=		J		J
				SW8020	Ethylbenzene	=		J		J
				SW8020	Xylenes (Total)	=		J		J
MW-5	5-Nov-94	4.50-5.50	SOIL	SW8020	Benzene	=		J		J
				SW8020	Ethylbenzene	=		J		J
				SW8020	Xylenes (Total)	=		J		J
MW-6	5-Nov-94	3.50-4.50	SOIL	SW8020	Xylenes (Total)	=	U	J		U
MW-7	5-Nov-94	4.50-5.50	SOIL	SW8020	1,2,3-Trimethylbenzene	=	U	J	U	U
				SW8020	Toluene	=	U	J		U
				SW8020	Xylenes (Total)	=	U	J		U
MW-8	9-Nov-94	4.50-5.50	SOIL	SW8020	Toluene	=	U	J		U
				SW8020	Xylenes (Total)	=	U	J		U
MW-9	9-Nov-94	4.50-5.50	SOIL	M8015	Total Volatile Hydrocarbons	=		J		J
				SW8020	Benzene	=		J		J
				SW8020	Ethylbenzene	=		J		J
				SW8020	Xylenes (Total)	=	U	J		U
				E415.1	Total Organic Carbon	=		J		J
MW-11	9-Nov-94	3.00-4.00	SOIL	SW8020	1,2,3-Trimethylbenzene	=	U	J	U	U
				SW8020	Toluene	=	U	J		U
				SW8020	Xylenes (Total)	=	U	J		U

TABLE A.16
DATA VALIDATION QAULIFIER APPLICATION
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Depth	Matrix	Analytical Method	Analyte	Laboratory Flag	Method Blank Flag	PQL Flag	Field Flag	Final Report
MW-12	10-Nov-94	4.50-5.50	SOIL	E415.1	Total Organic Carbon	=		J		J
				M8015	Total Extractable Hydrocarbons	=		J		J
				SW8020	Ethylbenzene	=		J		J
				SW8020	Toluene	=		J		J
				SW8020	Toluene	=	U	J		U
				SW8020	Xylenes (Total)	=	U	J		U
SB-1	22-Oct-94	4.50-5.50	SOIL	SW8020	Toluene	=		J		J
SB-2	23-Oct-94	1.50-2.50	SOIL	SW8020	1,2,4-Trimethylbenzene	=		J		J
				SW8020	Toluene	=	U	J		U
				SW8020	1,2,3-Trimethylbenzene	=	U	J	U	U
				SW8020	1,2,4-Trimethylbenzene	=		J		J
				SW8020	1,3,5-Trimethylbenzene	=		J		J
				SW8020	Toluene	=	U	J		U
BS	10-Nov-94	4.50-5.50	SOIL	SW8020	1,2,3-Trimethylbenzene	=	U	J	U	U
				SW8020	1,2,4-Trimethylbenzene	=		J		J
				SW8020	1,3,5-Trimethylbenzene	=		J		J
				SW8020	Ethylbenzene	=		J		J
				SW8020	Toluene	=	U	J		U
				SW8020	Xylenes (Total)	=		J		J
SG-1	21-Oct-94	3.00-3.50	SOIL GAS	TO3	Ethylbenzene	=		J		J
				TO3	Toluene	=		J		J
				TO3	Xylenes (Total)	=		J		J
FLUX-1	16-Nov-94	0.00-0.00	FLUX GAS	TO3	Xylenes (Total)	=		J		J
FLUX-2	16-Nov-94	0.00-0.00	FLUX GAS	TO3	Toluene	=		J		J
				TO3	Xylenes (Total)	=		J		J
FLUX-3	16-Nov-94	0.00-0.00	FLUX GAS	TO3	Ethylbenzene	=		J		J
				TO3	Toluene	=		J		J
				TO3	Xylenes (Total)	=		J		J
FLUX-4	16-Nov-94	0.00-0.00	FLUX GAS	TO3	Ethylbenzene	=		J		J
				TO3	Petroleum Hydrocarbons	=		J		J
				TO3	Toluene	=		J		J
				TO3	Xylenes (Total)	=		J		J

TABLE A.16
DATA VALIDATION QAULIFIER APPLICATION
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Depth	Matrix	Analytical Method	Analyte	Laboratory Flag	Method Blank Flag	PQL Flag	Field Flag	Final Report
FLUX-5	16-Nov-94	0.00-0.00	FLUX GAS	TO3	Petroleum Hydrocarbons	=		J		J
				TO3	Toluene	=		J		J
				TO3	Xylenes (Total)	=		J		J
MW-2	12-Nov-94	0.00-0.00	GROUND WATER	E602	1,2,3-Trimethylbenzene	=		J		J
				E602	1,2,4-Trimethylbenzene	=		J		J
				E602	1,3,5-Trimethylbenzene	=		J		J
				E602	Ethylbenzene	=		J		J
				E602	Toluene	=	U	J		U
				E602	Xylenes (Total)	=	U	J		U
				H8008	Total Iron	=		J		J
				H8146	Iron, Ferrous	=		J		J
MW-3	17-Mar-95	0.00-0.00	GROUND WATER	E602	1,2,3-Trimethylbenzene	J		J		J
				E602	1,2,4-Trimethylbenzene	J		J		J
				E602	Ethylbenzene	J		J		J
				E602	Toluene	J		J		J
MW-4	11-Nov-94	0.00-0.00	GROUND WATER	E602	Toluene	=	U	J		U
				E602	Xylenes (Total)	=	U	J		U
				H8008	Total Iron	=		J		J
				H8146	Iron, Ferrous	=		J		J
MW-5	14-Nov-94	0.00-0.00	GROUND WATER	E602	Ethylbenzene	=		J		J
				E602	Toluene	=	U	J		U
				E602	Xylenes (Total)	=	U	J		U
MW-6	12-Nov-94	0.00-0.00	GROUND WATER	E602	Toluene	=	U	J		U
				E602	Xylenes (Total)	=	U	J		U
MW-7	11-Nov-94	0.00-0.00	GROUND WATER	E602	Toluene	=	U	J		U
				E602	Xylenes (Total)	=	U	J		U
				H8507	Nitrite	=		J		J
MW-9	15-Nov-94	0.00-0.00	GROUND WATER	E602	Benzene	=		J		J
				E602	Ethylbenzene	=		J		J
				E602	Toluene	=	U	J		U
				E602	Xylenes (Total)	=	U	J		U

TABLE A.16
DATA VALIDATION QAULIFIER APPLICATION
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Depth	Matrix	Analytical Method	Analyte	Laboratory Flag	Method Blank Flag	PQL Flag	Field Flag	Final Report
MW-10	14-Nov-94	0.00-0.00	GROUND WATER	E602	1,2,3-Trimethylbenzene	=		J		J
				E602	1,2,4-Trimethylbenzene	=		J		J
				E602	1,3,5-Trimethylbenzene	=		J		J
				E602	Benzene	=		J		J
				E602	Ethylbenzene	=		J		J
				E602	Toluene	=	U	J		U
				E602	Xylenes (Total)	=	U	J		U
				H8507	Nitrite	=		J		J
				M8015	Total Extractable Hydrocarbons	=		J		J
				M8015	Total Volatile Hydrocarbons	=		J		J
MW-12	13-Nov-94	0.00-0.00	GROUND WATER	E602	1,2,3-Trimethylbenzene	=		J		J
				E602	1,2,4-Trimethylbenzene	=		J		J
				E602	1,3,5-Trimethylbenzene	=		J		J
				E602	Ethylbenzene	=		J		J
				E602	Toluene	=	U	J		U
				E602	Xylenes (Total)	=	U	J		U
				H8507	Nitrite	=		J		J
				E602	1,2,3,4-Tetramethylbenzene	J		J		J
				E602	1,3,5-Trimethylbenzene	J		J		J
MW-15	14-Nov-94	0.00-0.00	GROUND WATER	E602	Toluene	=	U	J		U
MW-18	15-Nov-94	0.00-0.00	GROUND WATER	E602	Toluene	=		J		J
GW-6	10-Nov-94	0.00-0.00	GROUND WATER	E602	Toluene	=		J		J
SB-1	22-Oct-94	7.00-7.50	GROUND WATER	E602	Toluene	=	U	J		U
SB-2	23-Oct-94	6.00-6.50	GROUND WATER	E602	1,2,3-Trimethylbenzene	=		J		J
				E602	Ethylbenzene	=		J		J
VW	13-Nov-94	0.00-0.00	GROUND WATER	E602	Toluene	=	U	J		U
				E602	Xylenes (Total)	=	U	J		U
				H8507	Nitrite	=		J		J
SW-2	22-Oct-94	0.00-0.00	SURFACE WATER	E602	1,2,4-Trimethylbenzene	=		J		J
				E602	1,3,5-Trimethylbenzene	=		J		J
SW-4	22-Oct-94	0.00-0.00	SURFACE WATER	E415.1	Total Organic Carbon	=		J		J
SED-2	10-Nov-94	0.00-.25	SEDIMENT	SW8020	Toluene	=	U	J		U
SED-5	10-Nov-94	0.00-.25	SEDIMENT	SW8020	Toluene	=	U	J		U

TABLE A.16
DATA VALIDATION QAULIFIER APPLICATION
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Depth	Matrix	Analytical Method	Analyte	Laboratory Flag	Method Blank Flag	PQL Flag	Field Flag	Final Report
SED-7	10-Nov-94	0.00-.25	SEDIMENT	SW8020	1,2,3-Trimethylbenzene	=	U	J	U	U
SED-9	10-Nov-94	0.00-.25	SEDIMENT	SW8020	Benzene	=		J		J
SED-10	10-Nov-94	0.00-.25	SEDIMENT	SW8020	1,2,4-Trimethylbenzene	=		J		J
				SW8020	1,3,5-Trimethylbenzene	=		J		J
				SW8020	Ethylbenzene	=		J		J
				SW8020	Toluene	=	U	J		U

TABLE A.17
DUPLICATE AND REPLICATE SAMPLE RESULTS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Depth	Matrix	Analytical Method	Analyte	Primary Sample Result	Duplicate Sample Result	Units	RPD
MW-12	10-Nov-94	9.00-10.00	SOIL	SW8020	1,2,3-Trimethylbenzene	4.7 U	4.9 U	UG/KG	
				SW8020	1,2,4-Trimethylbenzene	4.7 U	1.1 J	UG/KG	
				SW8020	1,3,5-Trimethylbenzene	4.7 U	4.9 U	UG/KG	
				SW8020	Benzene	0.47 U	0.9 J	UG/KG	
				SW8020	Ethylbenzene	4.7 U	2 J	UG/KG	
				SW8020	Toluene	4.7 U	4.9 U	UG/KG	
				SW8020	Xylenes (Total)	4.7 U	4.9 U	UG/KG	
MW-3	17-Mar-95	0.00-0.00	GROUND WATER	E602	1,2,3,4-Tetramethylbenzene	11	17	UG/L	10.71
				E602	1,2,3-Trimethylbenzene	3.8 J	1.3 J	UG/L	24.51
				E602	1,2,4-Trimethylbenzene	3.2 J	4.1	UG/L	6.16
				E602	1,3,5-Trimethylbenzene	4 U	1 J	UG/L	
				E602	Benzene	0.4 U	0.8 J	UG/L	
				E602	Chlorobenzene	4 U	4 U	UG/L	
				E602	Ethylbenzene	0.9 J	3.8 J	UG/L	30.85
				E602	Toluene	1.9 J	3.5 J	UG/L	14.81
				E602	Xylenes (Total)	4 U	4.2	UG/L	
MW-6	12-Nov-94	0.00-0.00	GROUND WATER	H8008	Iron	0.024 U	0.024 U	MG/L	
				H8146	Iron, Ferrous	0.024 U	0.024 U	MG/L	
				H8149	Manganese	0.05 U	0.05 U	MG/L	
				H2238	Sulfide	0.01 U	0.01 U	MG/L	
				H8039	Nitrate	1.8	1.7	MG/L	1.43
				H8051	Sulfate	267	255.8	MG/L	1.07
				H8131	Hydrogen Sulfide	0.024 U	0.024 U	MG/L	
				H8221	Alkalinity, Carbonate	600	600	MG/L	0
				H8223	Carbon Dioxide	80	70	MG/L	3.33
				H8507	Nitrite	0.005 U	0.001 J	MG/L	

TABLE A.17
DUPLICATE AND REPLICATE SAMPLE RESULTS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
MALMSTROM AFB, MONTANA

Sample Location	Sample Date	Sample Depth	Matrix	Analytical Method	Analyte	Primary Sample Result	Duplicate Sample Result	Units	RPD
MW-10	14-Nov-94	0.00-0.00	GROUND WATER	H8008	Iron	0.83	0.83	MG/L	0
				H8146	Iron, Ferrous	0.59	0.61	MG/L	0.83
				H8149	Manganese	0.8	0.9	MG/L	2.94
				H2238	Sulfide	0.01 U	0.01 U	MG/L	
				H8039	Nitrate	13.8	12.3	MG/L	2.87
				H8051	Sulfate	807.6	808.6	MG/L	0.03
				H8131	Hydrogen Sulfide	0.024 U	0.024 U	MG/L	
				H8221	Alkalinity, Carbonate	1600	1600	MG/L	0
				H8223	Carbon Dioxide	210	220	MG/L	1.16
				H8507	Nitrite	0.003 J	0.002 J	MG/L	10
MW-12	13-Nov-94	0.00-0.00	GROUND WATER	E602	1,2,3-Trimethylbenzene	0.7 J	0.7 J	UG/L	0
				E602	1,2,4-Trimethylbenzene	1.6 J	1.5 J	UG/L	1.61
				E602	1,3,5-Trimethylbenzene	0.7 J	0.7 J	UG/L	0
				E602	Benzene	0.4 U	0.4 U	UG/L	
				E602	Ethylbenzene	0.7 J	0.7 J	UG/L	0
				E602	Toluene	4 U	4 U	UG/L	
				E602	Xylenes (Total)	4 U	4 U	UG/L	
MW-18	15-Nov-94	0.00-0.00	GROUND WATER	E602	1,2,3-Trimethylbenzene	440	430	UG/L	0.57
				E602	1,2,4-Trimethylbenzene	760	800	UG/L	1.28
				E602	1,3,5-Trimethylbenzene	290	270	UG/L	1.79
				E602	Benzene	680	630	UG/L	1.91
				E602	Ethylbenzene	710	690	UG/L	0.71
				E602	Toluene	18 J	17 J	UG/L	1.43
				E602	Xylenes (Total)	4200	4100	UG/L	0.6

Table 4-2
SWMU PS-3 Subsurface Soil Samples
Summary of VOCs Analyses

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB12-005[1]	PS3-SB12-010	PS3-SB12-015	PS3-SB12-020
Volatile Organic Compounds, µg/kg:				
Acetone	320	77[2]	36[2]	14[3]
Benzene	23	U (6.4)	U (6.0)	U (6.0)
Ethylbenzene	100	U (6.4)	U (6.0)	U (6.0)
Xylenes	350	U (6.4)	U (6.0)	U (6.0)

Notes:
[1] Dilution of 1:2 required.
[2] Laboratory artifact; method blank contained acetone concentration of 13 µg/kg.
[3] Laboratory artifact; method blank contained acetone concentration of 12 µg/kg.
U = Undetected
( ) = Reporting limit of compound

Table 4-2
SWMU PS-3 Subsurface Soil Samples
Summary of VOCs Analyses

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification	
	PS3-SB14-005[1]	PS3-SB14-010
Volatile Organic Compounds, µg/kg:		
Acetone	1700[2]	50[3]
Benzene	U (650)	U (6.9)
Ethylbenzene	900	U (6.9)
Xylenes	1500	U (6.9)

Notes:
[1] Dilution of 1:100 required.
[2] Laboratory artifact; method blank contained acetone concentration of 1500 µg/kg.
[3] Laboratory artifact; method blank contained acetone concentration of 13 µg/kg.
U = Undetected
( ) = Reporting limit of compound

Table 4-6
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of BTEX Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB09-005	PS3-SB09-010	PS3-SB09-015	PS3-SB09-020
BTEX, µg/kg:				
Benzene	U (62)	U (60)	U (59)	U (60)
Toluene	U (62)	U (60)	U (59)	U (60)
Ethylbenzene	810	U (60)	U (59)	U (60)
Xylenes (total)	510	U (60)	U (59)	U (60)

Notes:
U = Undetected
( ) = Reporting limit of compound

Table 4-6
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of BTEX Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB11-005[1]	PS3-SB11-010	PS3-SB11-015	PS3-SB11-020
BTEX, µg/kg:				
Benzene	U (1300)	U (60)	U (61)	U (59)
Toluene	U (1300)	U (60)	U (61)	U (59)
Ethylbenzene	7500	170	U (61)	U (59)
Xylenes (total)	U (1300)	U (60)	U (61)	U (59)

Notes:
[1] Dilution of 1:20 required.
U = Undetected
( ) = Reporting limit of compound

Table 4-6
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of BTEX Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB10-005	PS3-SB10-010	PS3-SB10-015	PS3-SB10-020
BTEX, µg/kg:				
Benzene	U (67)	U (62)	U (60)	U (60)
Toluene	U (67)	U (62)	U (60)	U (60)
Ethylbenzene	U (67)	300	U (60)	U (60)
Xylenes (total)	U (67)	U (62)	U (60)	U (60)

Notes:
U = Undetected
( ) = Reporting limit of compound

Table 4-6
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of BTEX Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB13-005	PS3-SB13-010[1]	PS3-SB13-015	PS3-SB13-020
BTEX, µg/kg:				
Benzene	U (64)	U (3100)	U (60)	U (60)
Toluene	U (64)	U (3100)	U (60)	U (60)
Ethylbenzene	U (64)	12000	U (60)	U (60)
Xylenes (total)	U (64)	U (3100)	U (60)	U (60)

Notes:
[1] Dilution of 1:50 required.
U = Undetected
( ) = Reporting limit of compound

Table 4-6
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of BTEX Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification	
	PS3-SB14-015	PS3-SB14-020
BTEX, µg/kg:		
Benzene	U (59)	U (60)
Toluene	U (59)	U (60)
Ethylbenzene	U (59)	U (60)
Xylenes (total)	U (59)	U (60)

Notes:
U = Undetected
( ) = Reporting limit of compound

Table 4-6
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of BTEX Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification					
	PS3-MW15-005[1]	PS3-MW15-005 Duplicate (Sample No. PS3-002)[2]	RPD (%)	PS3-MW15-010	PS3-MW15-015	PS3-MW15-020
BTEX, µg/kg:						
Benzene	U (3200)	U (6500)	0	U (60)	U (59)	U (60)
Toluene	U (3200)	U (6500)	0	U (60)	U (59)	U (60)
Ethylbenzene	17000	16000	6	U (60)	U (59)	U (60)
Xylenes (total)	67000	71000	6	U (60)	U (59)	U (60)

Notes:
[1] Dilution of 1:50 required.
[2] Dilution of 1:100 required.
RPD = Relative Percent Difference
U = Undetected
( ) = Reporting limit of compound

Table 4-6
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of BTEX Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB16-005	PS3-SB16-010	PS3-SB16-015	PS3-SB16-020
BTEX, µg/kg:				
Benzene	U (64)	U (60)	U (60)	U (60)
Toluene	U (64)	U (60)	U (60)	U (60)
Ethylbenzene	78	U (60)	U (60)	U (60)
Xylenes (total)	U (64)	U (60)	U (60)	U (60)

Notes:
U = Undetected
( ) = Reporting limit of compound

Table 4-6
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of BTEX Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB17-005[1]	PS3-SB17-010	PS3-SB17-015	PS3-SB17-020
BTEX, µg/kg:				
Benzene	U (650)	U (59)	U (60)	U (60)
Toluene	U (650)	U (59)	U (60)	U (60)
Ethylbenzene	5600	U (59)	U (60)	U (60)
Xylenes (total)	710	U (60)	U (60)	U (60)

Notes:
[1] Dilution of 1:10 required.
U = Undetected
( ) = Reporting limit of compound

Table 4-6
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of BTEX Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification					
	PS3-MW18-005[1]	PS3-MW18-005 Duplicate (Sample No. PS3-004)[1]	RPD (%)	PS3-MW18-010	PS3-MW18-015	PS3-MW18-020
BTEX, µg/kg:						
Benzene	U (6100)	U (5900)	0	U (60)	U (60)	U (60)
Toluene	U (6100)	U (5900)	0	U (60)	U (60)	U (60)
Ethylbenzene	83000	73000	13	U (60)	89	U (60)
Xylenes (total)	300000	280000	7	140	250	U (60)

Notes:
[1] Dilution of 1:100 required.
RPD = Relative Percent Difference
U = Undetected
( ) = Reporting limit of compound

Table 4-10
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of General Inorganics Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB09-005	PS3-SB09-010	PS3-SB09-015	PS3-SB09-020
General Inorganics:				
Moisture, %	20	17	16	17
Total Petroleum Hydrocarbons, mg/kg	U (24.9)	U (24.2)	U (23.8)	U (24.0)

Notes:
U = Undetected
( ) = Reporting limit of compound

Table 4-10
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of General Inorganics Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB10-005	PS3-SB10-010	PS3-SB10-015	PS3-SB10-020
General Inorganics:				
Moisture, %	25.9	19.7	17.1	16.2
Total Petroleum Hydrocarbons, mg/kg	U (27.0)	U (24.9)	U (24.1)	U (23.9)

Notes:
U = Undetected
( ) = Reporting limit of compound

Table 4-10
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of General Inorganics Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB11-005	PS3-SB11-010	PS3-SB11-015	PS3-SB11-020
General Inorganics:				
Moisture, %	20.3	17	17.7	15.8
Total Petroleum Hydrocarbons, mg/kg	211	U (24.1)	U (24.3)	U (23.8)

Notes:
U = Undetected
( ) = Reporting limit of compound

Table 4-10
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of General Inorganics Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification				
	PS3-SS12-001	PS3-SB12-005	PS3-SB12-010	PS3-SB12-015	PS3-SB12-020
General Inorganics:					
Moisture, %	11.6	17.5	21.3	16.5	16.1
Total Petroleum Hydrocarbons, mg/kg	33	U (24.2)	U (25.4)	U (23.9)	U (23.8)

Notes:
U = Undetected
( ) = Reporting limit of compound

Table 4-10
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of General Inorganics Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification			
	PS3-SB13-005	PS3-SB13-010	PS3-SB13-015	PS3-SB13-020
General Inorganics:				
Moisture, %	22	19.2	16.6	16.2
Total Petroleum Hydrocarbons, mg/kg	72.9	66.4	U (24.0)	U (23.9)

Notes:
U = Undetected
( ) = Reporting limit of compound

Table 4-10
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of General Inorganics Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification						
	PS3-SS14-001	PS3-SS14-001 Duplicate (Sample No. PS3-001)	RPD (%)	PS3-SB14-005	PS3-SB14-010	PS3-SB14-015	PS3-SB14-020
General Inorganics:							
Moisture, %	11.9	14.5	20	22.6	27	15.4	17
Total Petroleum Hydrocarbons, mg/kg	U (22.7)	U (23.4)	0	U (25.8)	U (27.4)	U (23.6)	U (24.1)

Notes:
RPD = Relative Percent Difference
U = Undetected
( ) = Reporting limit of compound

Table 4-10
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of General Inorganics Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification						
	PS3-SS15-001	PS3-MW15-005	PS3-MW15-005 Duplicate (Sample No. PS3-002)	RPD (%)	PS3-MW15-010	PS3-MW15-015	PS3-MW15-020
General Inorganics:							
Moisture, %	12.8	22	22.7	3	16.2	15.3	16.6
Total Petroleum Hydrocarbons, mg/kg	51.2	429	467	8	U (23.9)	U (23.6)	U (24.0)

Notes:
RPD = Relative Percent Difference
U = Undetected
( ) = Reporting limit of compound

Table 4-10
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of General Inorganics Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification				
	PS3-SS16-001[1]	PS3-SB16-005	PS3-SB16-010	PS3-SB16-015	PS3-SB16-020
General Inorganics:					
Moisture, %	11.5	22.3	17.2	16.5	16.5
Total Petroleum Hydrocarbons, mg/kg	3310	U (25.7)	U (24.2)	U (23.9)	U (24.0)

Notes:
[1] Dilution of 1:5 required.
U = Undetected
( ) = Reporting limit of compound

Table 4-10
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of General Inorganics Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification				
	PS3-SS17-001	PS3-SB17-005	PS3-SB17-010	PS3-SB17-015	PS3-SB17-020
General Inorganics:					
Moisture, %	16	22.8	15.6	16	16.5
Total Petroleum Hydrocarbons, mg/kg	378	168	U (23.7)	U (23.8)	U (24.0)

Notes:
U = Undetected
( ) = Reporting limit of compound

Table 4-10
SWMU PS-3 Surface and Subsurface Soil Samples
Summary of General Inorganics Analysis

Malmstrom AFB, Great Falls, Montana
DACA45-92-C-0139, 02285-039-134

Analyte	Sample Identification					
	PS3-MW18-005[1]	PS3-MW18-005 Duplicate (Sample No. PS3-004)[1]	RPD (%)	PS3-MW18-010	PS3-MW18-015	PS3-MW18-020
General Inorganics:						
Moisture, %	17	16	6	16	17	17
Total Petroleum Hydrocarbons, mg/kg	7980	6560	20	U (23.9)	U (24.1)	U (24.0)

Notes:
[1] Dilution of 1:10 required.
RPD = Relative Percent Difference
U = Undetected
( ) = Reporting limit of compound

UST Closure Sample Results
expressed as mg/kg (ppm)

Sample #	GRO-1	GRO-2	GRO-3	DRO-1	DRO-2	DRO-3	Benzene	Toluene	Ethyl benzene	Xylenes
245-6/20-03-T3E	2.34	2.34	4.32	ND	ND	ND	<0.050	<0.050	<0.050	<0.050
245-6/20-04-T4E	341	341	541	240	240	262	<0.050	0.703	1.860	9.910
245-6/20-05-T5E	117	117	197	106	106	119	<0.050	0.434	0.796	4.530
245-6/20-06-T6E	2.62	2.62	4.35	ND	ND	ND	<0.050	<0.050	<0.050	<0.050
245-6/21-01-T1E	0.68	0.68	1.14	ND	ND	ND	<0.050	<0.050	<0.050	<0.050
245-7/05-04-PN	9.69	9.69	18	ND	ND	ND	<0.050	0.0862	0.0772	0.219
245-5/08-01-T7E	116	116	225	1080	1080	1270	<0.050	<0.050	1.130	0.804
245-5/08-02-T7W	26.2	26.2	54.5	124	124	261	<0.050	<0.050	0.164	0.192
245-6/14-01-T1W	19.7	19.7	31.4	49.8	49.8	85.9	<0.050	<0.050	0.096	0.287
245-6/14-02-T2W	1.70	1.70	2.69	ND	ND	ND	<0.050	<0.050	<0.050	<0.050
245-6/14-03-T3W	ND	ND	ND	ND	ND	ND	<0.050	<0.050	<0.050	<0.050
245-6/14-05-T4W	ND	ND	ND	ND	ND	ND	<0.050	<0.050	<0.050	<0.050
245-6/14-06-T5W	ND	ND	ND	ND	ND	ND	<0.050	<0.050	<0.050	<0.050
245-6/14-07-T6W	1.28	1.28	2.03	ND	ND	ND	<0.050	<0.050	<0.050	<0.050
245-6/20-02-T2E	0.90	0.90	1.81	ND	ND	ND	<0.050	<0.050	<0.050	<0.050
245-7/06-02-PS*	10.9	10.9	18.7	ND	ND	ND	<0.050	<0.050	0.0661	0.193

* - Split QA samples were shipped to the USACOE labs in Troutdale, Oregon

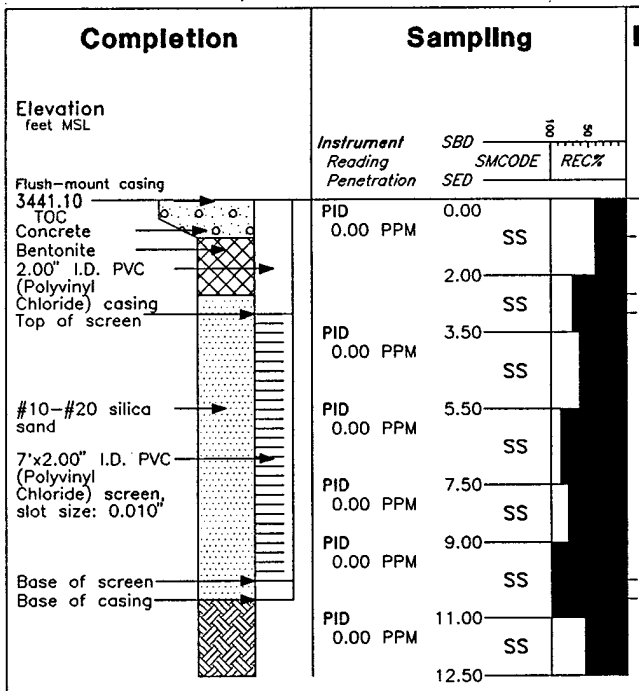
APPENDIX B

BORING LOGS, WELL CONSTRUCTION DIAGRAMS, AND WELL DEVELOPMENT REPORTS

Geologic Borehole and Well Completion Log

725525.03000

Date	11/04/94 ESTDATE	Establishing Company	ESCI ESCCODE	**MALMSTROM AIR FORCE BASE, MONTANA**	
Northing	1195259.20 ft. NCOORD	Drilling Company	OKEB DRLCODE	Air Force Installation	MLMSM AFIID
Easting	1554196.35 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP	Location Identification	**MW-1** LOCID
Borehole Total Depth	12.50 ft. DEPTH	Construction Method	HS CMCCODE		



MW-1

Geologic Borehole and Well Completion Log

MLMSM MW-1 TD 12.50' 1"=5.00' 1:60.00 950126 1309 Sheet 1 of 1

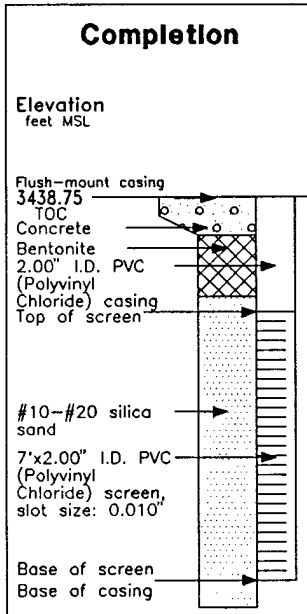
PARSONS ENGINEERING SCIENCE, INC.

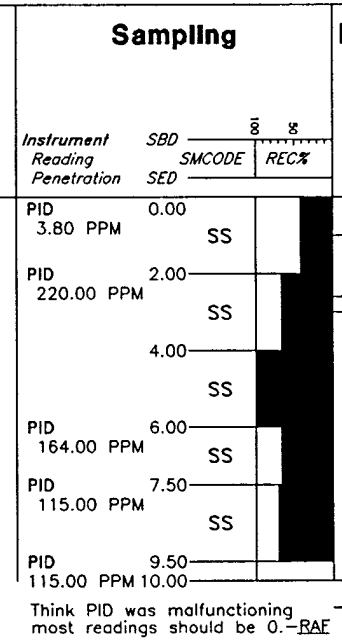
Denver, Colorado (303) 831-8100

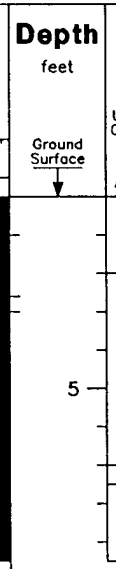
Geologic Borehole and Well Completion Log

725525.03000

Date	11/04/94 ESTDATE	Establishing Company	ESCI ESCCODE	**MALMSTROM AIR FORCE BASE, MONTANA**	
Northing	1195442.70 ft. NCOORD	Drilling Company	OKEB DRLCODE		
Easting	1554338.50 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP	Air Force Installation	MLMSM AFIID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE	Location Identification	**MW-2** LOCID







Lithology				Remarks
USCS Unified Soil Classification System / ASTMCODE	Lithologic Symbols & Codes / LITHCODE	Description — *SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. –Initials*	STRATORDER	*Depth, Borehole Diameter, Drilling Problems, Weather; Time, Equipment, Water Level –Initials*
NA		GRAVEL fill w/ sand, tan to reddish brown, no odor –RAF		0.00' Windy, cloudy, ~35 F –RAF
CH		CLAY w/ tr silt, gray to olive, sl moist, odor at 3' BGS in seam. @4' clay, till, moist, gray to olive, very plastic. @6' SAA		6.00' BTEX and TPH SAMPLE –RAF
SC		Seam of SAND, black staining and POL odor, very moist –RAF		7.00' Water –RAF
CH		CLAY, dk brown, till, w/ sm SAND and GRAVEL, moist and stiff –RAF		10.00' –RAF

MW-2

Geologic Borehole and Well Completion Log

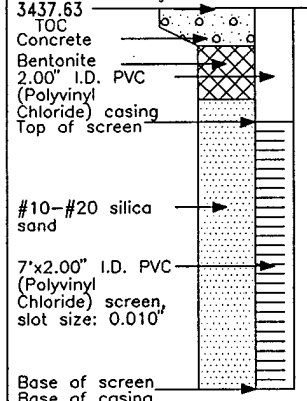
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MLMSM MW-2 TD 10.00' 1"=5.00' 1:60.00 950126 1425 Sheet 1 of 1

Geologic Borehole and Well Completion Log

725525.03000

Date	11/04/94 ESTDATE	Establishing Company	ESCI ESCCODE	**MALMSTROM AIR FORCE BASE, MONTANA**	
Northing	1195543.00 ft. NCOORD	Drilling Company	OKEB DRLCODE		
Easting	1543339.58 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP	Air Force Installation	MLMSM AFIID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE	Location Identification	**MW-3** LOCID



Completion	Sampling	Depth (feet)	Lithology				Remarks
Elevation feet MSL	Instrument Reading Penetration / SBD SED / SMCODE / REC%	Ground Surface	USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description: SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. –Initials	STRATORDER	Depth / Borehole Diameter / Drilling Problems / Weather / Time / Equipment / Water Level –Initials
	PID 4.80 PPM 0.00 SS		NA		FILL, GRAVEL w/ sm SAND and SILT –RAF		0.00' Windy, cloudy, ~35 F –RAF 1.00' No odor –RAF
	2.00 SS						
	4.00 SS				POOR RECOVERY 2–4'. @4' CLAY, tr f sand very contaminated, gray staining, very moist. @6' SAA, saturated and stained. @7.5' CLAY, drk brn, sm gravel, not as moist. @9.5' fat brn CLAY w/ sm GRAVEL, sl moist, stiff –RAF		2.00' Poor Recovery –RAF
	PID 220.00 PPM 6.00 SS	5	CH				5.00' BTEX SAMPLE –RAF 5.50' Water –RAF 6.00' Strong odor –RAF
	PID 130.00 PPM 7.50 SS						7.50' Strong odor –RAF
	PID <0.00 PPM due to high moisture –RAF 9.50 10.00	10					9.00' BTEX SAMPLE –RAF 10.00' TD –RAF

MW-3
Geologic Borehole and Well Completion Log

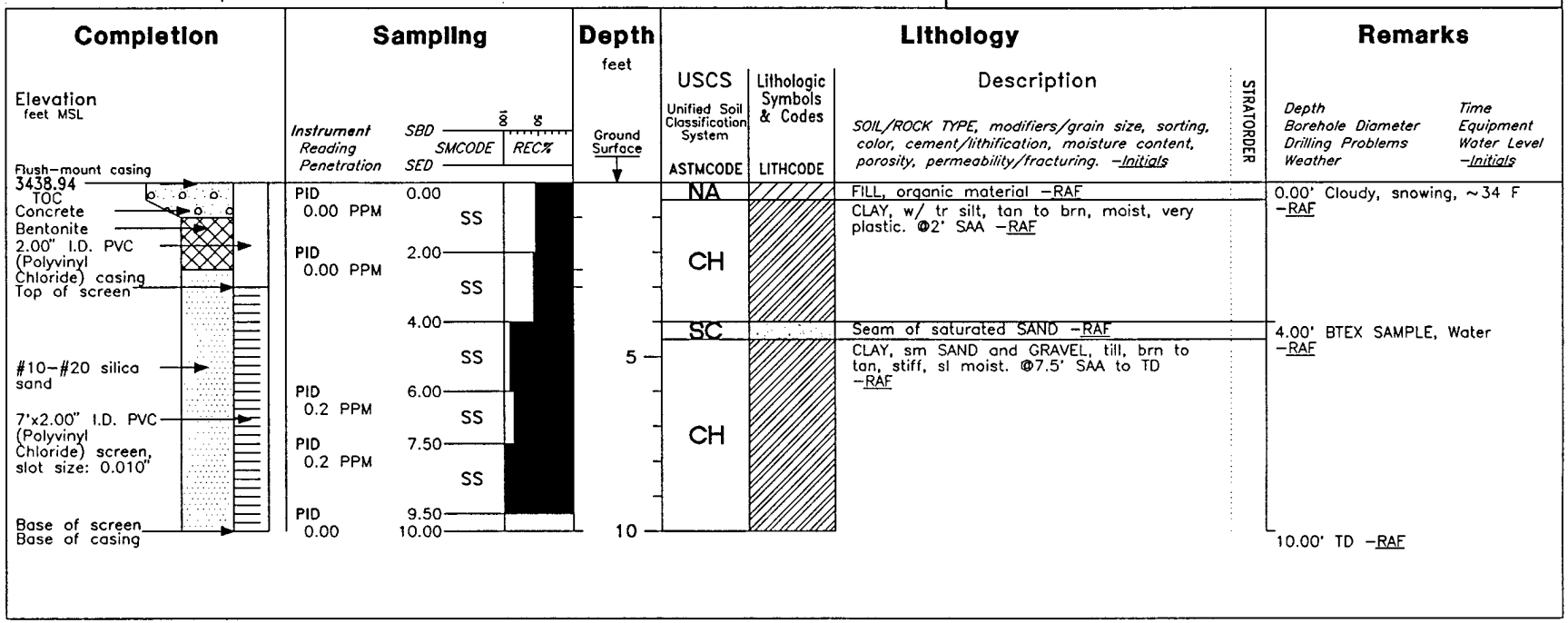
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Geologic Borehole and Well Completion Log

725525.03000

Date	11/05/94 ESTDATE	Establishing Company	ESCI ESCCODE	**MALMSTROM AIR FORCE BASE, MONTANA**	
Northing	1195675.65 ft. NCOORD	Drilling Company	OKEB DRLCODE	Air Force Installation	MLMSM AFIID
Easting	1554102.01 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP	Location Identification	**MW-4** LOCID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE		



MW-4

Geologic Borehole and Well Completion Log

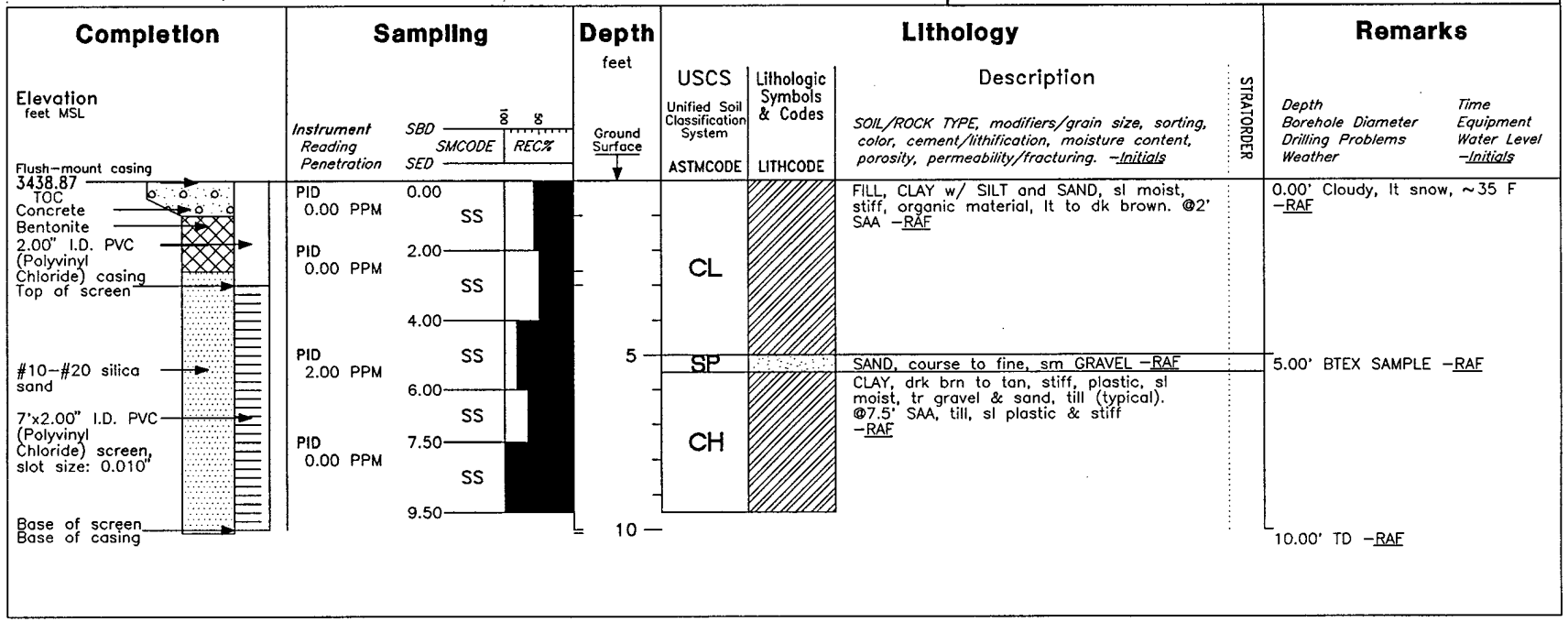
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Geologic Borehole and Well Completion Log

725525.03000

Date	11/05/94 ESTDATE	Establishing Company	ESCI ESCCODE	**MALMSTROM AIR FORCE BASE, MONTANA**	
Northing	1195735.93 ft. NCOORD	Drilling Company	OKEB DRLCODE		
Easting	1554170.77 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP	Air Force Installation	MLMSM AFIID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE	Location Identification	**MW-5** LOCID



MW-5

Geologic Borehole and Well Completion Log

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MLMSM MW-5 TD 10.00' 1"=5.00' 1:60.00 950126 1311 Sheet 1 of 1

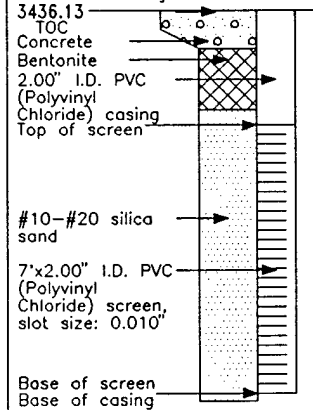
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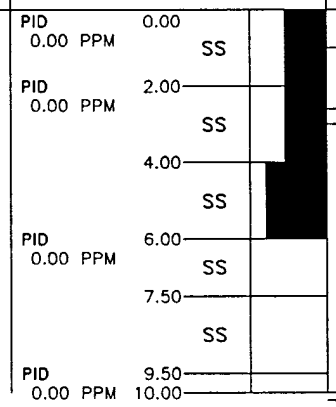
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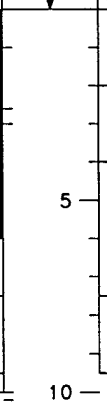
Date	11/05/94 ESTDATE	Establishing Company	ESCI ESCCODE
Northing	1195615.69 ft. NCOORD	Drilling Company	OKEB DRLCODE
Easting	1554417.67 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE

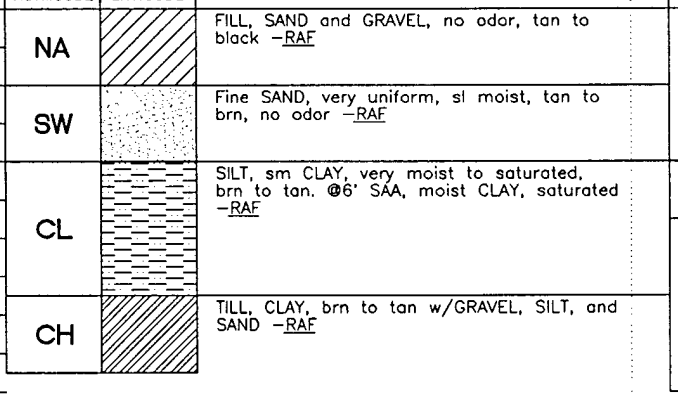
MALMSTROM AIR FORCE BASE, MONTANA

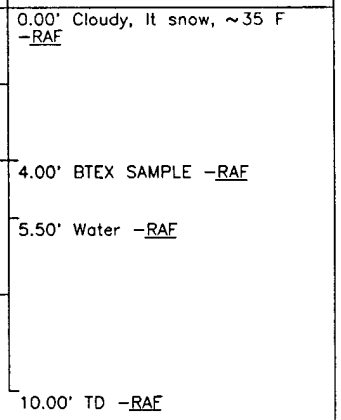
Air Force Installation	MLMSM	AFIID
Location Identification	**MW-6**	LOCID











MW-6

Geologic Borehole and Well Completion Log

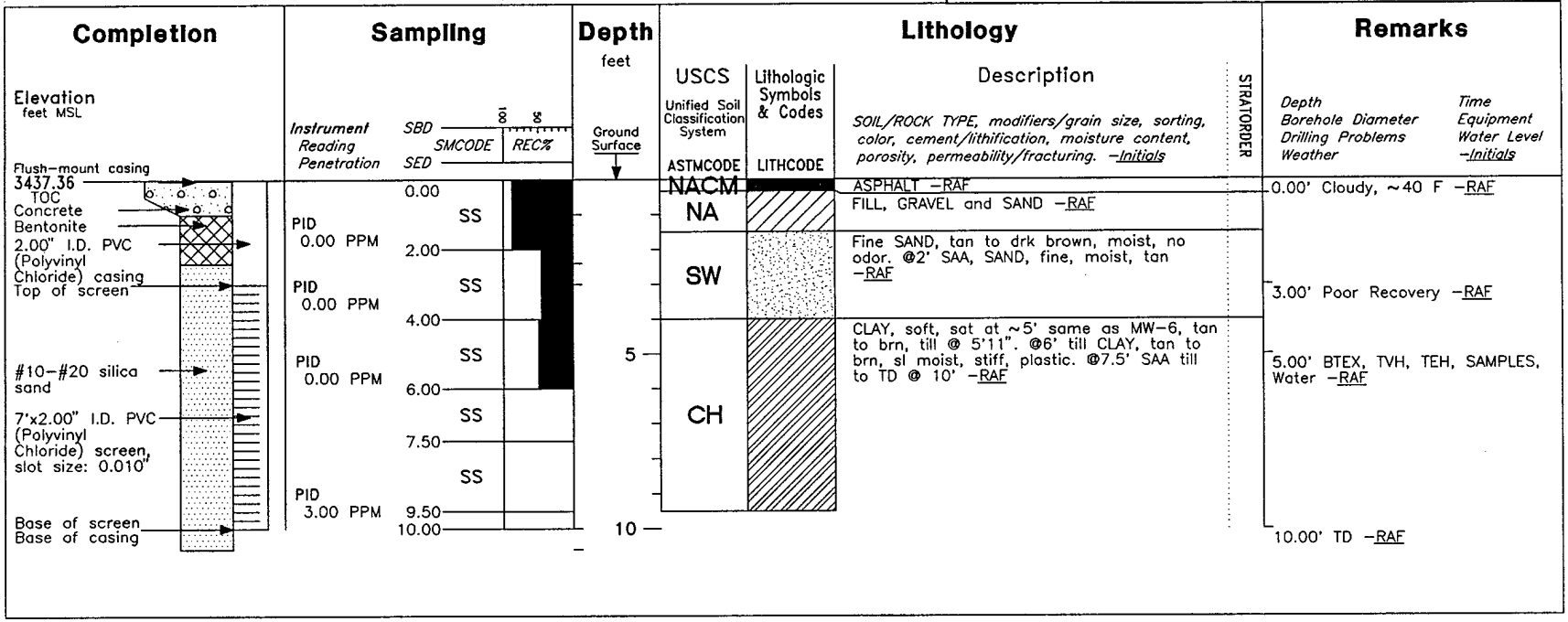
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Geologic Borehole and Well Completion Log

725525.03000

Date	11/05/94 ESTDATE	Establishing Company	ESCI ESCCODE	**MALMSTROM AIR FORCE BASE, MONTANA**	
Northing	1195513.21 ft. NCOORD	Drilling Company	OKEB DRLCODE		
Easting	1554435.40 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP	Air Force Installation	MLMSM AFIID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE	Location Identification	**MW-7** LOCID



MW-7

Geologic Borehole and Well Completion Log

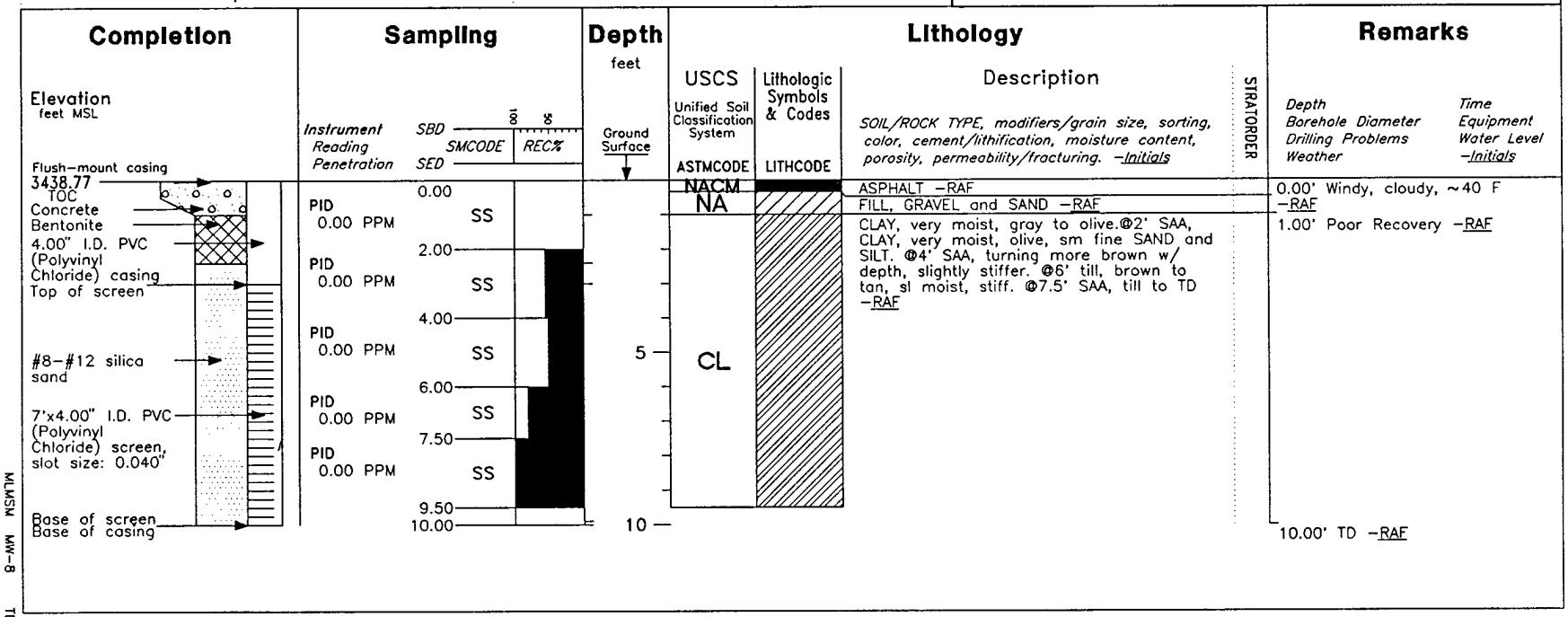
MLMSM MW-7 TD 10.00' 1"=5.00' 1:60.00 950126 1311 Sheet 1 of 1

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Geologic Borehole and Well Completion Log

725525.03000

Date	11/09/94 ESTDATE	Establishing Company	ESCI ESCCODE	**MALMSTROM AIR FORCE BASE, MONTANA**	
Northing	1195590.55 ft. NCOORD	Drilling Company	OKEB DRLCODE	Air Force Installation	MLMSM AFIID
Easting	1554087.96 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP	Location Identification	**MW-8** LOCID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE		



MW-8

Geologic Borehole and Well Completion Log

MLMSM MW-8 TD 10.00' 1"=5.00' 1:60.00 950202 1309 Sheet 1 of 1

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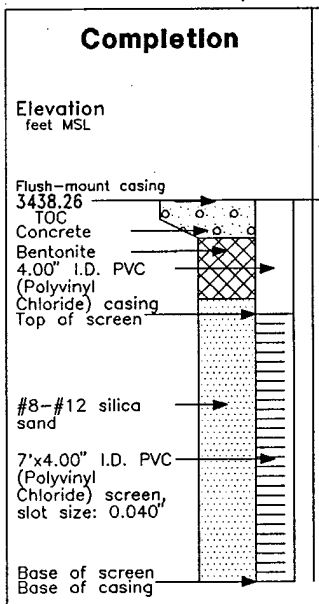
MW-9

Geologic Borehole and Well Completion Log

Geologic Borehole and Well Completion Log

725525.03000

Date	11/09/94 ESTDATE	Establishing Company	ESCI ESCCODE	**MALMSTROM AIR FORCE BASE, MONTANA**	
Northing	1195622.15 ft. NCOORD	Drilling Company	OKEB DRLCODE	Air Force Installation	MLMSM AFIID
Easting	1554118.95 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP	Location Identification	**MW-9** LOCID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE		



Sampling				Depth (feet)	Lithology				Remarks
Instrument Reading Penetration	SBD SED	SMCODE	REC%	Ground Surface	USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description (SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. –Initials)	STRATORDER	Depth, Borehole Diameter, Drilling Problems, Weather / Time, Equipment, Water Level –Initials
	0.00				NACM		ASPHALT –RAF		0.00' Windy, cloudy, ~40 F –RAF
PID 0.00 PPM		SS			NA		FILL, SAND and GRAVEL –RAF		
	2.00				SC		Fn SAND and CLAY –RAF		
PID 0.00 PPM		SS			CL		CLAY, pockets of fine sand, tan to olive, sl moist, sl stiff, @4' SAA –RAF		3.00' MOISTURE/CLASSIFICATION SAMPLE –RAF
	4.00	SS		5	SC		SAND lense, sl moist, not saturated –RAF		5.00' BTEX, TEH, TVH, TOC, pH SAMPLE –RAF
PID 0.00 PPM	6.00	SS			CL		CLAY, @6' till starts, till to TD –RAF		
PID 0.00 PPM	7.50	SS							7.50' No Recovery –RAF
	9.50								
	10.00			10					10.00' TD –RAF

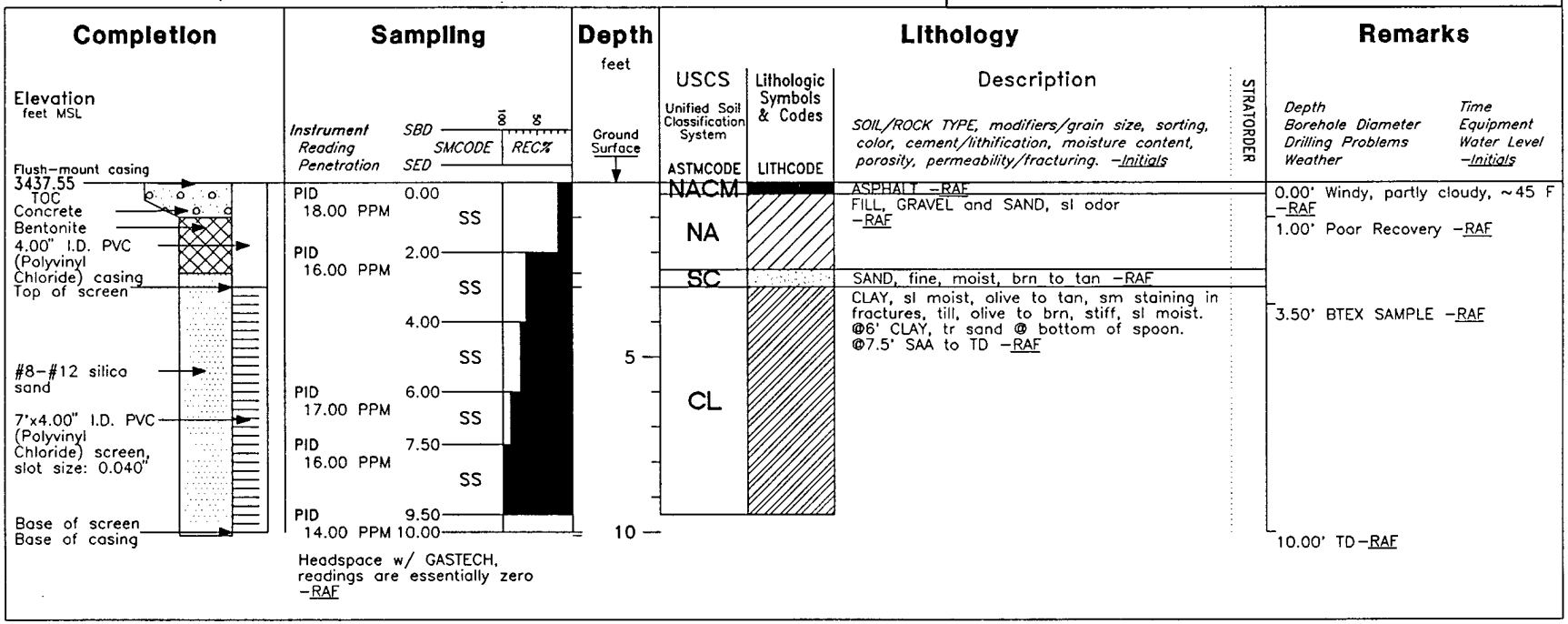
MLMSM MW-9 TD 10.00' 1"=5.00' 1:60.00 950202 130 Sheet 1 of 1

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Geologic Borehole and Well Completion Log

725525.03000

Date	11/09/94 ESTDATE	Establishing Company	ESCI ESCCODE	**MALMSTROM AIR FORCE BASE, MONTANA**	
Northing	1195657.93 ft. NCOORD	Drilling Company	OKEB DRLCODE		
Easting	1554154.24 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP	Air Force Installation	MLMSM AFIID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE	Location Identification	**MW-11** LOCID



MW-11

Geologic Borehole and Well Completion Log

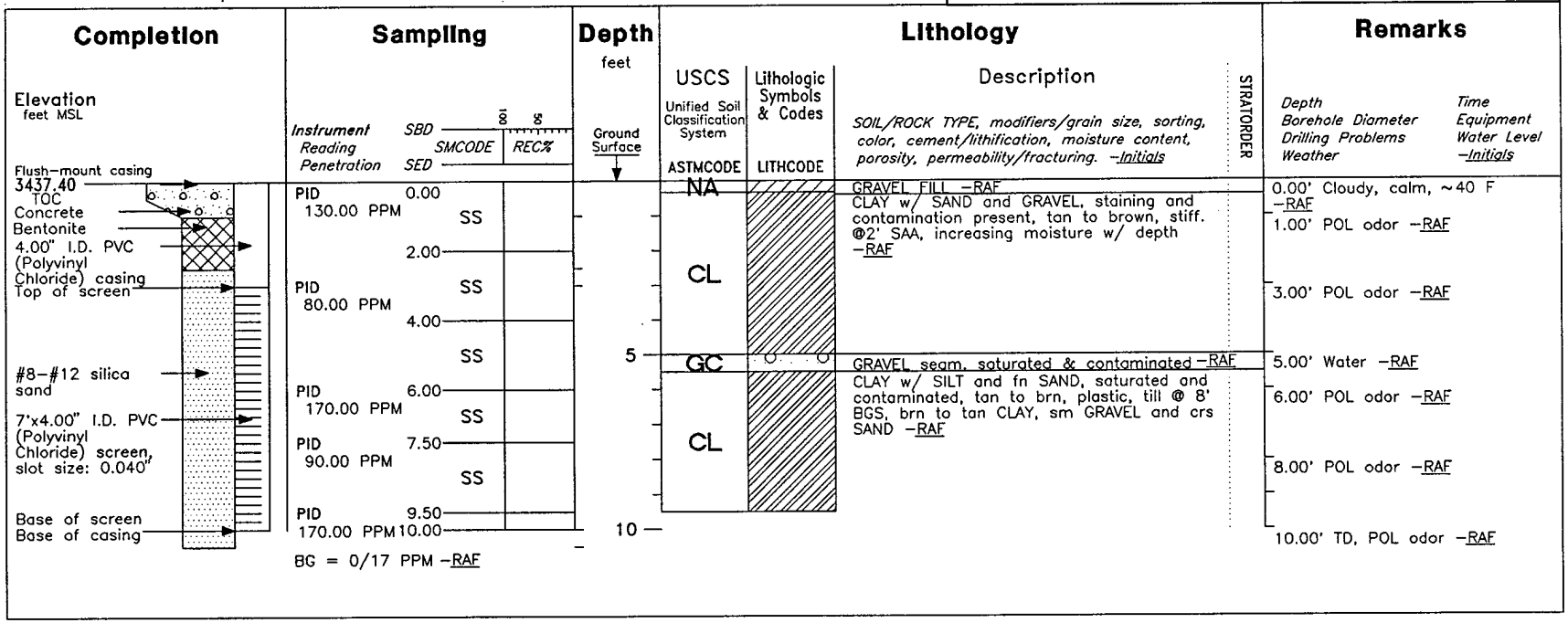
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MLMSM MW-11 TD 10.00' 1"=5.00' 1:60.00 950126 1312 Sheet 1 of 1

Geologic Borehole and Well Completion Log

725525.03000

Date	11/10/94 ESTDATE	Establishing Company	ESCI ESCCODE	**MALMSTROM AIR FORCE BASE, MONTANA**	
Northing	1195566.89 ft. NCOORD	Drilling Company	OKEB DRLCODE		
Easting	1554201.80 ft. ECOORD	Drill Rig Type	MOBILE59 DRLEQP	Air Force Installation	MLMSM AFIID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE	Location Identification	**MW-12** LOCID



MW-12

Geologic Borehole and Well Completion Log

MLMSM MW-12 TD 10.00' 1"=5.00' 1:60.00 950202 1310 Sheet 1 of 1

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MW-13
Geologic Borehole and Well Completion Log

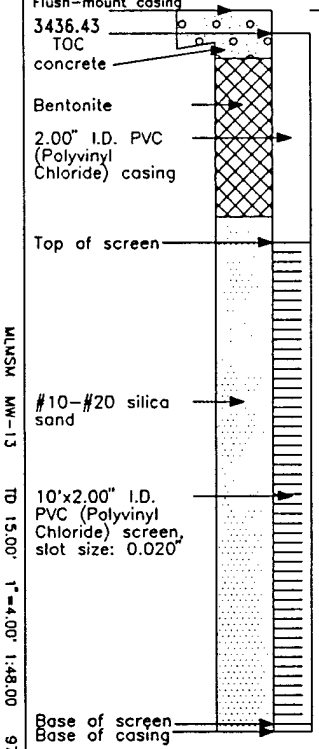
Geologic Borehole and Well Completion Log

725525.06000

Date	10/05/96 ESTDATE	Establishing Company	PARD ESCCODE	**Malmstrom Air Force Base, Montana**	
Northing	1195649.38 ft. NCOORD	Drilling Company	MAXM DRLCODE	Installation	MLMSM
Easting	1554361.40 ft. ECOORD	Drill Rig Type	B61Mobil DRLEQP	Location Identification	**MW-13** LOCID
Borehole Total Depth	15.00 ft. DEPTH	Construction Method	HS CMCCODE		

Completion

Elevation feet MSL
3436.92



Sampling

Instrument
Reading
Penetration
SBD
SED
SMCODE
REC%

Depth

feet

Ground Surface

5

10

15

Lithology

USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description: SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. -Initials	STRATORDER
NACM		ASPHALT. -BJS	
GM		GRAVEL, poorly sorted, some fine sand, dry, brown at 1 foot, turns black for about an inch. -BJS	
CH		CLAY, dark brown, some gravel, stiff, dry, little fine sand, trace of calcite nodules. @4.0', SAA, no gravel. @6.0', SAA, trace petroleum staining. @9.0', SAA, slight odor. -BJS	

Remarks

Depth
Borehole Diameter
Drilling Problems
Weather

Time
Equipment
Water Level
-Initials

1.00' PID (HS/BG) = 7.0/1.5 PPM -BJS

2.00' PID (HS/BG) = 5.6/2.5 PPM PID (BZ/BG) = 1.5/1.5 PPM PID (BH/BG) = 1.5/1.5 PPM -BJS

4.00' PID (HS/BG) = 5.9/2.2 PPM @ 0915 -BJS

7.00' PID (HS/BG) = 5.6/2.2 PPM @ 0920 -BJS

8.00' PID (HS/BG) = 5.9/1.9 PPM @ 0930 -BJS

10.50' PID (HS/BG) = 5.9/1.9 PPM @ 0935 PID (BZ/BG) = 1.4/1.4 PPM PID (BH/BG) = 1.4/1.4 PPM -BJS

11.50' PID (HS/BG) = 5.6/1.9 PPM @ 0945 -BJS

MLMSM MW-13 TD 15.00' 1"=4.00' 1:48.00 970203 1300 Sheet 1 of 1

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Geologic Borehole and Well Completion Log

725525.06000

Date	10/04/96 ESTDATE	Establishing Company	PARD ESCCODE
Northing	1195857.58 ft. NCOORD	Drilling Company	DRLCODE
Easting	1554462.83 ft. ECOORD	Drill Rig Type	DRLEQP
Borehole Total Depth	9.00 ft. DEPTH	Construction Method	HA CMCCODE

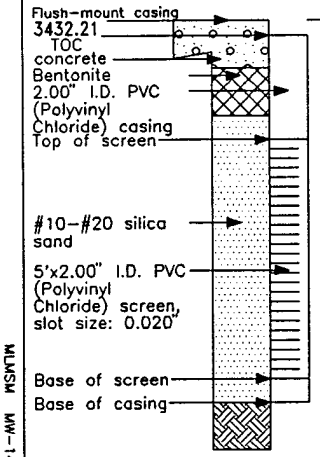
Malmstrom Air Force Base, Montana

Installation: MLMSM

Location Identification: **MW-14** LOCID

Completion

Elevation feet MSL: 3432.54



Sampling

Instrument Reading Penetration: SBD, SED, SMCODE, REC%

Depth

feet

Ground Surface

Lithology

USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description: SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. -Initials	STRATORDER
CH		CLAY, dark brown, trace silt, stiff, moist. @2.5', SAA, some petroleum staining, no odor. @4.0', trace gravel. @4.5', SAA, no gravel, trace fine sand. @9.0', SAA, slight odor. -BJS	

5

Remarks

Depth, Borehole Diameter, Drilling Problems, Weather — Time, Equipment, Water Level -Initials

- 1.00' PID (HS/BG) = 5.6/1.7 PPM -BJS
- 1.50' PID (HS/BG) = 4.9/1.5 PPM -BJS
- 3.00' PID (HS/BG) = 5.6/1.5 PPM -BJS
- 3.50' PID (HS/BG) = 5.7/1.5 PPM -BJS
- 4.00' PID (HS/BG) = 6.6/1.4 PPM -BJS
- 4.50' PID (HS/BG) = 8.8/1.4 PPM -BJS
- 5.50' PID (HS/BG) = 87.1/1.4 PPM -BJS
- 6.00' PID (HS/BG) = 12.1/1.4 PPM -BJS
- 7.00' PID (HS/BG) = 178/1.4 PPM -BJS
- 8.00' PID (HS/BG) = 35.5/1.9 PPM -BJS

MW-14

Geologic Borehole and Well Completion Log

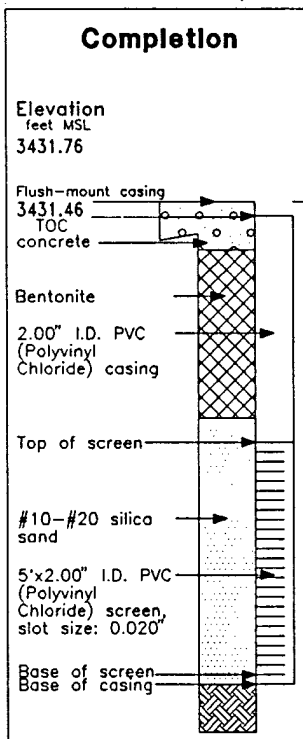
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MLMSM MW-14 TD 9.00' 1"=4.00' 1:48.00 970128 1602 Sheet 1 of 1

Geologic Borehole and Well Completion Log

725525.06000

Date	10/04/96 ESTDATE	Establishing Company	PARD ESCCODE	**Malmstrom Air Force Base, Montana**	
Northing	1196000.49 ft. NCOORD	Drilling Company	DRLCODE	Installation	MLMSM
Easting	1554529.99 ft. ECOORD	Drill Rig Type	DRLEQP	Location Identification	**MW-16** LOCID
Borehole Total Depth	11.00 ft. DEPTH	Construction Method	HA CMCCODE		



Sampling	Depth	Lithology			Remarks
Instrument Reading Penetration SBD SED SMCODE REC%	feet Ground Surface	USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description: SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. -Initials	Depth Borehole Diameter Drilling Problems Weather / Time Equipment Water Level -Initials
				CLAY, some fine sand, brown, trace iron oxide staining. -BJS	
	5	CH			3.00' PID (HS/BG) = 5.4/1.9 PPM -BJS
					4.50' PID (HS/BG) = 5.2/1.9 PPM -BJS
					6.00' PID (HS/BG) = 4.3/1.7 PPM -BJS
					7.00' PID (HS/BG) = 5.0/1.7 PPM -BJS
	10				

MW-16
Geologic Borehole and Well Completion Log

MLMSM MW-16 TD 11.00' 1"=4.00' 1:48.00 970129 1442 Sheet 1 of 1

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Geologic Borehole and Well Completion Log

725525.06000

Date	10/04/96 ESTDATE	Establishing Company	PARD ESCCODE
Northing	1195484.44 ft. NCOORD	Drilling Company	MAXM DRLCODE
Easting	1554252.99 ft. ECOORD	Drill Rig Type	B61Mobil DRLEQP
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE

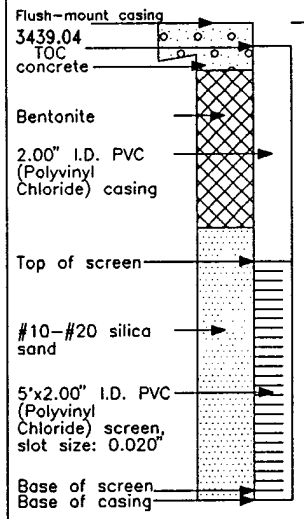
Malmstrom Air Force Base, Montana

Installation: MLMSM

Location Identification: **MW-17A** LOCID

Completion

Elevation feet MSL: 3439.54



Sampling

Instrument / Reading / Penetration — SBD — SMCODE — REC% (100 / 50)

Depth

feet

Ground Surface

5

10

Lithology

USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description — SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. –Initials	STRATORDER
SC		SAND, fine grained, some clay, dark brown, trace pebble, well sorted, dry. –BJS	
GPCH		GRAVEL and CLAY, gravel from 0.5–1" diameter, dark brown, clay friable, gravel poorly sorted, dry, soft. –BJS	
CH		CLAY, some gravel, dark brown, trace fine sand, dry. Water @7.5'. @10.0', SAA, clay black, petroleum staining, saturated. –BJS	

Remarks

Depth / Borehole Diameter / Drilling Problems / Weather — *Time / Equipment / Water Level –Initials*

2.50' PID (HS/BG) = 6.9/1.3 PPM @ 0935 –BJS

5.00' PID (HS/BG) = 7.0/1.3 PPM @ 0940 PID (BZ/BG) = 1.3/1.3 PPM –BJS

7.50' Water @ 5.85' @ 1235 PM. –BJS

MW-17A

Geologic Borehole and Well Completion Log

MLMSM MW-17A TD 10.00' 1"=4.00' 1:48.00 970129 1508 Sheet 1 of 1

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Geologic Borehole and Well Completion Log

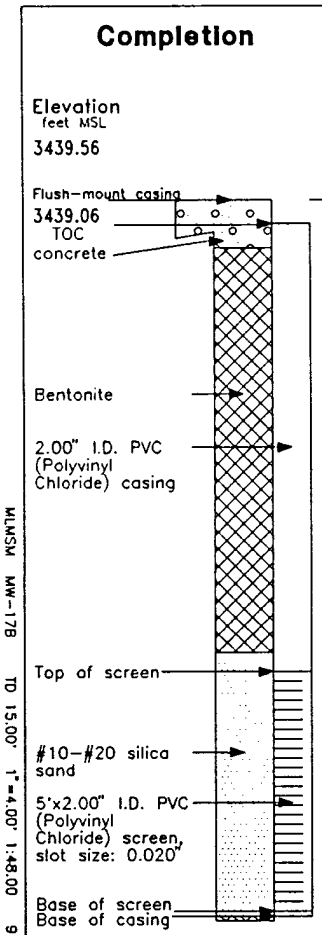
725525.06000

Date	10/04/96 ESTDATE	Establishing Company	PARD ESCCODE
Northing	1195478.54 ft. NCOORD	Drilling Company	MAXM DRLCODE
Easting	1554258.74 ft. ECOORD	Drill Rig Type	B61Mobil DRLEQP
Borehole Total Depth	15.00 ft. DEPTH	Construction Method	HS CMCCODE

Malmstrom Air Force Base, Montana

Installation: MLMSM

Location Identification: **MW-17B** LOCID



Sampling

Instrument / Reading / Penetration — SBD — SED — SMCODE — REC%

Depth (feet)

Ground Surface

USCS Unified Soil Classification System (ASTMCODE)	Lithologic Symbols & Codes (LITHCODE)	Description (SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. -Initials)	STRATORDER	Depth	Remarks
SC		SAND, fine grained, some clay, dark brown, well sorted, trace pebble, dry. -BJS			
GPCH		GRAVEL AND CLAY, dark brown, gravel from 0.5-1", poorly sorted, clay friable, dry. -BJS		5	
CH		CLAY, some gravel, dark brown, trace fine sand, dry. @10.0', SAA, petroleum staining, strong odor, trace gravel, saturated. -BJS		10	5.50' PID (BZ/BG) = 1.1/1.1 PPM -BJS 5.78' Water @ 1235 PM. -BJS 8.00' PID (BZ/BG) = 2.6/1.4 PPM -BJS 13.00' PID (HS/BG) = 60.9/1.9 PPM -BJS
				15	

Depth / Borehole Diameter / Drilling Problems / Weather — Time / Equipment / Water Level -Initials

MW-17B
Geologic Borehole and Well Completion Log

MLMSM MW-17B TD 15.00' 1"=4.00' 1:48.00 970203 1259 Sheet 1 of 1

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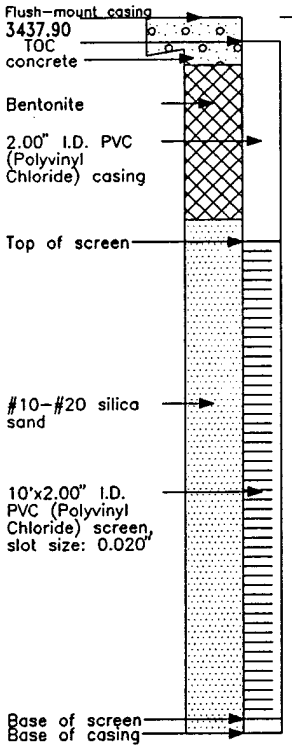
Geologic Borehole and Well Completion Log

725525.06000

Date	10/03/96 ESTDATE	Establishing Company	PARD ESCCODE	**Malmstrom Air Force Base, Montana**	
Northing	1195561.49 ft. NCOORD	Drilling Company	MAXM DRLCODE	Installation	MLMSM
Easting	1554273.79 ft. ECOORD	Drill Rig Type	B61Mobil DRLEQP	Location Identification	**MW-19** LOCID
Borehole Total Depth	15.00 ft. DEPTH	Construction Method	HS CMCCODE		

Completion

Elevation feet MSL
3438.41



Sampling

Instrument Reading Penetration SBD SMCODE SED REC% (100 50)

Depth

feet

Ground Surface

5

10

15

Lithology

USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description *SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. -Initials*	STRATORDER
SC		SAND, very fine grained, clayey, dark brown, dry, well sorted. -BJS	
GP		GRAVEL, some coarse sand, dark brown, dry, gravel 0.5-1" in size, poorly sorted. -BJS	
CH		CLAY, petroleum staining, black, trace silt, dry, petroleum odor. @6.5', SAA, moist. @7.5', SAA, no staining evident, no odor, dry. @9.0', SAA, slight petroleum staining, slight odor, dry. @12.5', SAA, no staining, no odor, dry. -BJS	

Remarks

Depth Borehole Diameter Drilling Problems Weather / *Time Equipment Water Level -Initials*

4.50' PID (HS/BG) = 1142/1.4 PPM @ 1110 -BJS

6.00' PID (HS/BG) = 135/1.7 PPM @ 1120 -BJS

7.00' PID (HS/BG) = 93.7/0.3 PPM -BJS

9.50' PID (HS/BG) = 55.0/1.7 PPM @ 1135 PID (BZ/BG) = 1.8/1.8 PPM PID (BH/BG) = 8.2/1.8 PPM -BJS

12.00' PID (HS/BG) = 11.5/1.7 PPM @ 1145 PID (BZ/BG) = 1.3/1.3 PPM -BJS

MW-19
Geologic Borehole and Well Completion Log

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MLMSM MW-19 TD 15.00' 1"=4.00' 1:48.00 970129 1602 Sheet 1 of 1

Geologic Borehole and Well Completion Log

725525.06000

Date	10/03/96 ESTDATE	Establishing Company	PARD ESCCODE
Northing	1195418.82 ft. NCOORD	Drilling Company	MAXM DRLCODE
Easting	1554227.81 ft. ECOORD	Drill Rig Type	B61Mobil DRLEQP
Borehole Total Depth	15.00 ft. DEPTH	Construction Method	HS CMCCODE

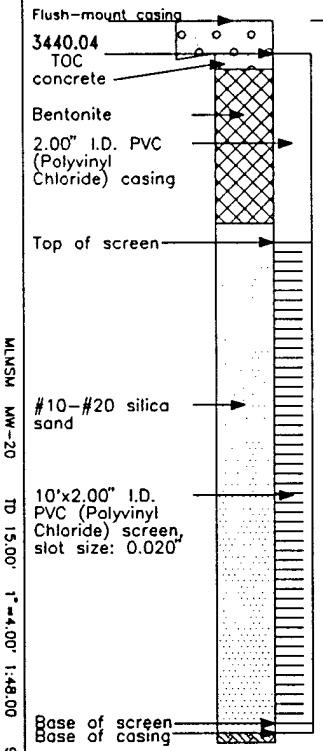
Malmstrom Air Force Base, Montana

Installation: MLMSM

Location Identification: **MW-20** LOCID

Completion

Elevation feet MSL
3440.72



Sampling

Instrument Reading Penetration — SBD — SED — SMCODE — REC%

Depth

feet

Ground Surface

5

10

15

Lithology

USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description — SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. -Initials	STRATORDER
SC		SAND, fine grained, dark brown, trace pebble, some clay, at 2.0' hit petroleum staining, strong odor, well sorted. -BJS	
CH		CLAY, petroleum staining, odor, black, stiff, fine sand. @5.5' SAA, wet, gray, trace of calcite nodules, odor, petroleum staining. @10.0', SAA, color dark brown, staining not evident. -BJS	

Remarks

Depth / Borehole Diameter / Drilling Problems / Weather — Time / Equipment / Water Level -Initials

2.00' PID (HS/BG) = 122/1.3 PPM @ 1555 -BJS

5.00' PID (BZ/BG) = 1.7/1.7 PPM @ 1615 PID (BH/BG) = 122/1.7 PPM -BJS

7.50' PID (BZ/BG) = 1.3/1.3 PPM @ 1635 -BJS

14.00' PID (HS/BG) = 152/2.4 PPM (DRILL CUTTINGS) -BJS

MLMSM MW-20 TD 15.00' 1"=4.00' 1:48.00 970130 1010 Sheet 1 of 1

MW-20
Geologic Borehole and Well Completion Log

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MW-21

Geologic Borehole and Well Completion Log

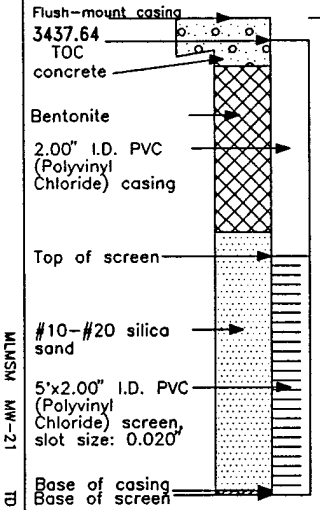
Geologic Borehole and Well Completion Log

725525.06000

Date	10/04/96 ESTDATE	Establishing Company	PARD ESCCODE	**Malmstrom Air Force Base, Montana**	
Northing	1195591.68 ft. NCOORD	Drilling Company	MAXM DRLCODE	Installation	MLMSM
Easting	1554229.66 ft. ECOORD	Drill Rig Type	B61Mobil DRLEQP	Location Identification	**MW-21** LOCID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HS CMCCODE		

Completion

Elevation feet MSL
3438.11



Sampling

Instrument Reading Penetration
SBD
SED
SMCODE
REC%

Depth

feet

Ground Surface

5

10

Lithology

USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description *SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. –Initials*	STRATORDER
SC		SAND, fine grained, some pebble, some clay, poorly sorted, dry, dark brown. –BJS	
CH		CLAY, some fine sand, soft, dark brown, dry, trace pebble. @4.5', SAA, black, petroleum staining, strong odor. @8.0', water. –BJS	
SC		SAND, some clay, well sorted, black, petroleum stained, saturated. –BJS	
CH		CLAY, some fine sand, black, petroleum stained, strong odor, saturated. –BJS	

Remarks

Depth Borehole Diameter Drilling Problems Weather — *Time Equipment Water Level –Initials*

4.50' PID (HS/BG) = 31.1/2.1 PPM @ 1325 –BJS

6.00' PID (HS/BG) = 27.2/1.4 PPM @ 1330 –BJS

7.50' PID (HS/BG) = 10.3/2.4 PPM –BJS

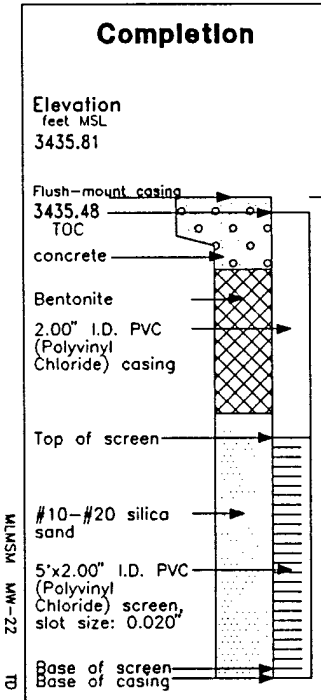
MLMSM MW-21 TD 10.00' 1"=4.00' 1:48.00 970130 1103 Sheet 1 of 1

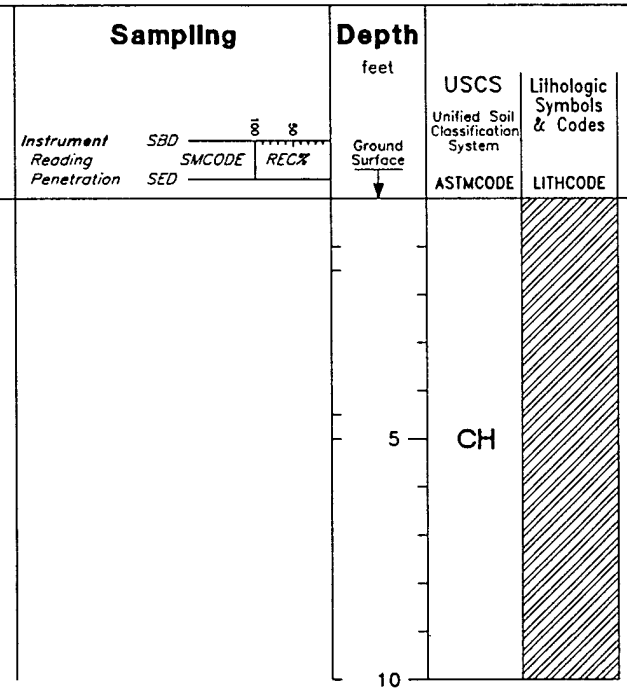
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Geologic Borehole and Well Completion Log

725525.06000

Date	10/04/96 ESTDATE	Establishing Company	PARD ESCCODE	**Malmstrom Air Force Base, Montana**	
Northing	1195651.53 ft. NCOORD	Drilling Company	DRLCODE	Installation	MLMSM
Easting	1554268.66 ft. ECOORD	Drill Rig Type	DRLEQP	Location Identification	**MW-22** LOCID
Borehole Total Depth	10.00 ft. DEPTH	Construction Method	HA CMCCODE		





Remarks

Depth / Borehole Diameter / Drilling Problems / Weather — *Time / Equipment / Water Level -Initials*

- 1.50' PID (HS/BG) = 7.4/1.4 PPM -BJS
- 2.50' PID (HS/BG) = 16.7/1.4 PPM -BJS
- 3.00' PID (HS/BG) = 201/1.9 PPM -BJS
- 4.50' PID (HS/BG) = 105/3.3 PPM -BJS
- 6.00' PID (HS/BG) = 87.2/2.4 PPM -BJS

MW-22
Geologic Borehole and Well Completion Log

MLMSM MW-22 TD 10.00' 1"=4.00' 1:48.00 970130 1141 Sheet 1 of 1

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Geologic Borehole and Well Completion Log

725525.06000

Date	10/03/96 ESTDATE	Establishing Company	PARD ESCCODE	**Malmstrom Air Force Base, Montana**	
Northing	1195733.44 ft. NCOORD	Drilling Company	DRLCODE	Installation	MLMSM
Easting	1554345.01 ft. ECOORD	Drill Rig Type	DRLEQP	Location Identification	**SB-20** LOCID
Borehole Total Depth	9.40 ft. DEPTH	Construction Method	HA CMCCODE		

Completion	Sampling	Depth	Lithology				Remarks	
Elevation feet MSL	Instrument Reading Penetration / SBD SED / SMCODE / REC%	Depth feet Ground Surface	USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description *SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. –Initials*	STRATORDER	*Depth Borehole Diameter Drilling Problems Weather*	*Time Equipment Water Level –Initials*
3434.30		5	CH		CLAY, silty and sandy, fine grained, brown, moist. @2.5', SAA, except very moist, slight petroleum odor, gray/some caliche. @3.5', black staining starts, CLAY, some silt, light brown, wet, some staining @ 3.5–5.5' bgs. –DBT		2.50' PID (HS/BG) = 6.9/1.5PPM –DBT 4.00' PID (HS/BG) = 143/1.2 PPM –DBT	

SB-20

Geologic Borehole and Well Completion Log

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MLMSM SB-20 TD 9.40' 1"=4.00' 1:48.00 970130 1335 Sheet 1 of 1

Geologic Borehole and Well Completion Log

725525.06000

Date	10/03/96 ESTDATE	Establishing Company	PARD ESCCODE	**Malmstrom Air Force Base, Montana**	
Northing	1195940.08 ft. NCOORD	Drilling Company	DRLCODE		
Easting	1554539.38 ft. ECOORD	Drill Rig Type	DRLEQP	Installation	MLMSM
Borehole Total Depth	9.00 ft. DEPTH	Construction Method	HA CMCCODE	Location Identification	**SB-21** LOCID

Completion	Sampling	Depth	Lithology			Remarks
Elevation feet MSL	Instrument Reading Penetration; SBD; SED; SMCODE; REC%	feet	USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description: SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. –Initials	Depth, Borehole Diameter, Drilling Problems, Weather; Time, Equipment, Water Level –Initials
3431.50		Ground Surface				0.00' Partly sunny, breezy, 75 degrees F. –BJS
			CH		CLAY, some silt, brown, moist. @ 3' some possible staining. @ 3.5' trace iron oxide staining. @ 4–9' some gravel –BJS	1.50' PID (HS/BG) = 6.8/1.5 PPM –BJS
						2.00' PID (HS/BG) = 7.0/1.5 PPM –BJS
						2.50' PID (HS/BG) = 6.7/1.2 PPM –BJS
						3.00' PID (HS/BG) = 6.7/1.2 PPM –BJS
		5				3.50' PID (HS/BG) = 6.2/1.2 PPM –BJS
						4.00' PID (HS/BG) = 6.2/1.2 PPM –BJS
						5.00' PID (HS/BG) = 5.0/1.2 PPM –BJS
						6.00' PID (HS/BG) = 5.5/1.1 PPM –BJS
						9.00' No water. –BJS

STRATORDER

SB-21
Geologic Borehole and Well Completion Log

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MLMSM SB-21 TD 9.00' 1"=4.00' 1:48.00 970130 1353 Sheet 1 of 1

Geologic Borehole and Well Completion Log

725525.06000

Date	10/24/96 ESTDATE	Establishing Company	PARD ESCCODE
Northing	1195572.75 ft. NCOORD	Drilling Company	DRLCODE
Easting	1554186.83 ft. ECOORD	Drill Rig Type	DRLEQP
Borehole Total Depth	3.00 ft. DEPTH	Construction Method	HA CMCCODE

Malmstrom Air Force Base, Montana

Installation: MLMSM

Location Identification: **SB-23** LOCID

Completion	Sampling	Depth	Lithology			Remarks
Elevation feet MSL	Instrument / Reading / Penetration; SBD / SED; SMCODE; REC%	feet; Ground Surface	USCS Unified Soil Classification System / ASTMCODE	Lithologic Symbols & Codes / LITHCODE	Description: SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. –Initials	STRATORDER	Depth, Borehole Diameter, Drilling Problems, Weather; Time, Equipment, Water Level –Initials
3435.90	0.00 – 0.25 HA		CHML		CLAY, some silt, brown, moist. @ 2' petroleum stained and odor. –DBT		0.00' Partly cloudy, mild wind, about 45 degrees F. –DBT
	pid 289.00 PPM; 2.00 – 3.00 HA						

SB-23
Geologic Borehole and Well Completion Log

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MLMSM SB-23 TD 3.00' 1"=4.00' 1:48.00 970130 1421 Sheet 1 of 1

SB-24
Geologic Borehole and Well Completion Log

Geologic Borehole and Well Completion Log

725525.06000

Date	10/24/96 ESTDATE	Establishing Company	PARD ESCCODE	**Malmstrom Air Force Base, Montana**	
Northing	1195604.19 ft. NCOORD	Drilling Company	DRLCODE	Installation	MLMSM
Easting	1554149.40 ft. ECOORD	Drill Rig Type	DRLEOP	Location Identification	**SB-24** LOCID
Borehole Total Depth	3.00 ft. DEPTH	Construction Method	HA CMCCODE		

Completion	Sampling	Depth	Lithology				Remarks	
Elevation feet MSL	Instrument Reading Penetration / SBD SED / SMCODE / REC%	feet	USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description: SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. -Initials	STRATORDER	Depth / Borehole Diameter / Drilling Problems / Weather	Time / Equipment / Water Level -Initials
3435.60	0.00–0.25 HA	Ground Surface	CHML		CLAY, silty, brown, moist. @2' stained and petroleum odor. -DBT		0.00' Partly cloudy, about 45 degrees F. -DBT	
	pid 251.00 PPM 2.00–3.00 HA							

MLMSM SB-24 TD 3.00' 1"=4.00' 1:48.00 970130 1440 Sheet 1 of 1

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Geologic Borehole and Well Completion Log

725525.06000

Date	10/24/96 ESTDATE	Establishing Company	PARD ESCCODE	**Malmstrom Air Force Base, Montana**	
Northing	1195771.29 ft. NCOORD	Drilling Company	DRLCODE	Installation	MLMSM
Easting	1554304.68 ft. ECOORD	Drill Rig Type	DRLEQP	Location Identification	**SB-25** LOCID
Borehole Total Depth	3.00 ft. DEPTH	Construction Method	HA CMCCODE		

Completion	Sampling			Depth	Lithology				Remarks	
Elevation feet MSL	*Instrument Reading Penetration*	SBD / SED	SMCODE / REC%	feet Ground Surface	USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description *SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. –Initials*	STRATORDER	*Depth, Borehole Diameter, Drilling Problems, Weather*	*Time, Equipment, Water Level* –Initials
3434.20		0.00	HA							
		0.25			CHML		CLAY, some silt, brown, moist. @ 2' slight petroleum staining. –DBT		0.00' Partly cloudy, about 45 degrees F. –DBT	
	pid 20.40 PPM	2.00	HA							
		3.00								

SB-25
Geologic Borehole and Well Completion Log

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MLMSM SB-25 TD 3.00' 1"=4.00' 1:48.00 970130 1459 Sheet 1 of 1

Geologic Borehole and Well Completion Log

725525.06000

Date	10/24/96 ESTDATE	Establishing Company	PARD ESCCODE	**Malmstrom Air Force Base, Montana**	
Northing	1195742.43 ft. NCOORD	Drilling Company	DRLCODE		
Easting	1554347.44 ft. ECOORD	Drill Rig Type	DRLEQP	Installation	MLMSM
Borehole Total Depth	3.00 ft. DEPTH	Construction Method	HA CMCCODE	Location Identification	**SB-26** LOCID

Completion	Sampling			Depth	Lithology			Remarks	
Elevation feet MSL	*Instrument Reading Penetration*	SBD / SED	SMCODE / REC%	feet	USCS Unified Soil Classification System ASTMCODE	Lithologic Symbols & Codes LITHCODE	Description *SOIL/ROCK TYPE, modifiers/grain size, sorting, color, cement/lithification, moisture content, porosity, permeability/fracturing. –Initials*	STRATORDER	*Depth, Borehole Diameter, Drilling Problems, Weather* / *Time, Equipment, Water Level* –Initials
3433.00		0.00 – 0.25	HA	Ground Surface	CHML		CLAY, some silt, brown, moist. –DBT		0.00' Partly cloudy, slight wind, about 45 degrees F. –DBT
	pid 21.80 PPM	2.00 – 3.00	HA						

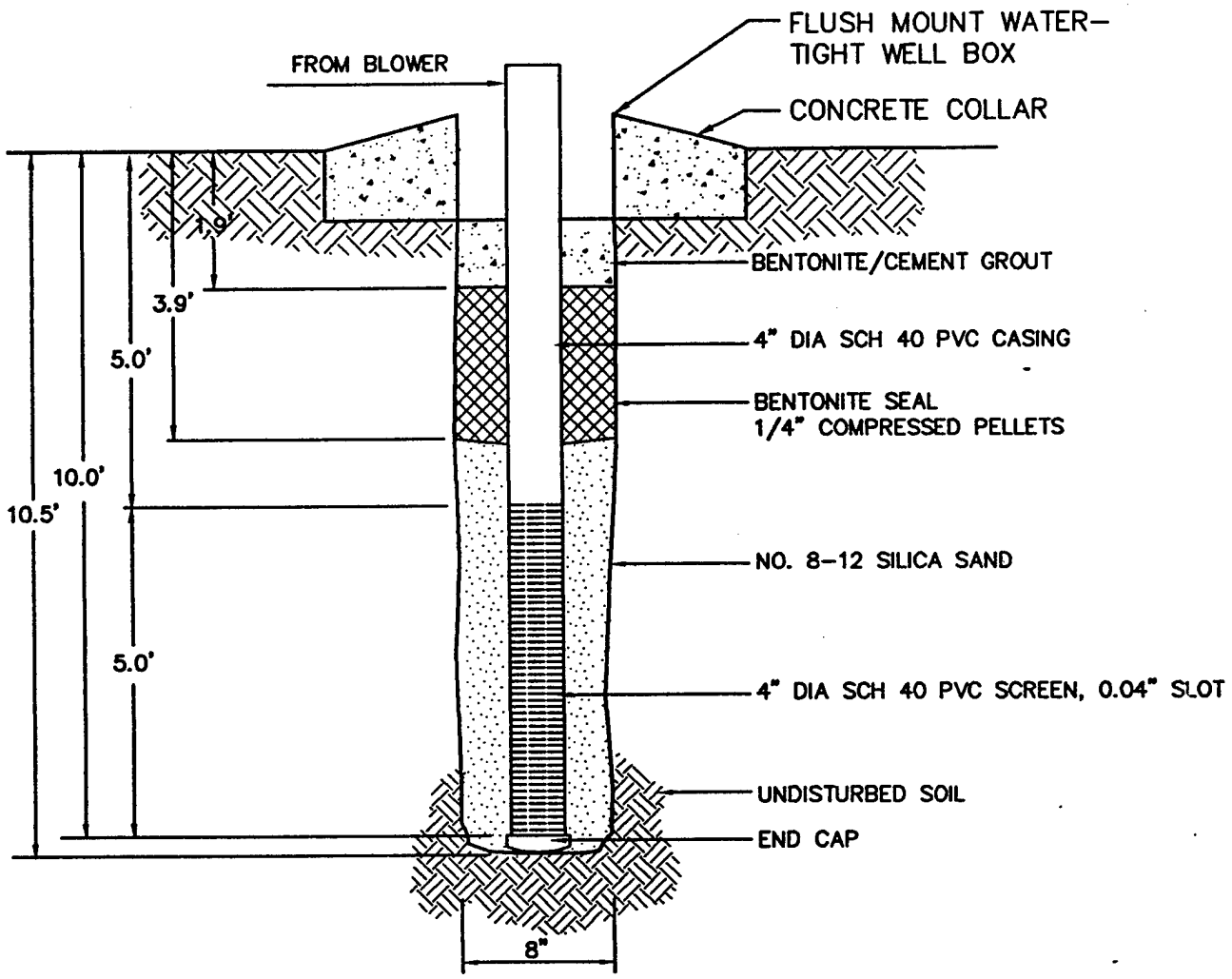
SB-26
Geologic Borehole and Well Completion Log

PARSONS ENGINEERING SCIENCE, INC
Denver, Colorado
(303) 831-8100

MLMSM SB-26 TD 3.00' 1"=4.00' 1:48.00 970130 1511 Sheet 1 of 1

Point	Northing	Easting	Elevation	Note
68	1195469.185900	1554053.384200	3440.030	CP 68
213	1195447.950400	1554431.312300	3444.845	CP 213
300	1195615.693500	1554417.673300	3436.830	~~MW 6~~ ~~MW 6~~ OK
301	1195616.360800	1554419.166400	3436.648	Grnd Shot
302	1195543.006300	1554339.587100	3437.786	MW 3
303	1195541.197700	1554338.279700	3437.626	Grnd Shot
304	1195513.217000	1554435.405700	3437.632	MW 7
305	1195514.842600	1554436.739300	3437.587	Asph
306	1195442.709300	1554338.507700	3439.187	MW 2
307	1195441.314500	1554337.164900	3439.262	Grnd Shot
308	1195344.582600	1554264.355600	3441.070	SB 13
309	1195343.142500	1554264.601200	3441.237	Grnd Shot
310	1195259.207500	1554196.354400	3441.348	MW 1
311	1195256.935200	1554197.554500	3441.209	Grnd Shot
312	1195735.936900	1554170.771000	3439.032	MW 5
313	1195735.205000	1554169.568200	3438.839	Grnd Shot
314	1195668.582100	1554181.386400	3437.472	PIN FLAG SB-1
315	1195641.802100	1554197.221000	3438.142	PIN FLAG SG-3
316	1195554.019100	1554261.184900	3438.313	MW 10
317	1195552.773500	1554259.927900	3438.173	Grnd Shot
318	1195564.365700	1554243.967000	3438.394	SB 10
319	1195506.952000	1554317.253600	3438.271	PIN FLAG GW-2
320	1195400.173100	1554231.710200	3440.754	MW 15
321	1195398.660300	1554231.000700	3440.590	Grnd Shot
323	1195590.557600	1554087.969100	3439.099	MW 8
324	1195591.211800	1554086.817400	3439.101	Asph
325	1195622.157100	1554118.954500	3438.660	~~MW 9~~ ~~MW 9~~ OK
326	1195622.721100	1554117.961000	3438.705	Asph
327	1195657.937700	1554154.245600	3438.053	MW 11
328	1195657.659400	1554152.722000	3438.121	Asph
329	1195675.651900	1554102.017100	3439.307	MW 4
330	1195674.569300	1554103.178900	3439.072	Grnd Shot
331	1195685.453600	1554222.357300	3434.738	PINFLAG SED-10
333	1195618.003600	1554156.466400	3436.401	PINFLAG SW-4
334	1195604.859200	1554148.605000	3435.768	STAKE SED-9
335	1195597.381100	1554152.766500	3438.396	MW 18+CASING
336	1195598.414300	1554153.571500	3438.373	Grnd Shot
337	1195598.226000	1554155.594600	3438.877	PINFLAG SG-4
338	1195580.778300	1554139.523500	3439.400	PINFLAG ~~SED-6~~ SG-5
339	1195566.732000	1554112.746100	3436.901	PINFLAG SED-8
340	1195520.035600	1554070.272200	3437.448	PINFLAG SW-3
341	1195494.464800	1554116.005600	3437.225	PINFLAG SED-1
342	1195531.357800	1554149.570900	3436.261	PINFLAG SED-5
343	1195564.383700	1554179.481400	3435.739	STAKE GW/SED-6
344	1195599.228200	1554211.878300	3435.163	PINFLAG SED-7
345	1195648.110000	1554258.757300	3434.785	PINFLAG SED/SW-2
346	1195559.781600	1554195.883700	3438.316	MW BIO
347	1195558.685500	1554197.139800	3438.356	Grnd Shot
348	1195566.898500	1554201.807400	3438.242	MW12 SG-2
349	1195564.724300	1554201.315000	3438.250	Grnd Shot
356	1195500.422100	1554134.827700	3438.515	PINFLAG SB-2/SG-1
VW	1195538.829550	1554170.968130	3438.779	LID

Point	Northing	Easting	Elevation	Note
13	1195649.380000	1554361.400000	3436.920	M WELL 13 LID
14	1195857.580000	1554462.830000	3432.540	M WELL 14 LID
16	1196000.490000	1554529.990000	3431.760	M WELL 16 LID
17	1195484.440000	1554252.990000	3439.540	M WELL 17A LID
18	1195478.540000	1554258.740000	3439.560	M WELL 17B LID
19	1195561.490000	1554273.790000	3438.410	M WELL 19 LID
20	1195418.820000	1554227.810000	3440.720	M WELL 20 LID
21	1195591.680000	1554229.660000	3438.110	M WELL 21 LID
22	1195651.530000	1554268.660000	3435.810	M WELL 22 LID
113	1195649.380000	1554361.400000	3436.430	M WELL 13 CASING
114	1195857.580000	1554462.830000	3432.210	M WELL 14 CASING
116	1196000.490000	1554529.990000	3431.460	M WELL 16 CASING
117	1195484.440000	1554252.990000	3439.040	MWELL 17A CASING
118	1195478.540000	1554258.740000	3439.060	MWELL 17B CASING
119	1195561.490000	1554273.790000	3437.900	M WELL 19 CASING
120	1195418.820000	1554227.810000	3440.040	M WELL 20 CASING
121	1195591.680000	1554229.660000	3437.640	M WELL 21 CASING
122	1195649.380000	1554361.400000	3435.480	M WELL 22 CASING
220	1195733.440000	1554345.010000	3434.300	SOIL BORE 20
221	1195940.080000	1554539.380000	3431.500	SOIL BORE 21
223	1195572.750000	1554186.830000	3435.900	SOIL BORE 23
224	1195604.190000	1554149.400000	3435.600	SOIL BORE 24
225	1195771.290000	1554304.680000	3434.200	SOIL BORE 25
226	1195742.430000	1554347.440000	3433.000	SOIL BORE 26



NOT TO SCALE

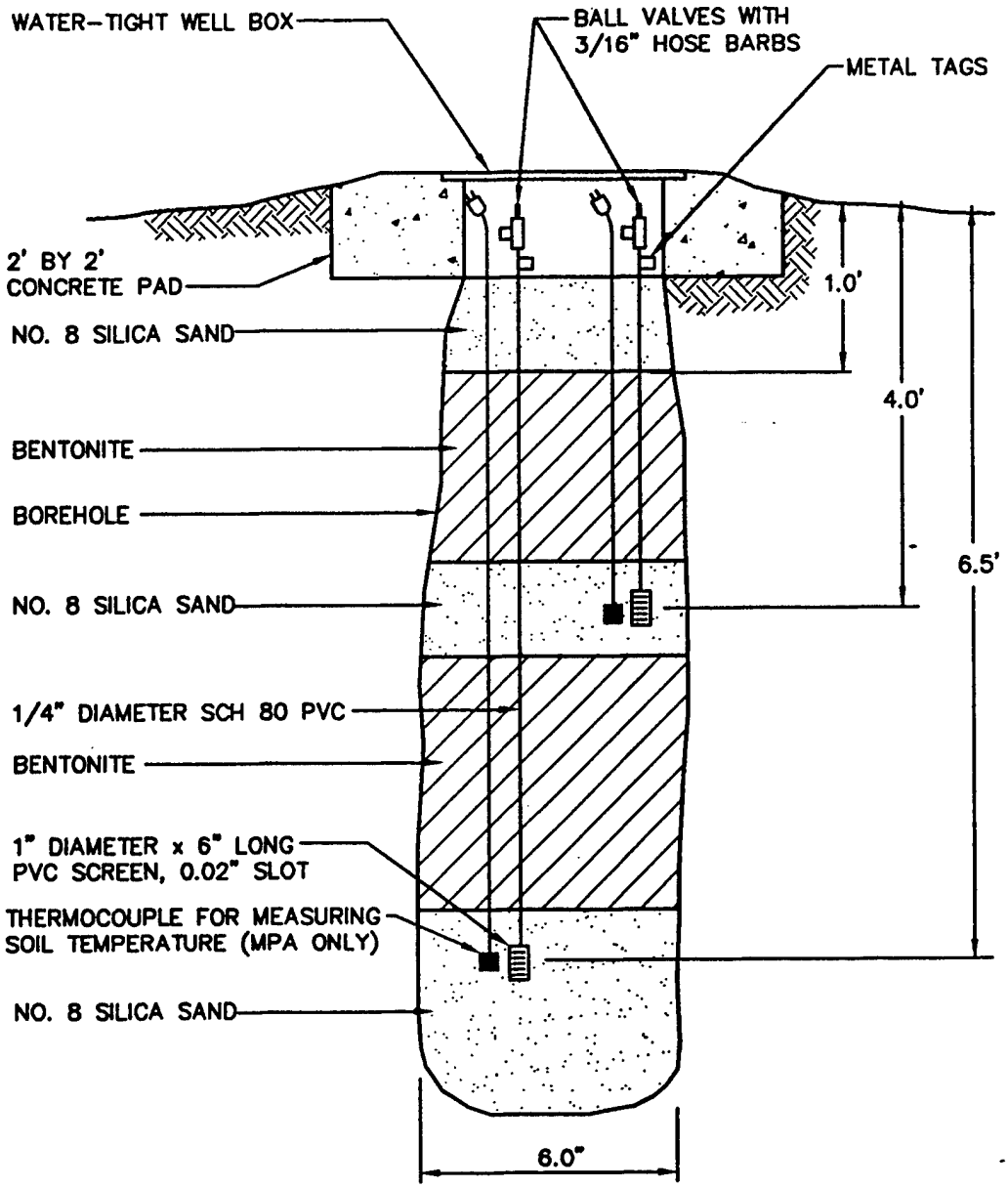
AS-BUILT INJECTION/VENT WELL CONSTRUCTION DETAIL PS-3, PUMPHOUSE 2

MALMSTROM AFB, MONTANA

ENGINEERING-SCIENCE, INC.

Denver, Colorado

93DN1349, 12/06/93 at 14:20



NOT TO SCALE

TYPICAL AS-BUILT MONITORING POINT CONSTRUCTION DETAIL PS-3, PUMPHOUSE 2

Malmstrom AFB, Montana

ENGINEERING-SCIENCE, INC.

Denver, Colorado

93DN0911, 12/06/93 at 11:26

9/30/93 DEZ68.38.04 RAF/DBT

PHZ- MPA

GS headspace

GRAVEL 1"-1½" w/ some CLAY — 1'

SAA

CLAY w/ sm gravel, odor — 2' 760ppm

CLAY w/ 5in sand lenses

SAA — 3' 220

V. moist SAA - increasing H_2O — 4' 280

SAA - less sand, v plastic + moist — 5' 250

▽ Stunted sand lenses + CLAY

SAA - definitely below GW — 6' 112

— 7'

poor sample recovery

— 8'

TD — 9'

— 10'

AF/DBT
- after shopper
calls Free
known that
o drill up hill

se 2
, plumbing
mongst owners
ill shovel
F lost coin
ng to 2 foot
field book,
l cuttings
. Soil of
staining and
r,
o wet day
, may be difficult
entative simple
s at MPA
s at MPA
SG MPA
s. Clean up

" BTUG

10/1/93 DEZ68.38.04 RAF/DBT

PHZ-MPB

6.5 H.S

GRAVEL w/ sm CLAY

CLAY w/ SAND seams — 1

SAA - STRONG ODOR sm — 2

Weak staining

increasing moisture w/ depth — 3

CLAY is very stiff 2,000

SAA — 4

▽ — 5

— 6

— 7

SAA

TD = 8' — 8

04 RAF/DBT

ll go in at

4' and 6.5'

ple Sam

5'

nterval MPA

drill MRB,

MPA.

3" and sample

, get deep point

ut 7' bgs in MPA.

ly.

we will try

ally.

out.

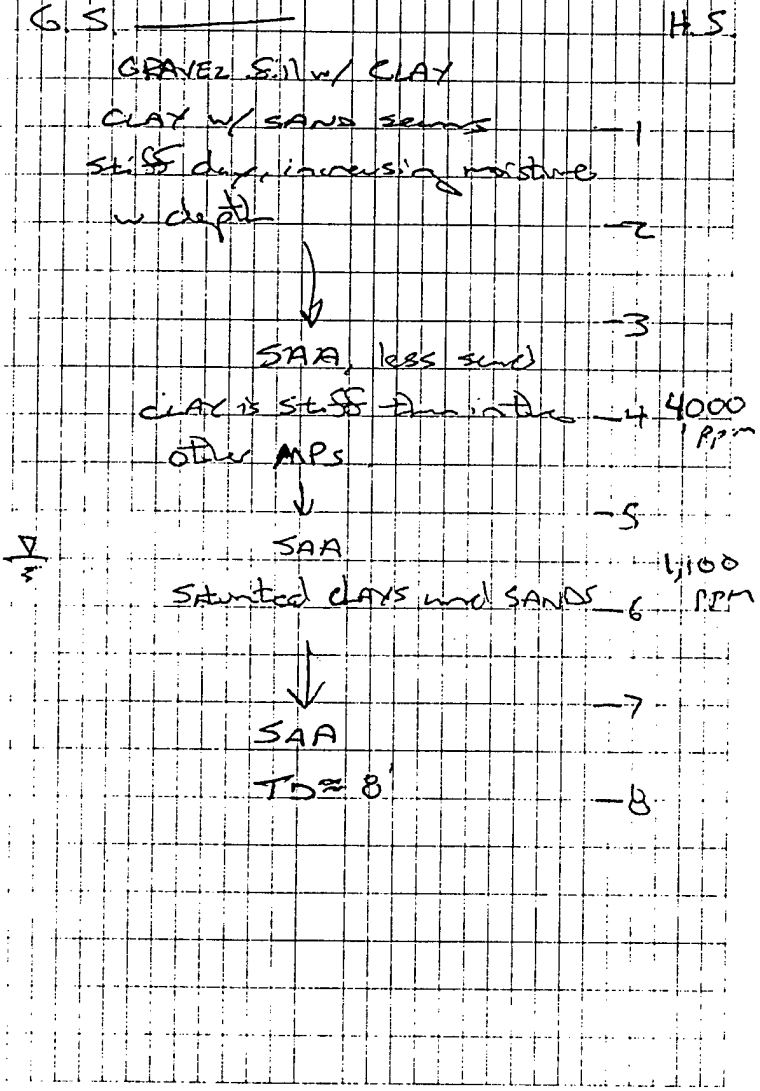
tonite chips and

with Dan Duff

n up.

10/2/93 DEZ68.38.0Z RAF/DBT

PHZ=MPC



DEZ68.38.0Z RAF/DBT
...ll MPs, install all
...d Sums for concrete
site, lock gate and

...de MGMT and leave
...it for day

...

WELL CONSTRUCTION FORM

Installation: MAFB
Site: GA #2
Well ID: MW-1
Comp. started 11 / 4 / 94 (9:45 am)

Project no. 725525.03000
Drilling contractors: O'KEEFE
Comp. finished: 11 / 4 / 94 (11:57 am)

1
1.5
2.5
2.5

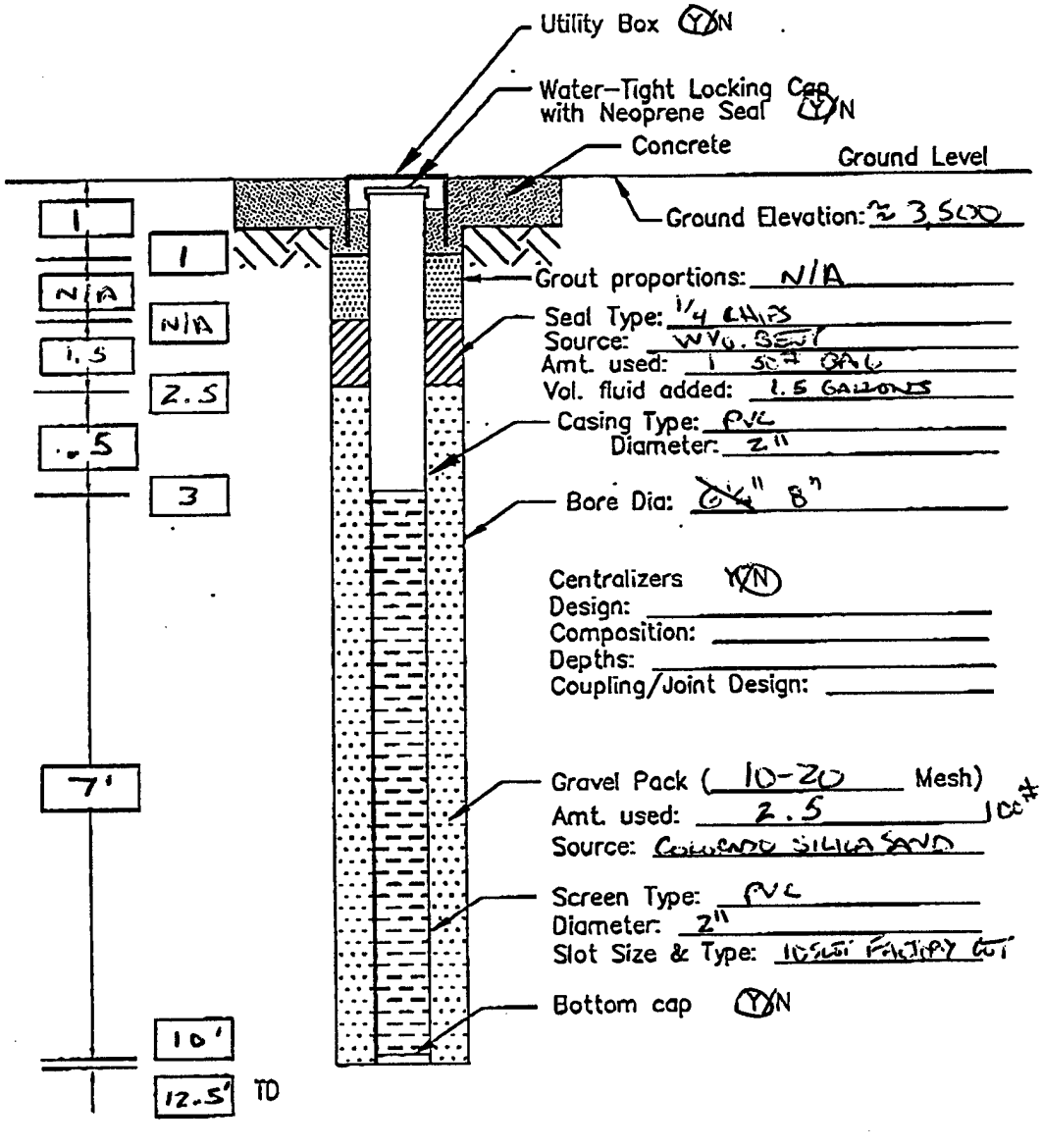


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: PH#2
Well ID: MW-2
Comp. started 11 / 4 / 94 (10:56 m)

Project no. 725525.03000
Drilling contractors: O'KEEFE
Comp. finished: 11 / 4 / 94 (11:20 m)

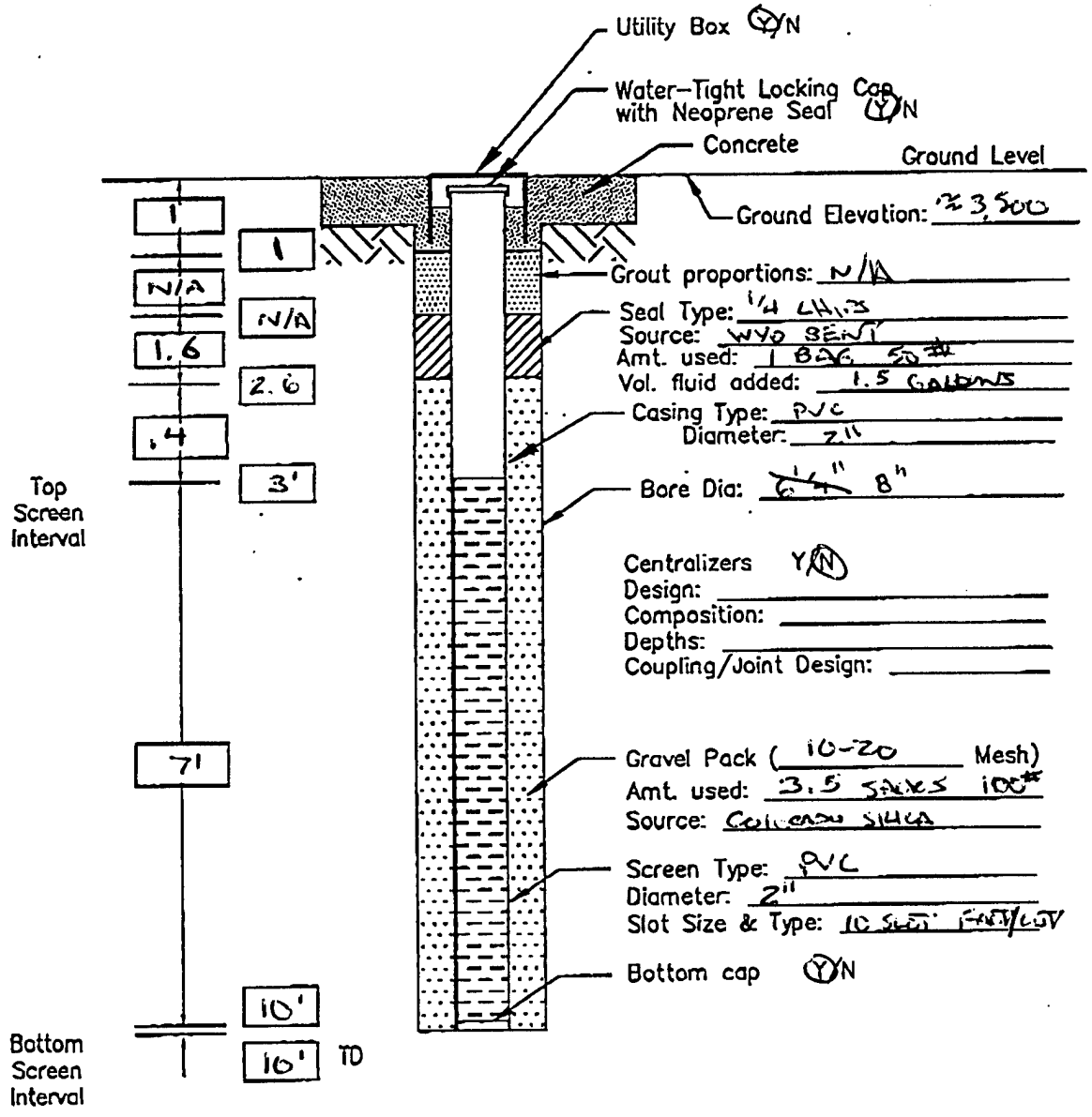


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: PH #2
Well ID: MW-3
Comp. started 11 / 4 / 94 (13:10 m)

Project no. 725525.030.02
Drilling contractors: O'KEEFE
Comp. finished: 11 / 4 / 94 (13:34 m)

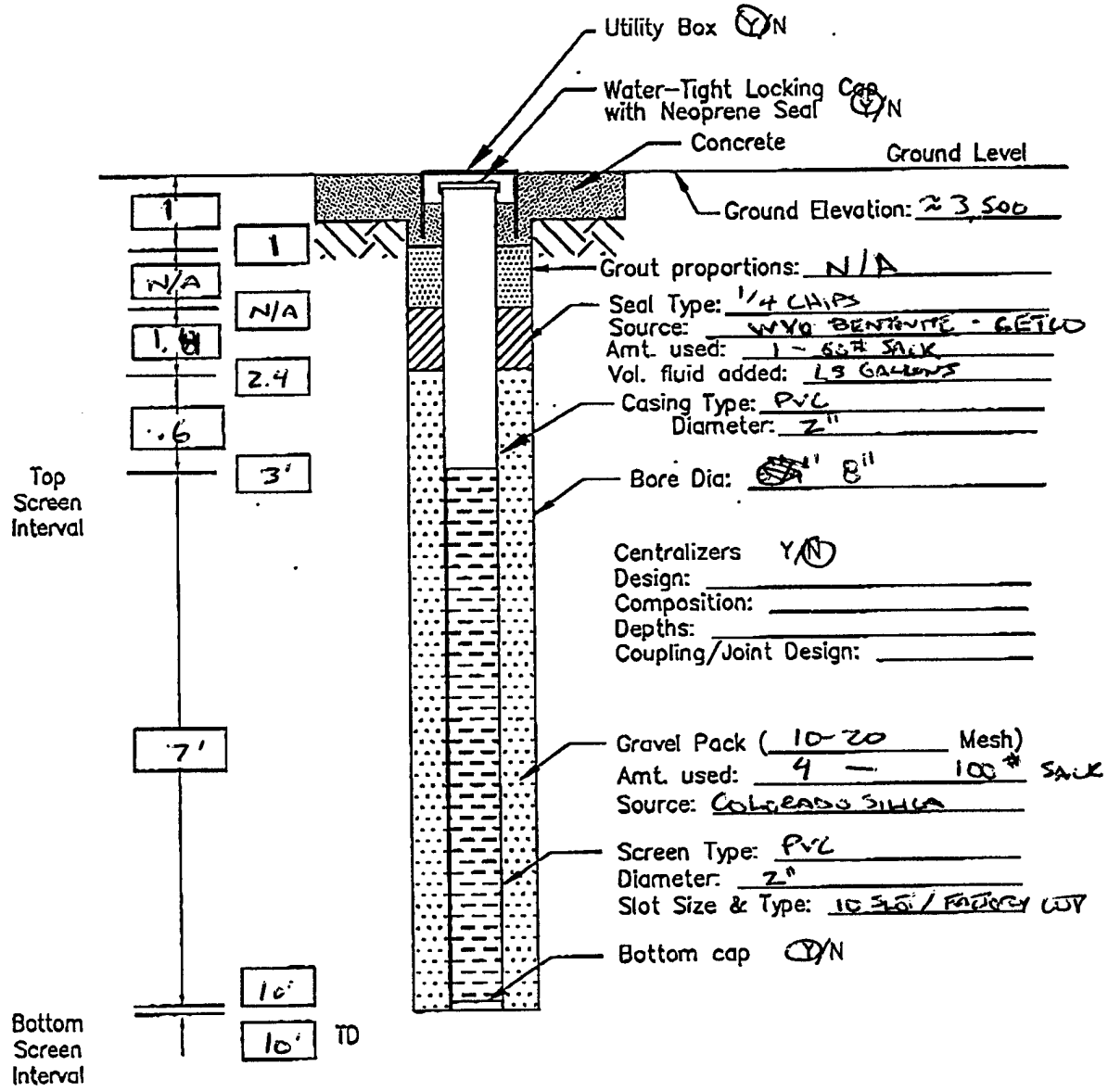


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: P&A #7
Well ID: MW-4
Comp. started 11 / 5 / 94 08:59 m)

Project no. 725525.03000
Drilling contractors: O'KEEFE
Comp. finished: 11 / 5 / 94 (09:12 m)

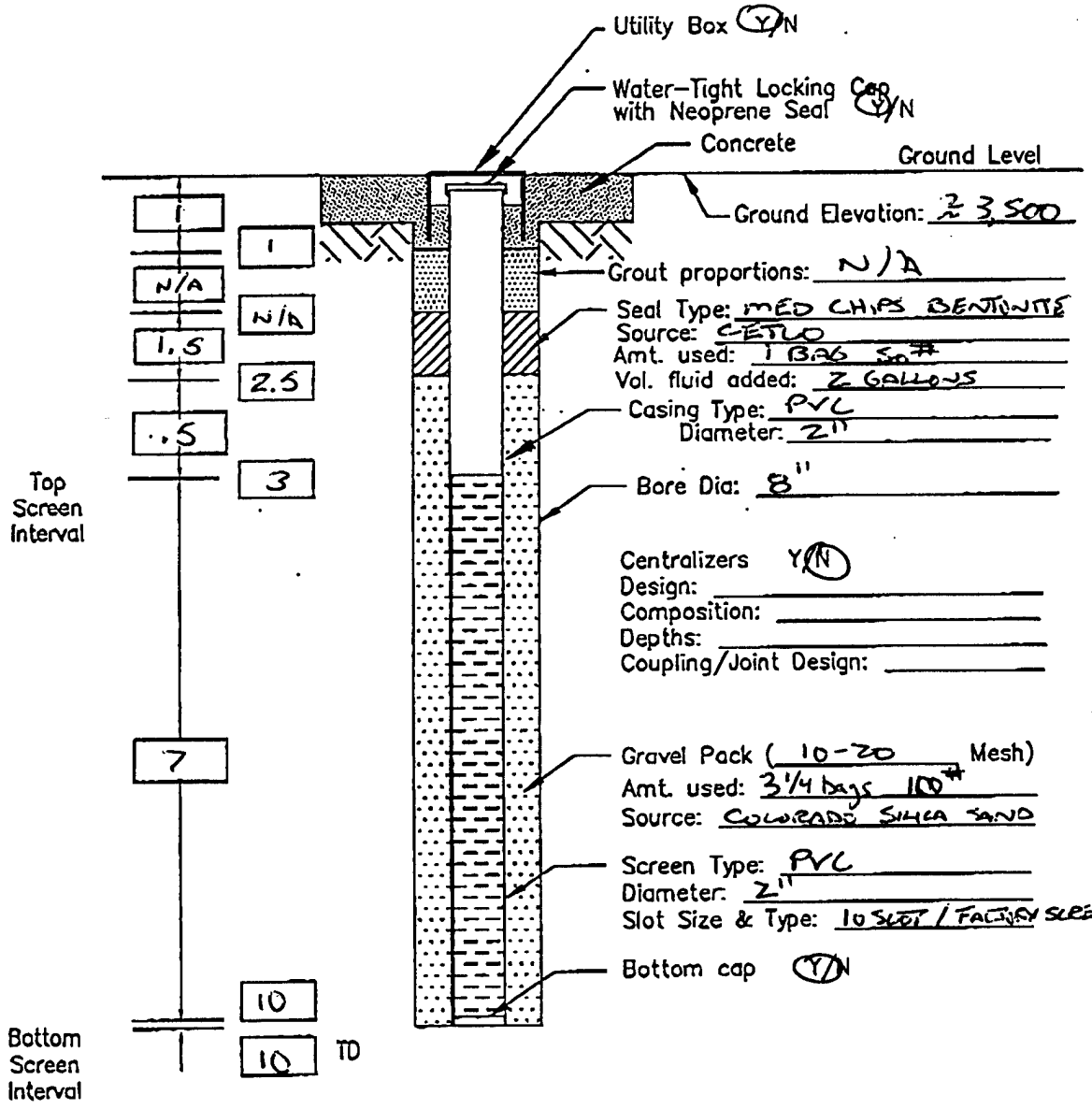


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: PA#2
Well ID: MW-5
Comp. started 11 / 5 / 94 (10:05 m)

Project no. 725525.03000
Drilling contractors: ~~BAF~~ O'KEEFE
Comp. finished: 11 / 5 / 94 (10:24 m)

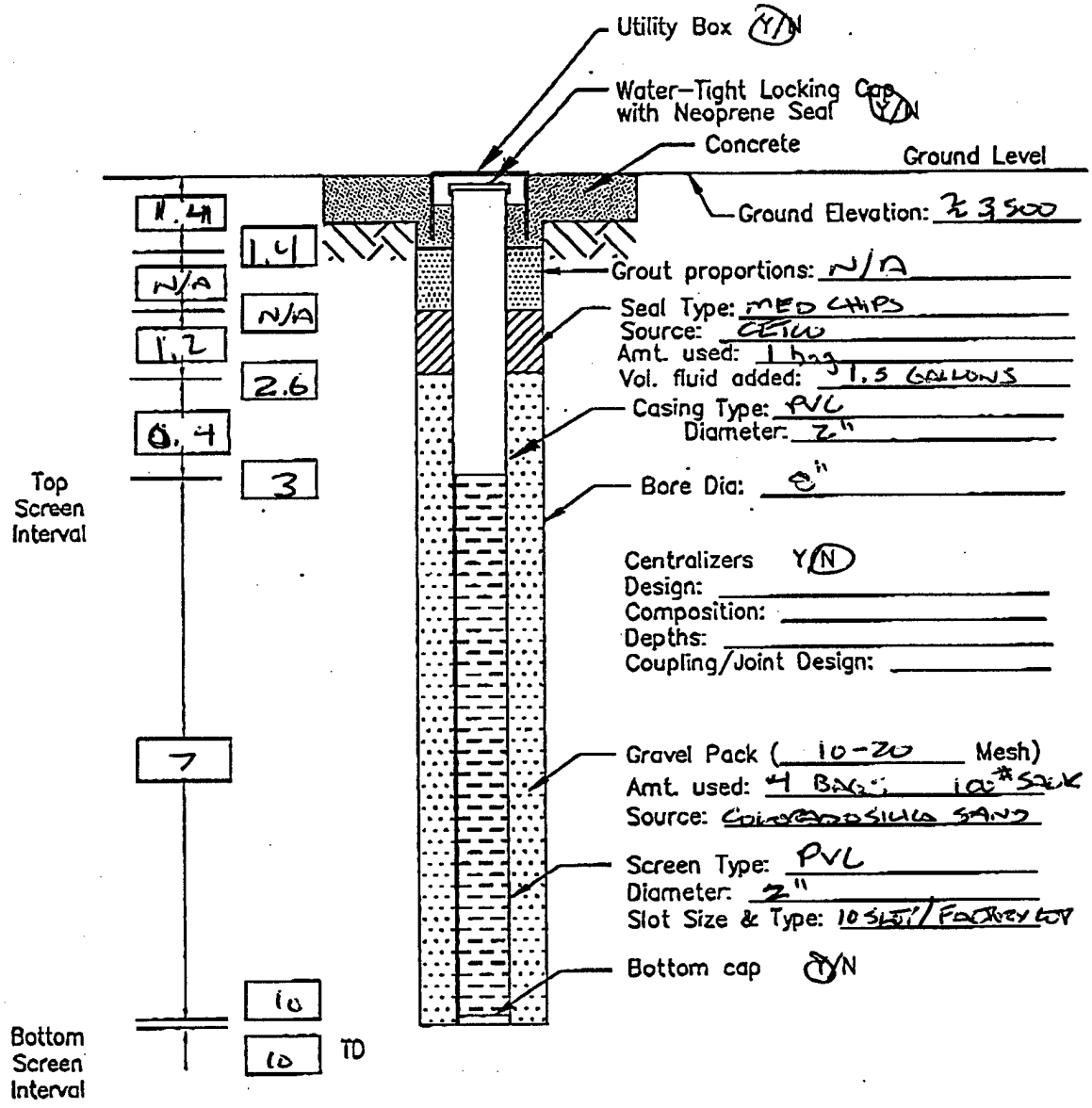


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: PA#2
Well ID: MW-6
Comp. started 11 / 5 / 94 (11:10 am)

Project no. 725525.030.00
Drilling contractors: O'KEEFE
Comp. finished: 11 / 5 / 94 (11:25 am)

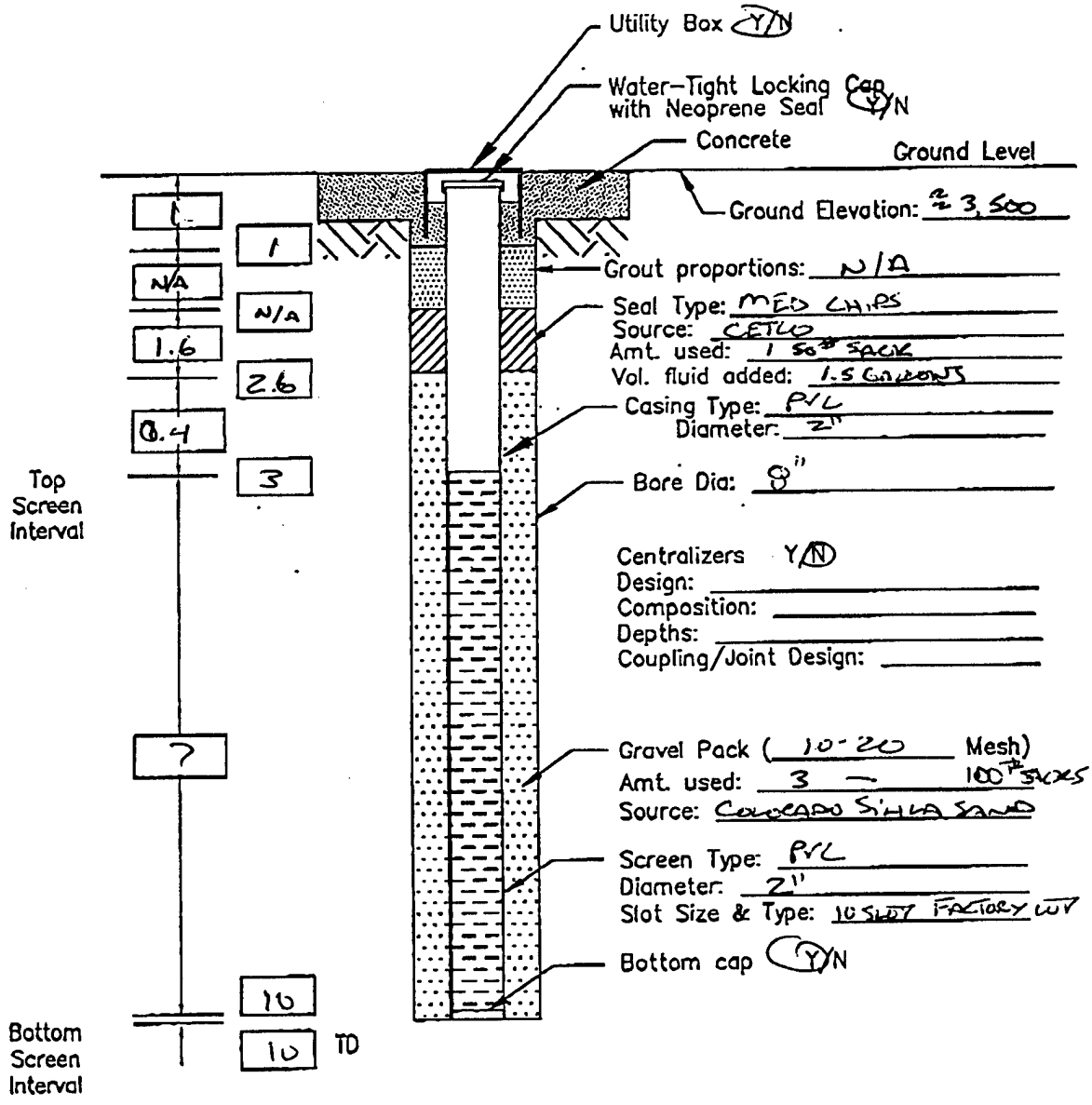


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: PA # 2
Well ID: MW-7
Comp. started 11/5/94 (13:45 m)

Project no. 725525.0500
Drilling contractors: O'KEEFE
Comp. finished: 11/5/94 (NR: m)
14:30

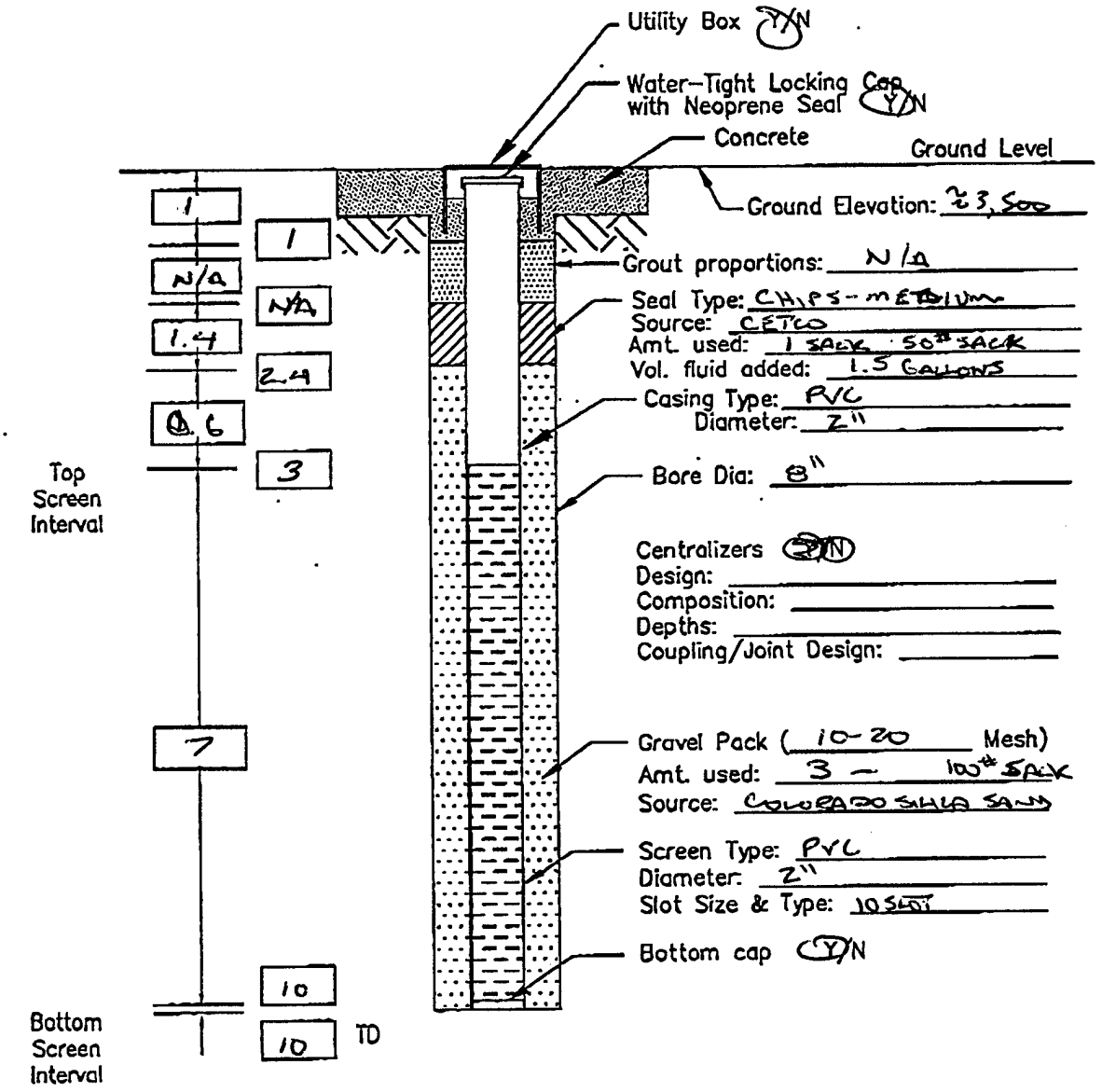


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: PA #2
Well ID: MW-8
Comp. started 11/09/94 (9:45 m)

Project no. 725525.03000
Drilling contractors: O'KEEFE
Comp. finished: 11/9/94 (10:15 m)

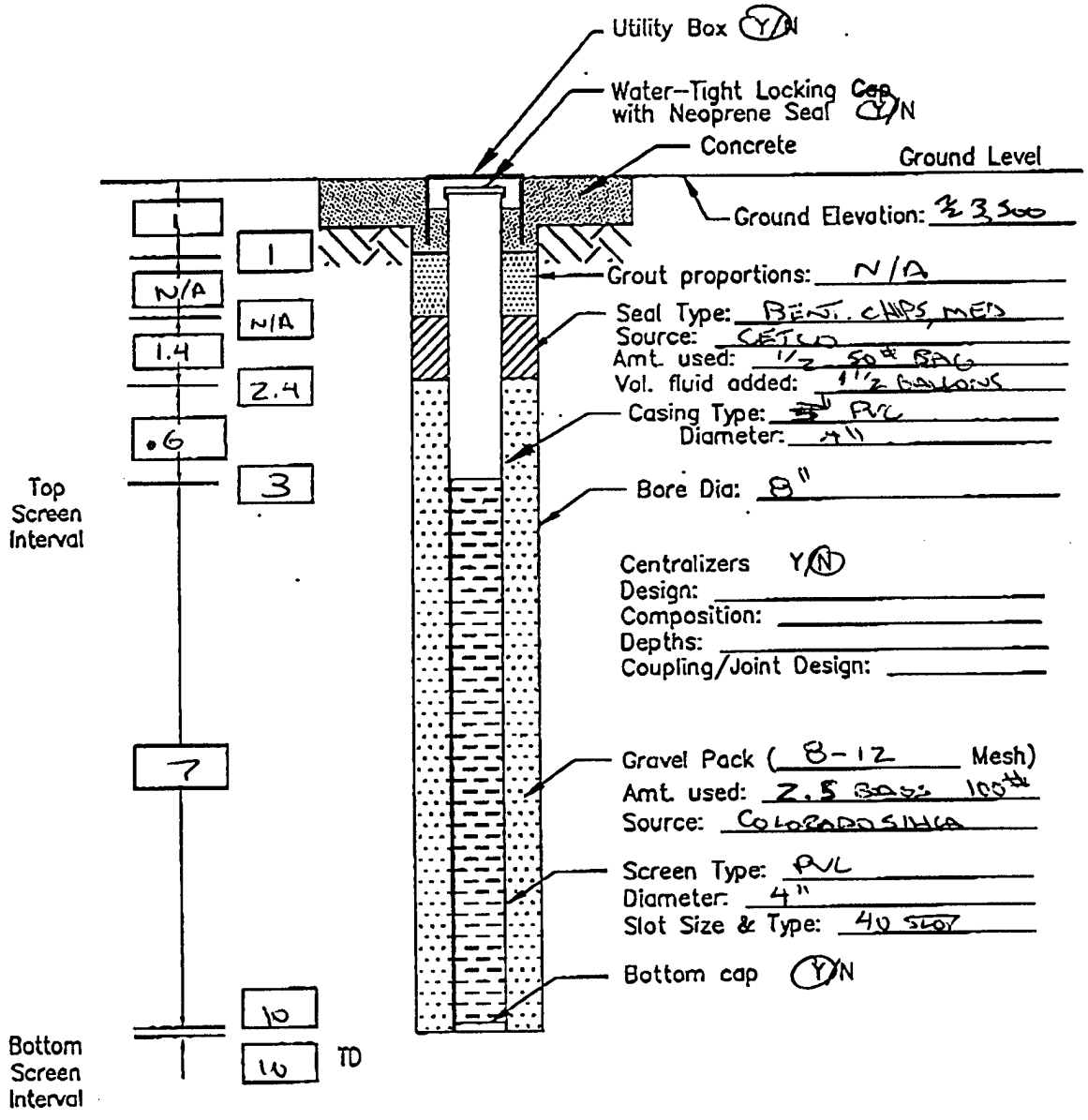


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: PH#2
Well ID: MW-9
Comp. started 11/9/94 (11:15 m)

Project no. 725525.03000
Drilling contractors: O'KEEFE
Comp. finished: 11/9/94 (: m)

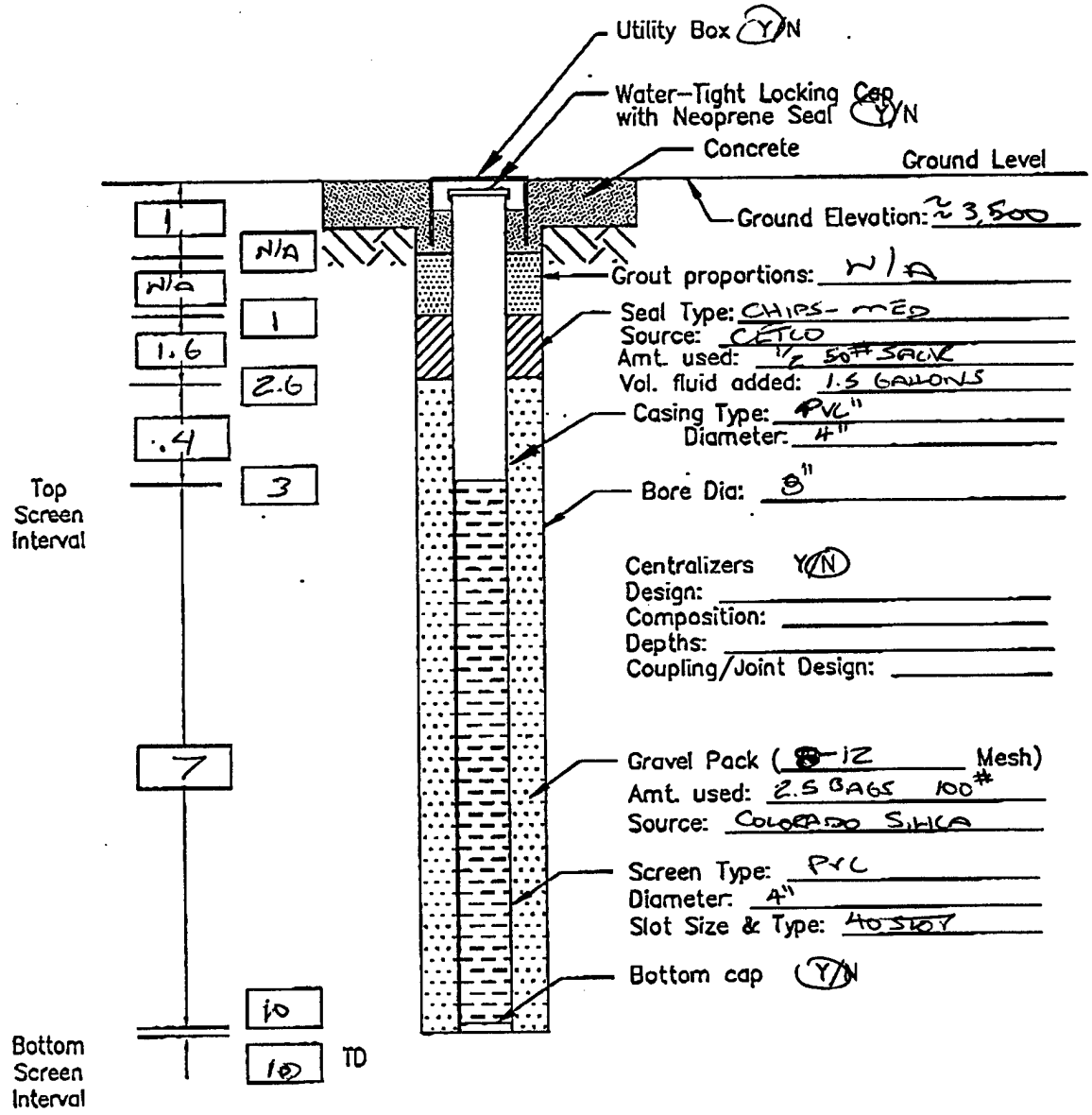


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: PW#2
Well ID: MW-11
Comp. started 11/9/94 (15:45 m)

Project no. 72552503000
Drilling contractors: O'KEEFE
Comp. finished: 11/9/94 (16:20 m)

NOTE: NUMBERING SCHEME SKIPS 10

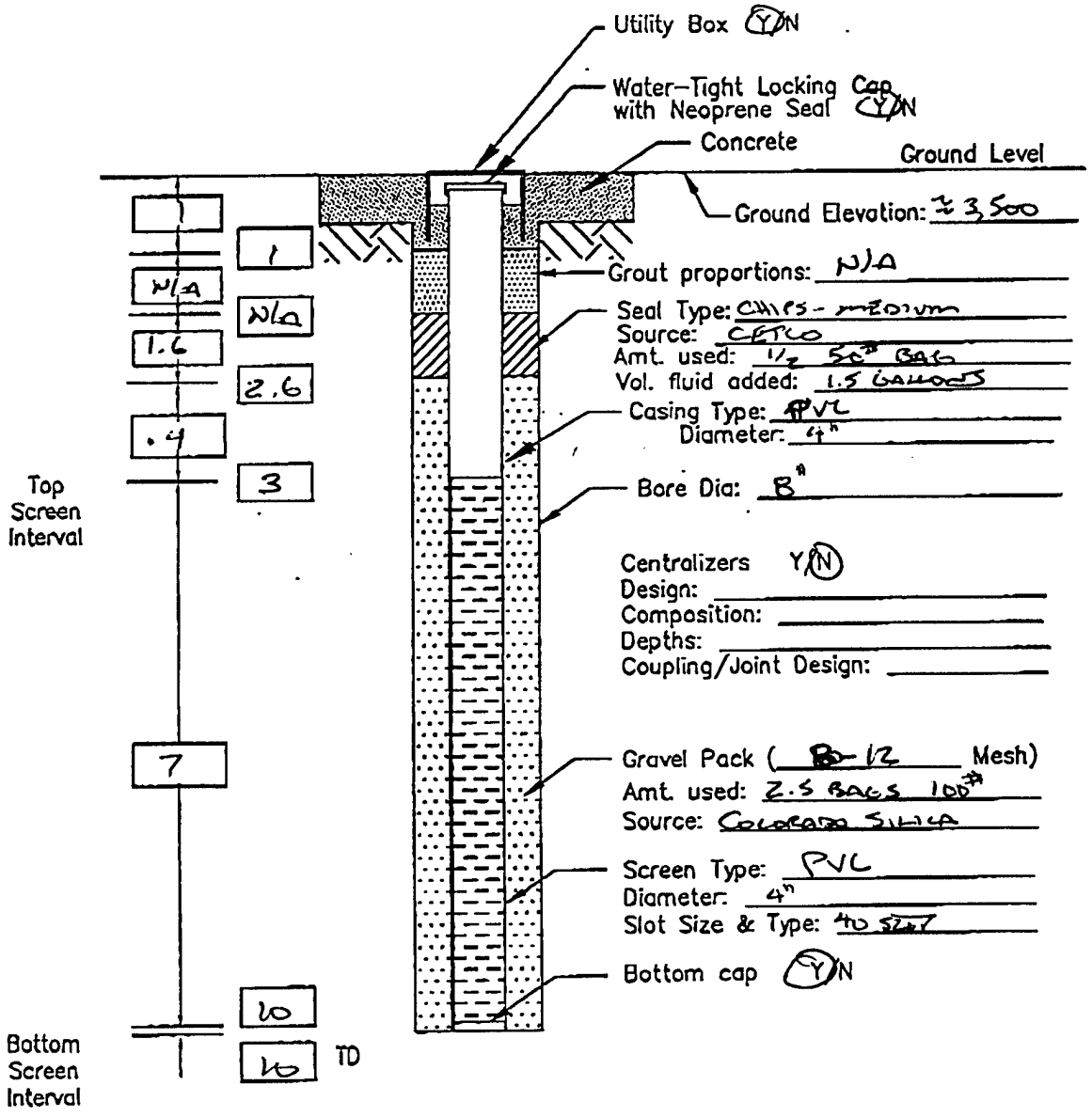


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: PH #2
Well ID: MW-12
Comp. started 11/10/94 (10:00 m)

Project no. 725525.03000
Drilling contractors: O'KEEFE
Comp. finished: 11/10/94 (10:30 m)

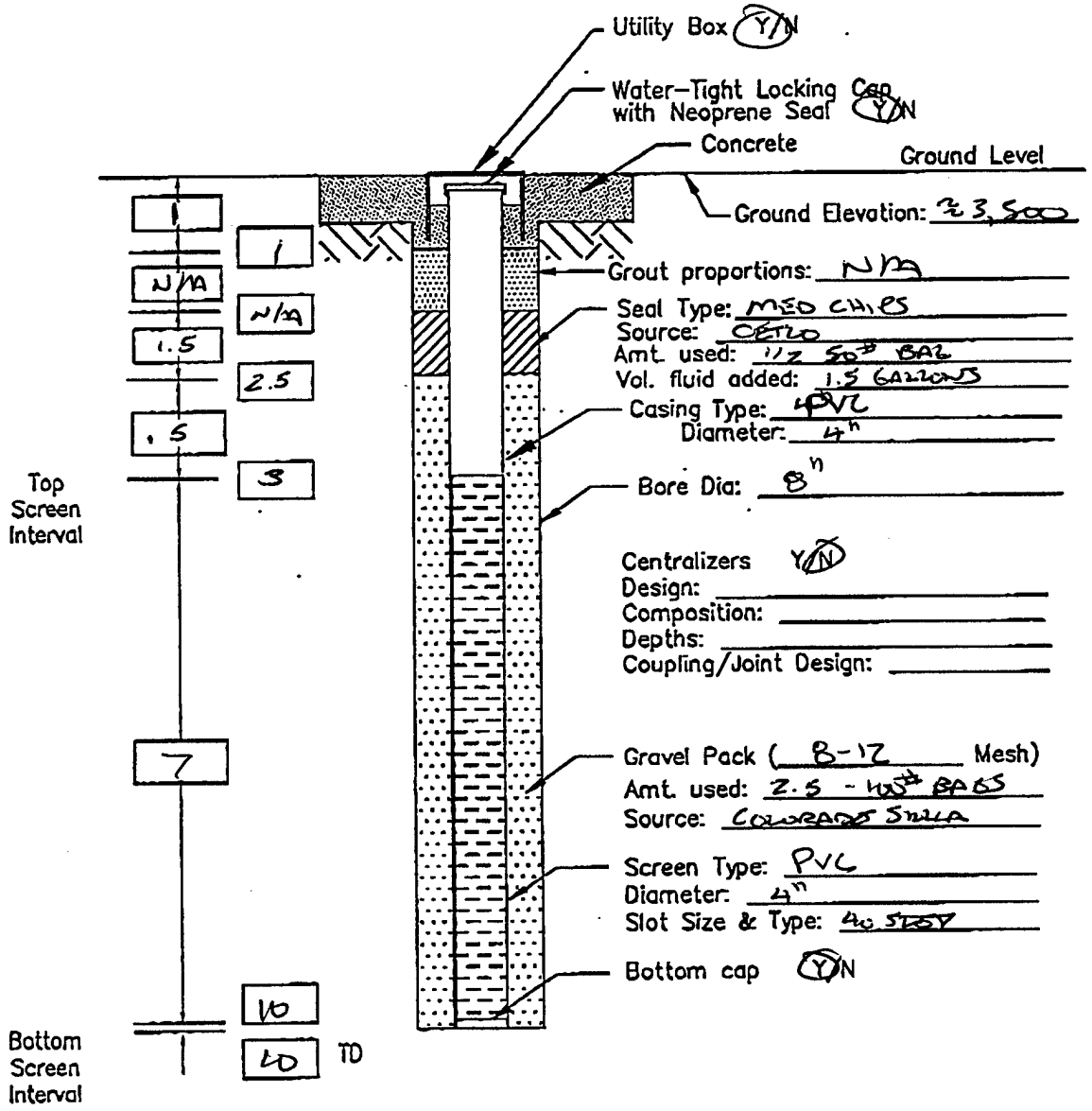


Figure A.3
Monitoring Well Installation Record

WELL CONSTRUCTION FORM

Installation: MAFB
Site: PAD 2
Well ID: BS
Comp. started 11 / 10 / 94 (11:30 m)

Project no. 725525.03000
Drilling contractors: O'KEEFE
Comp. finished: 11 / 10 / 94 (12:00 m)

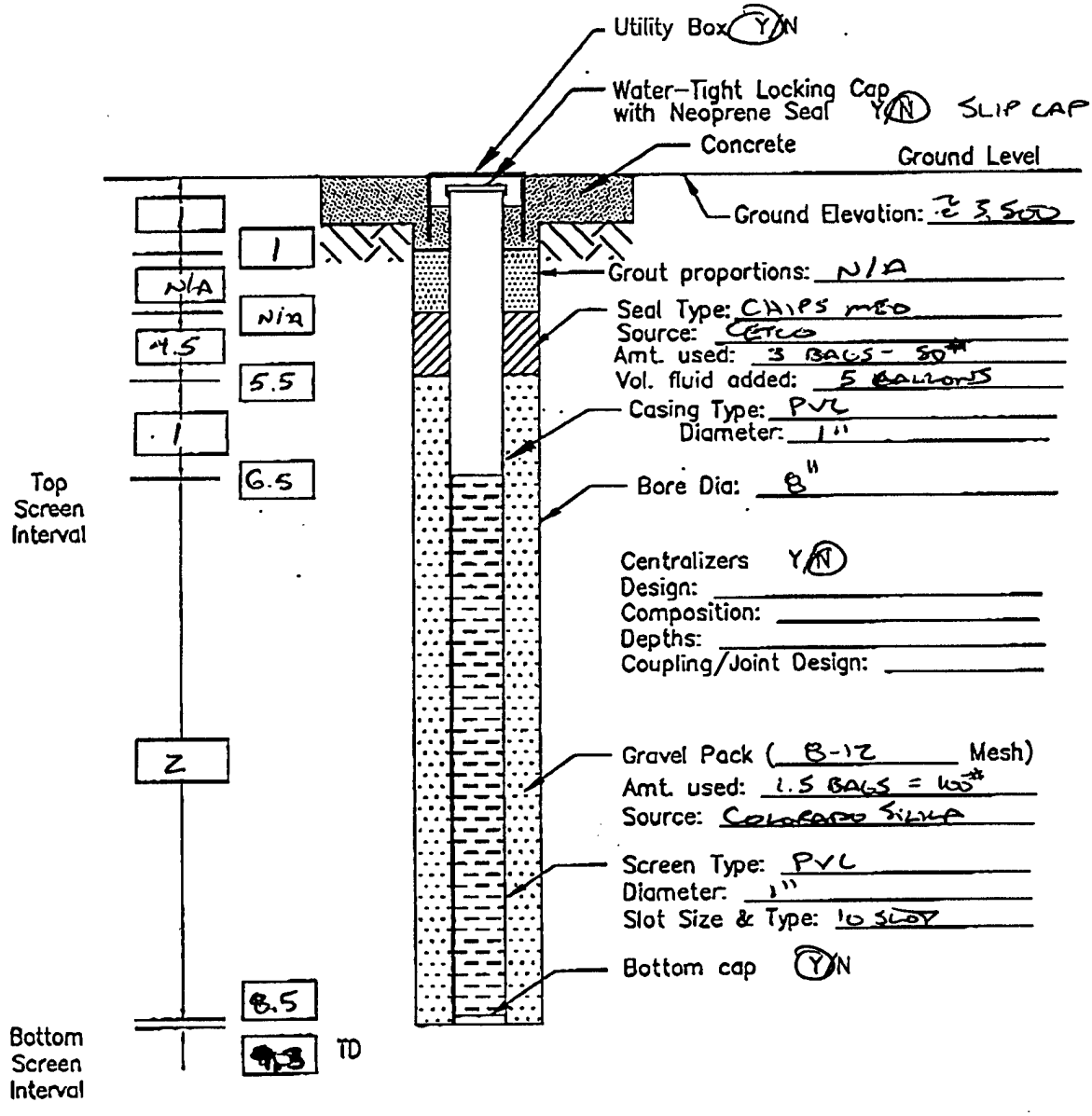
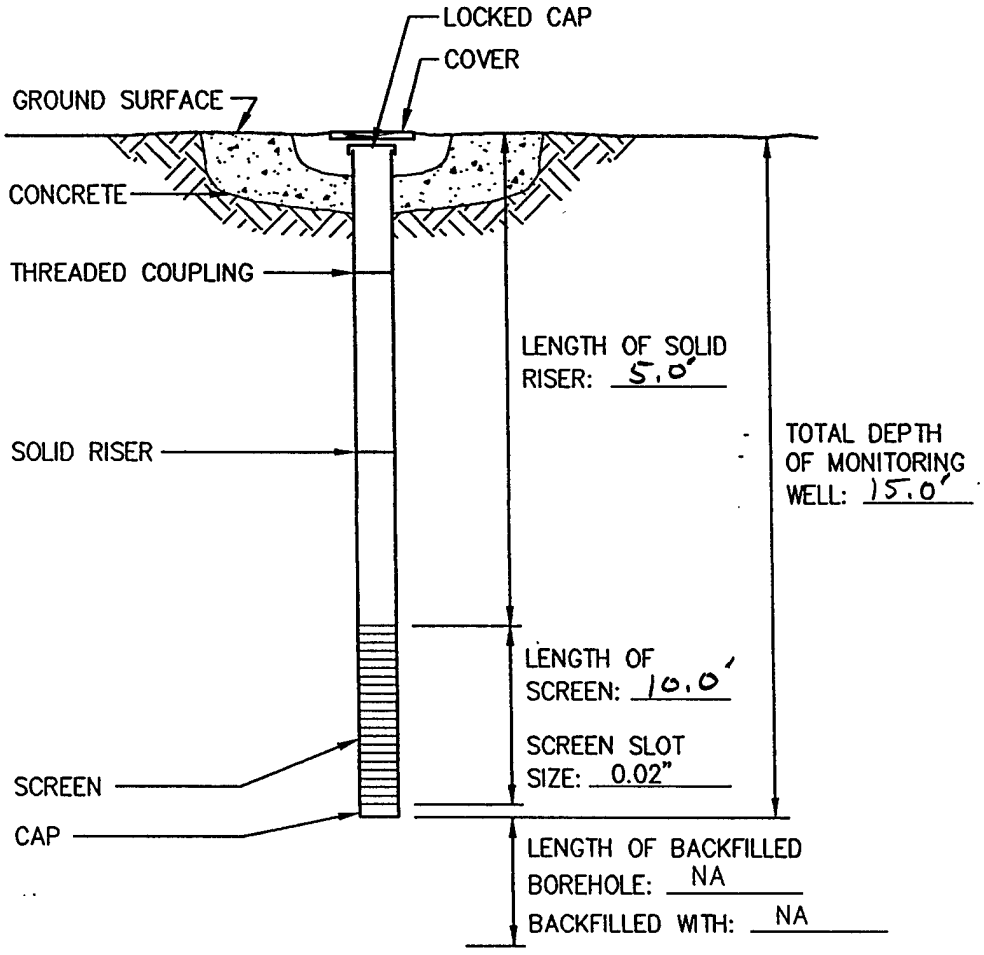


Figure A.3
Monitoring Well Installation Record

MLMW13.SCR
MLMSM MW-13

MONITORING WELL INSTALLATION RECORD

JOB NAME MALMSTROM AFB, PH2 MONITORING WELL NUMBER MW-13
JOB NUMBER 725525.06000 INSTALLATION DATE 10/5/96 LOCATION PUMPHOUSE 2
DATUM ELEVATION 3436.43 GROUND SURFACE ELEVATION 3436.92
DATUM FOR WATER LEVEL MEASUREMENT Top of PVC Casing
SCREEN DIAMETER & MATERIAL 2-inch Dia. PVC SLOT SIZE 0.010 inch
RISER DIAMETER & MATERIAL 2-inch Dia. PVC BOREHOLE DIAMETER 8 1/4"
DRILLING CONTRACTOR Maxim Technologies PARSONS ES REPRESENTATIVE B. Slayman, D. Teets



(NOT TO SCALE)

STABILIZED WATER LEVEL 13.73 FEET BELOW DATUM.

TOTAL MONITORING WELL DEPTH 14.55 FEET BELOW DATUM.

GROUND SURFACE 15.04 FEET

FIGURE A.3

MONITORING WELL INSTALLATION RECORD

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

K:\AFCEE\729691\96DN1186, 12/12/96 at 14:27

MONITORING WELL INSTALLATION RECORD

JOB NAME MALMSTROM AFB, PH2 MONITORING WELL NUMBER MW-14

JOB NUMBER 725525.06000 INSTALLATION DATE 10/4/96 LOCATION PUMPHOUSE 2

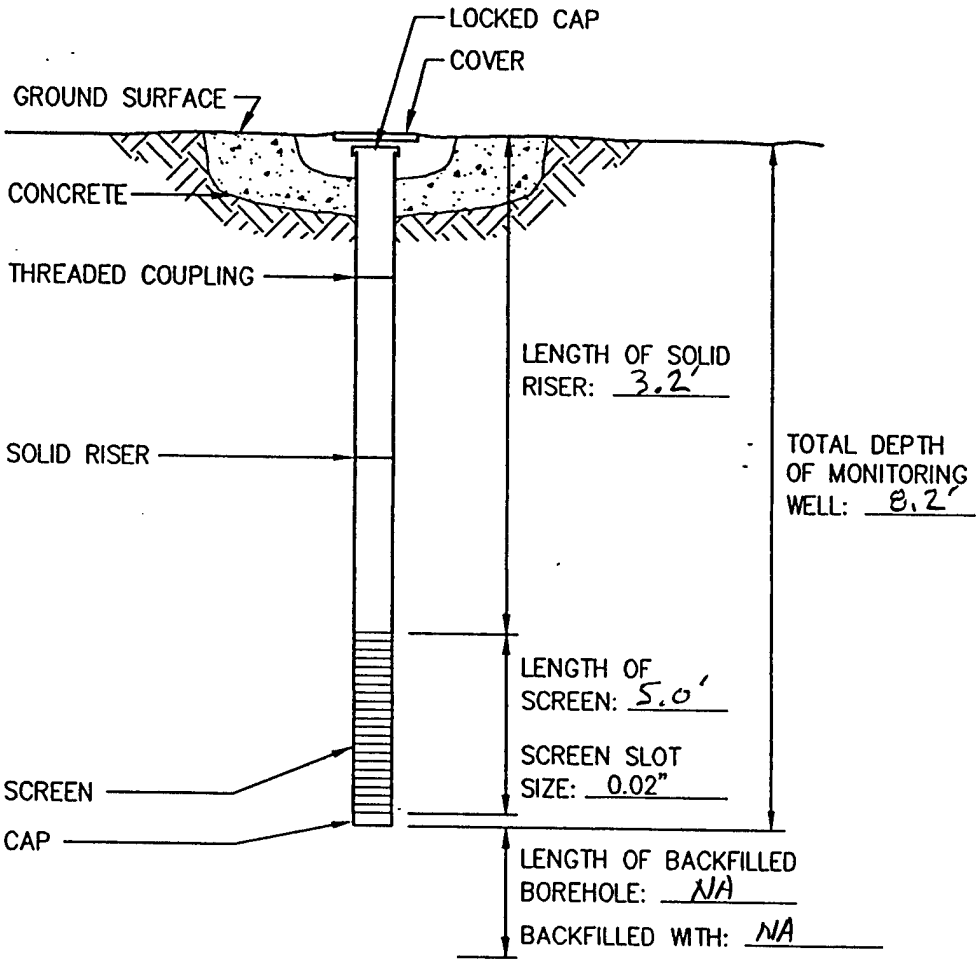
DATUM ELEVATION 3432.21 GROUND SURFACE ELEVATION 3432.54

DATUM FOR WATER LEVEL MEASUREMENT Top of PVC Casing

SCREEN DIAMETER & MATERIAL 2-inch Dia. PVC SLOT SIZE 0.010 inch

RISER DIAMETER & MATERIAL 2-inch Dia. PVC BOREHOLE DIAMETER 6"

DRILLING CONTRACTOR Parsons Engineering Science, Inc. PARSONS ES REPRESENTATIVE D. Teets



(NOT TO SCALE)

STABILIZED WATER LEVEL 3.07 FEET BELOW DATUM.

TOTAL MONITORING WELL DEPTH 7.91 FEET BELOW DATUM.

GROUND SURFACE 8.24 FEET

FIGURE A.3

MONITORING WELL INSTALLATION RECORD

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

K:\AFCEE\729691\96DN1186, 12/12/96 at 14:27

MONITORING WELL INSTALLATION RECORD

JOB NAME MALMSTROM AFB, PH2 MONITORING WELL NUMBER MW-16

JOB NUMBER 725525.06000 INSTALLATION DATE 10/4/96 LOCATION PUMPHOUSE 2

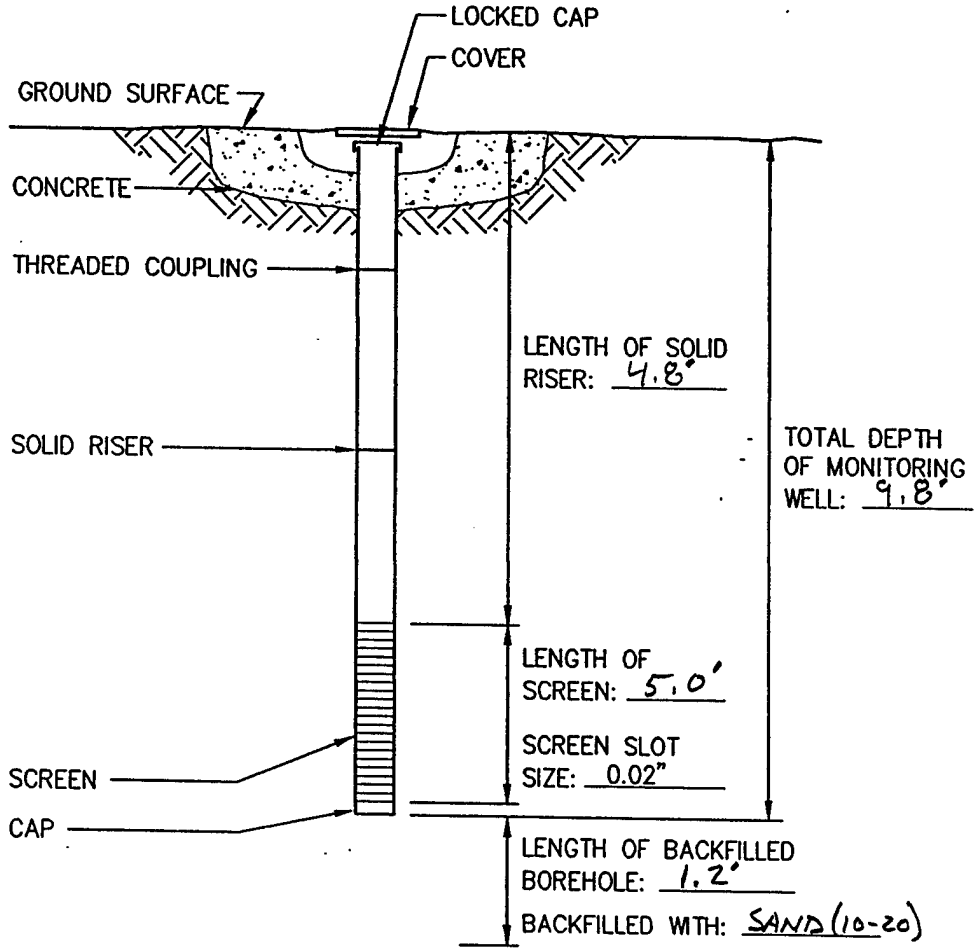
DATUM ELEVATION 3431.46 GROUND SURFACE ELEVATION 3431.76

DATUM FOR WATER LEVEL MEASUREMENT Top of PVC Casing

SCREEN DIAMETER & MATERIAL 2-inch Dia. PVC SLOT SIZE 0.010 inch

RISER DIAMETER & MATERIAL 2-inch Dia. PVC BOREHOLE DIAMETER 6"

DRILLING CONTRACTOR Parsons Engineering Science, Inc. PARSONS ES REPRESENTATIVE D. Teets



(NOT TO SCALE)

STABILIZED WATER LEVEL 6.28 FEET BELOW DATUM.

TOTAL MONITORING WELL DEPTH 9.53 FEET BELOW DATUM.

GROUND SURFACE 9.83 FEET

FIGURE A.3

MONITORING WELL INSTALLATION RECORD

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

K:\AFCEE\729691\96DN1186, 12/12/96 at 14:27

MONITORING WELL INSTALLATION RECORD

JOB NAME MALMSTROM AFB, PH2 MONITORING WELL NUMBER MW-17A

JOB NUMBER 725525.06000 INSTALLATION DATE 10/4/96 LOCATION PUMPHOUSE 2

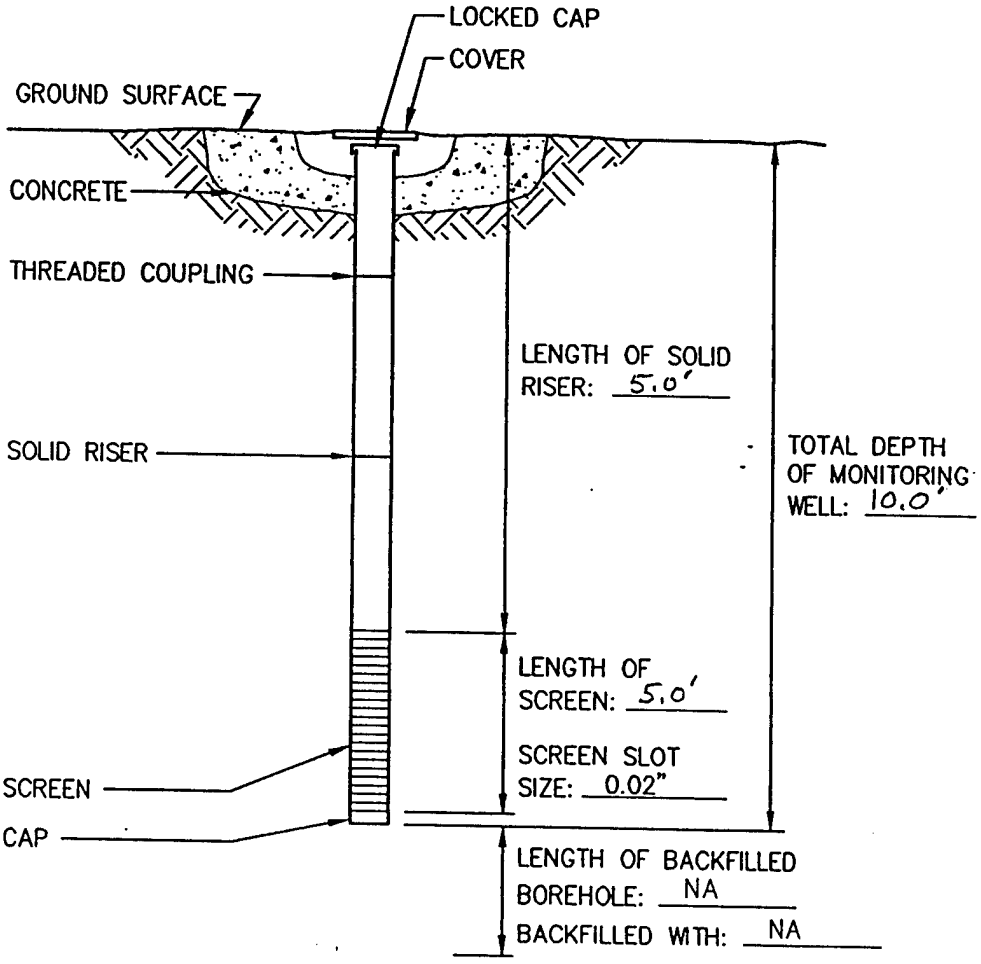
DATUM ELEVATION 3439.04 GROUND SURFACE ELEVATION 3439.54

DATUM FOR WATER LEVEL MEASUREMENT Top of PVC Casing

SCREEN DIAMETER & MATERIAL 2-inch Dia. PVC SLOT SIZE 0.010 inch

RISER DIAMETER & MATERIAL 2-inch Dia. PVC BOREHOLE DIAMETER 8 1/4"

DRILLING CONTRACTOR Maxim Technologies PARSONS ES REPRESENTATIVE B. Slayman, D. Teets



(NOT TO SCALE)

STABILIZED WATER LEVEL 5.88 FEET BELOW DATUM.

TOTAL MONITORING WELL DEPTH 9.56 FEET BELOW DATUM.

GROUND SURFACE 10.0 FEET

FIGURE A.3

MONITORING WELL INSTALLATION RECORD

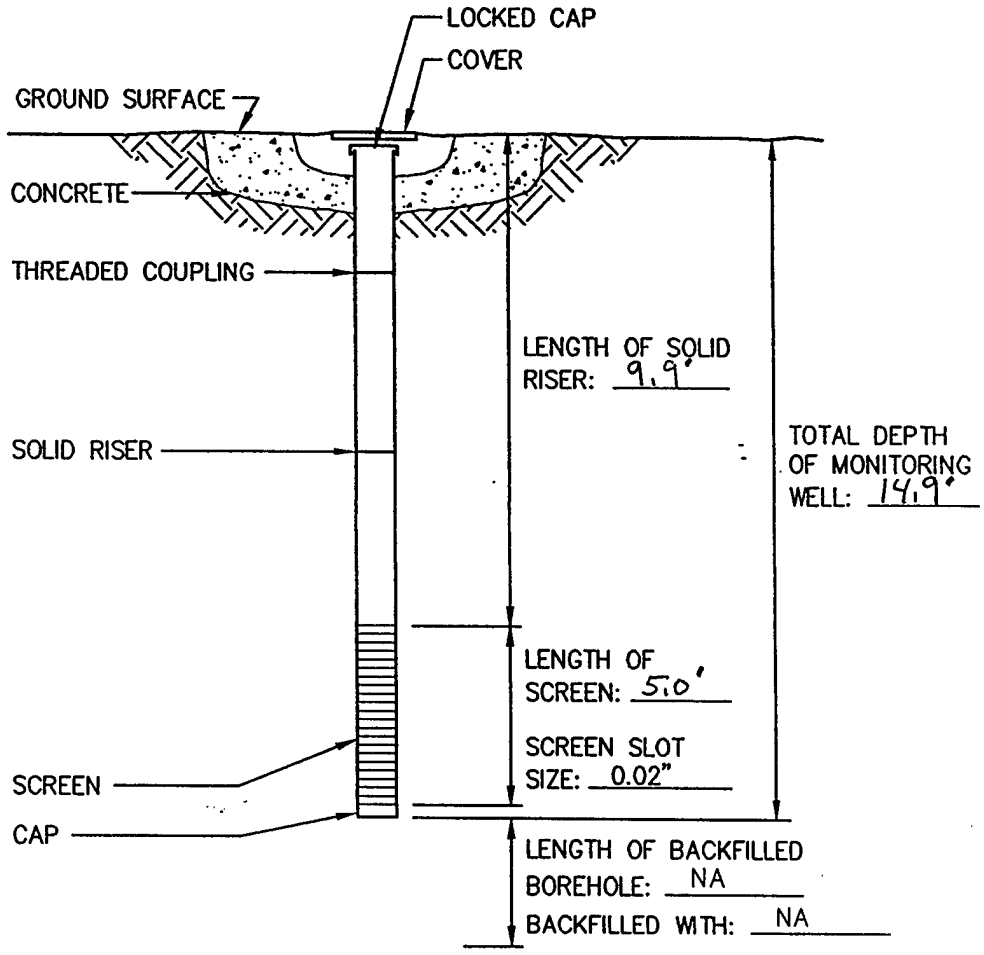
EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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MONITORING WELL INSTALLATION RECORD

JOB NAME MALMSTROM AFB, PH2 MONITORING WELL NUMBER MW-17B
JOB NUMBER 725525.06000 INSTALLATION DATE 10/4/96 LOCATION PUMPHOUSE 2
DATUM ELEVATION 3437.90 GROUND SURFACE ELEVATION 3438.41
DATUM FOR WATER LEVEL MEASUREMENT Top of PVC Casing
SCREEN DIAMETER & MATERIAL 2-inch Dia. PVC SLOT SIZE 0.010 inch
RISER DIAMETER & MATERIAL 2-inch Dia. PVC BOREHOLE DIAMETER 8 1/4"
DRILLING CONTRACTOR Maxim Technologies PARSONS ES REPRESENTATIVE B. Slayman
D. Teets



(NOT TO SCALE)

STABILIZED WATER LEVEL 6.02 FEET BELOW DATUM.

TOTAL MONITORING WELL DEPTH 14.41 FEET BELOW DATUM.

GROUND SURFACE 14.90 FEET

FIGURE A.3

MONITORING WELL INSTALLATION RECORD

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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MONITORING WELL INSTALLATION RECORD

JOB NAME MALMSTROM AFB, PH2 MONITORING WELL NUMBER MW-19

JOB NUMBER 725525.06000 INSTALLATION DATE _____ LOCATION PUMPHOUSE 2

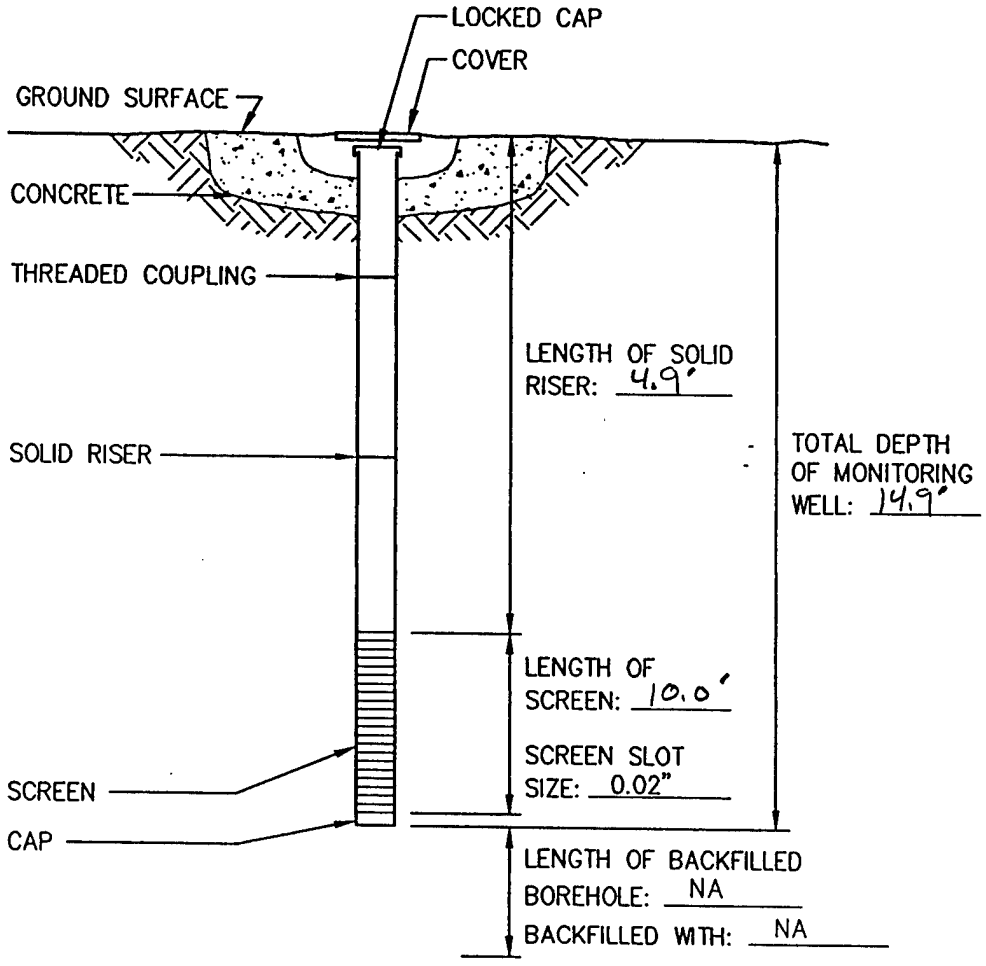
DATUM ELEVATION 3437.90 GROUND SURFACE ELEVATION 3438.41

DATUM FOR WATER LEVEL MEASUREMENT Top of PVC Casing

SCREEN DIAMETER & MATERIAL 2-inch Dia. PVC SLOT SIZE 0.010 inch

RISER DIAMETER & MATERIAL 2-inch Dia. PVC BOREHOLE DIAMETER 8 1/4"

DRILLING CONTRACTOR Maxim Technologies PARSONS ES REPRESENTATIVE B. Slayman, D. Teets



(NOT TO SCALE)

STABILIZED WATER LEVEL 12.19 FEET BELOW DATUM.

TOTAL MONITORING WELL DEPTH 14.35 FEET BELOW DATUM.

GROUND SURFACE 14.86 FEET

FIGURE A.3

MONITORING WELL INSTALLATION RECORD

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Monta

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

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MONITORING WELL INSTALLATION RECORD

JOB NAME MALMSTROM AFB, PH2 MONITORING WELL NUMBER MW-20

JOB NUMBER 725525.06000 INSTALLATION DATE 10/3/96 LOCATION PUMPHOUSE 2

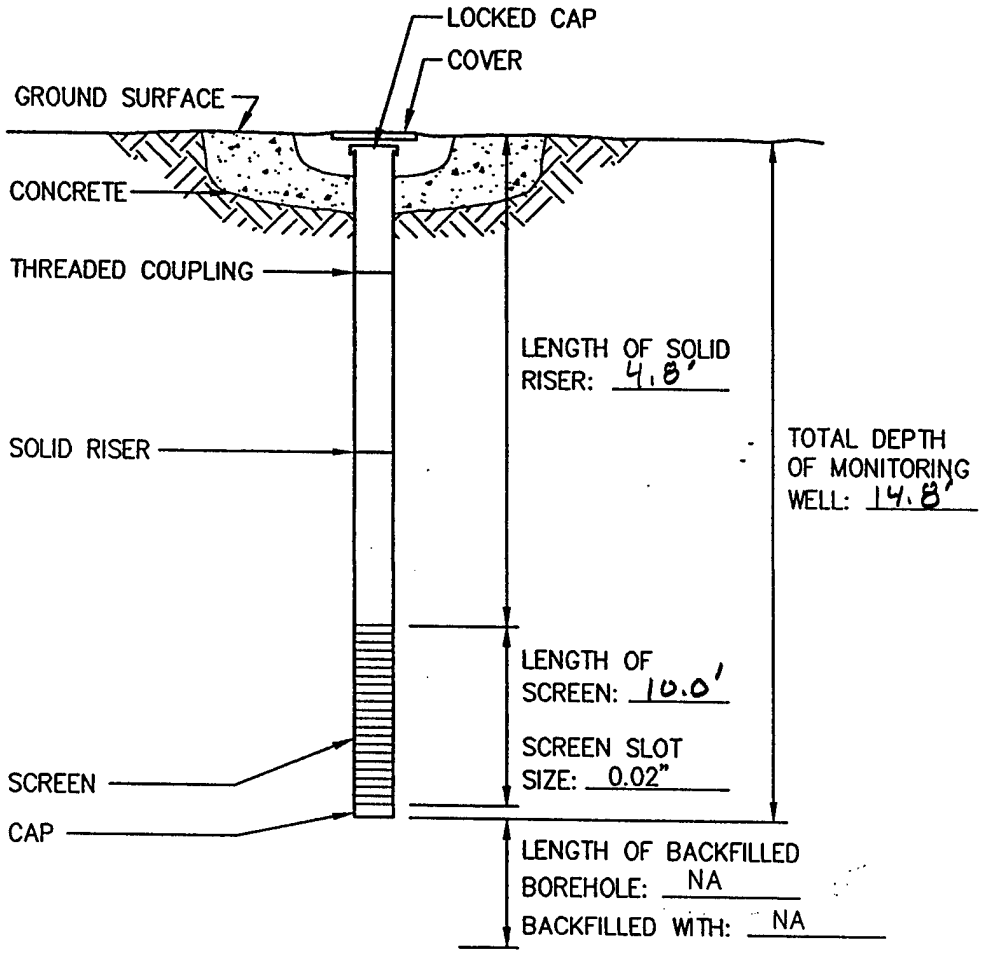
DATUM ELEVATION 3440.04 GROUND SURFACE ELEVATION 3440.72

DATUM FOR WATER LEVEL MEASUREMENT Top of PVC Casing

SCREEN DIAMETER & MATERIAL 2-inch Dia. PVC SLOT SIZE 0.010 inch

RISER DIAMETER & MATERIAL 2-inch Dia. PVC BOREHOLE DIAMETER 8 1/4"

DRILLING CONTRACTOR Maxim Technologies PARSONS ES REPRESENTATIVE B. Slayman, D. Teets



(NOT TO SCALE)

STABILIZED WATER LEVEL 9.61 FEET BELOW DATUM.

TOTAL MONITORING WELL DEPTH 14.11 FEET BELOW DATUM.

GROUND SURFACE 14.79 FEET

FIGURE A.3

MONITORING WELL INSTALLATION RECORD

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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MONITORING WELL INSTALLATION RECORD

JOB NAME MALMSTROM AFB, PH2 MONITORING WELL NUMBER MW-21

JOB NUMBER 725525.06000 INSTALLATION DATE 10/4/96 LOCATION PUMPHOUSE 2

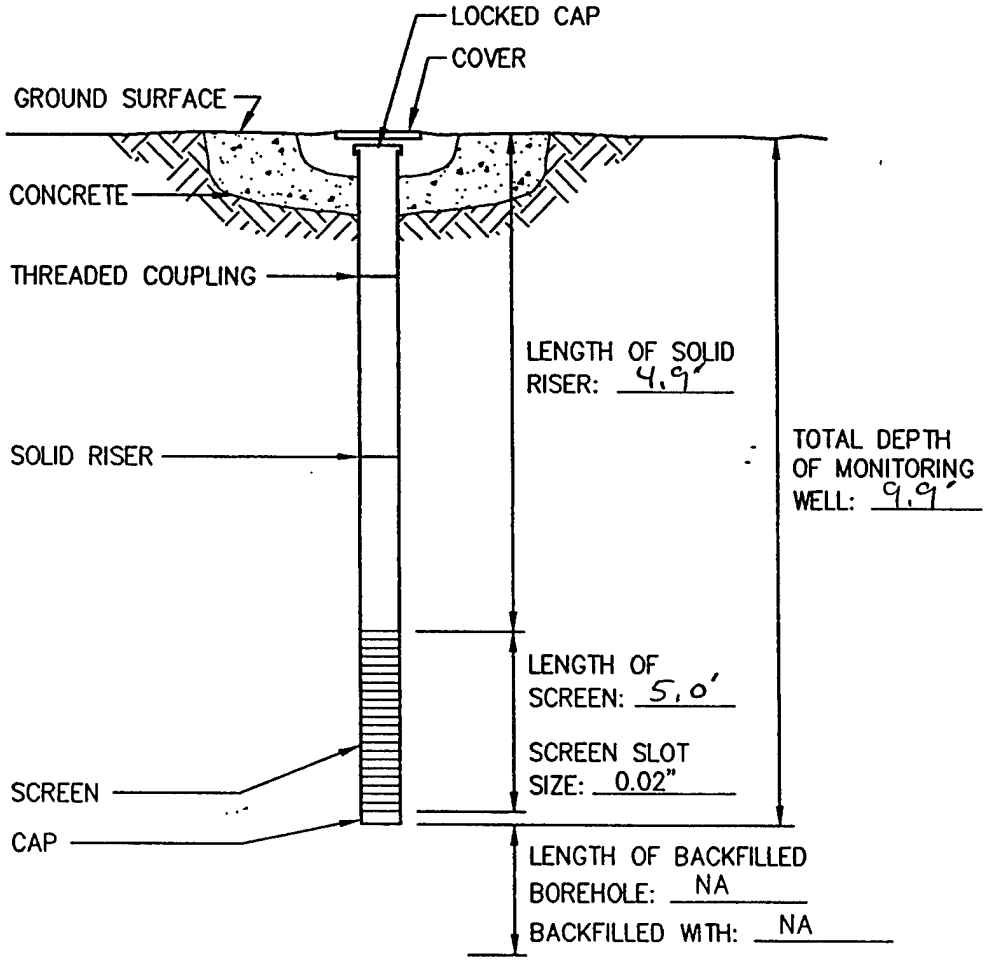
DATUM ELEVATION 3437.64 GROUND SURFACE ELEVATION 3438.11

DATUM FOR WATER LEVEL MEASUREMENT Top of PVC Casing

SCREEN DIAMETER & MATERIAL 2-inch Dia. PVC SLOT SIZE 0.010 inch

RISER DIAMETER & MATERIAL 2-inch Dia. PVC BOREHOLE DIAMETER 8 1/4"

DRILLING CONTRACTOR Maxim Technologies PARSONS ES REPRESENTATIVE B. Slayman, D. Teets



(NOT TO SCALE)

STABILIZED WATER LEVEL 4.48 FEET BELOW DATUM.

TOTAL MONITORING WELL DEPTH 9.41 FEET BELOW DATUM.

GROUND SURFACE 9.88 FEET

FIGURE A.3

MONITORING WELL INSTALLATION RECORD

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Mont

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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MONITORING WELL INSTALLATION RECORD

JOB NAME MALMSTROM AFB, PH2 MONITORING WELL NUMBER MW-22

JOB NUMBER 725525.06000 INSTALLATION DATE 10/4/96 LOCATION PUMPHOUSE 2

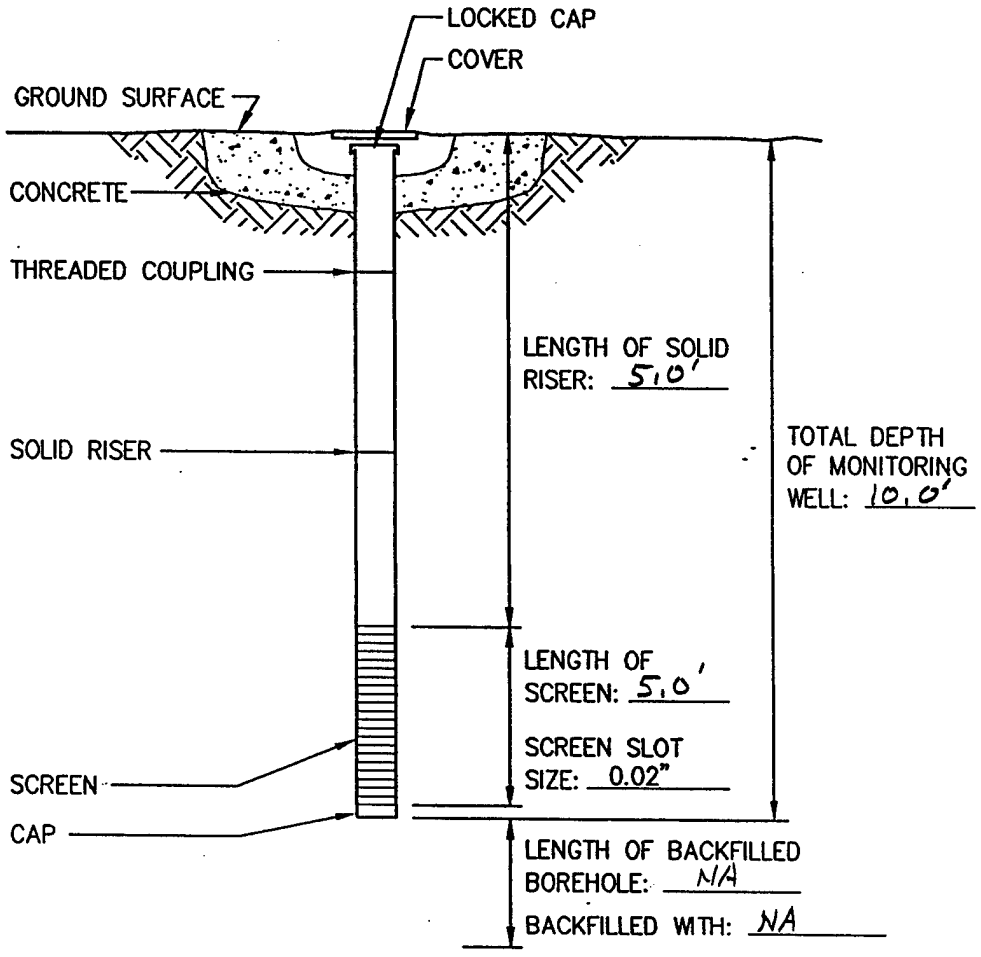
DATUM ELEVATION 3435.48 GROUND SURFACE ELEVATION 3435.81

DATUM FOR WATER LEVEL MEASUREMENT Top of PVC Casing

SCREEN DIAMETER & MATERIAL 2-inch Dia. PVC SLOT SIZE 0.010 inch

RISER DIAMETER & MATERIAL 2-inch Dia. PVC BOREHOLE DIAMETER 6"

DRILLING CONTRACTOR Parsons Engineering Science, Inc. PARSONS ES REPRESENTATIVE D. Teets



(NOT TO SCALE)

STABILIZED WATER LEVEL 4.41 FEET BELOW DATUM.

TOTAL MONITORING WELL DEPTH 9.70 FEET BELOW DATUM.

GROUND SURFACE 10.03 FEET

FIGURE A.3

MONITORING WELL INSTALLATION RECORD

EE/CA
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

K:\AFCEE\729691\96DN1186, 12/12/96 at 14:27

Figure A.4
Well Development Record

Job Number 722525.03000 Job Name Malstrom Risk Based
Location PH#2 By ASR Date 11/9
Well Number #1 Measurement Datum mark on N. side of casing

Pre-Development Information Time (Start): 1:15

Water Level: dry Total Depth of Well:

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Interim Water Characteristics

Gallons Removed

pH

Temperature (°F °C)

Specific Conductance(µS/cm)

Post-Development Information Time (Finish):

Water Level: Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Comments:

Figure A.4
Well Development Record

Page 1 of 1

Job Number 72552S.03000 Job Name Malmstrom Risk Based
Location PH #2 By AJR Date 11/9
Well Number #2 Measurement Datum mark on North side of casing

Pre-Development Information Time (Start): 10:40

Water Level: 6'2½" Total Depth of Well: 10'2¼"

Water Characteristics

Color clear (Clear) Cloudy
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material none apparent
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

4¼ - dry

Interim Water Characteristics

	0 gal	4 gal	8 g	12 g
Gallons Removed				
pH	7.035	7.129		
Temperature (°F °C)	13.2/13.1	12.1/12.0		
Specific Conductance ~~(µS/cm)~~ mS/cm	6.06	6.84		

Post-Development Information Time (Finish):

Water Level: Total Depth of Well:

Approximate Volume Removed: 4¼

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

* Bailed dry
Total volume removed
4¼ gal

Comments:

Bailed dry 4¼ gal. removed

see back of form for "redevelopment

Figure A.4
Well Development Record

Job Number 72555.03000 Job Name MALMSTROM RISK-BASED
Location PH # 2 By AJR Date 11/9/94
Well Number #3 Measurement Datum MARK ON NORTH SIDE OF CASING

Pre-Development Information Time (Start): 9:15a

Water Level: 9'11" Total Depth of Well: 10'05/8"

Water Characteristics * < 2" H_2O → did not bail or surge

Color NA Clear Cloudy
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material NA
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Interim Water Characteristics

Gallons Removed 3 BH VOLUMES (AT LEAST) 1 GALLON = 1 FT OF BH VOLUME FOR 2" WELL IN 8" HOLE

pH

Temperature (°F °C)

Specific Conductance(µS/cm)

Post-Development Information Time (Finish):

Water Level: Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Comments: less than 2" H_2O ⇒ essentially dry

Figure A.4
Well Development Record

Page 1 of 1

Job Number 72552S.03000 Job Name Malmstrom Risk Based
Location PH #2 By AEB Date 11/9
Well Number #4 Measurement Datum mark on North side of casing

Pre-Development Information Time (Start): 2:55

Water Level: 3'0" Total Depth of Well: 9'10 7/8"

Water Characteristics

Color clear (fairly) Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material none apparent
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Interim Water Characteristics

	0gal	7gal	14gal	21gal	
Gallons Removed					
pH	7.319	7.379			
Temperature (°F °C)	11.7	12.7			
Specific Conductance ~~(µS/cm)~~ mS/cm	2.99	5.03			

Baled dry @ 7gal

Post-Development Information Time (Finish):

Water Level: 7gal Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Comments:

Start recharge test on well after baled dry (Dry @ 7 gal removed)

Figure A.4
Well Development Record

Page 1 of 1

Job Number 725525.03000 Job Name malmstrom Risk Based
Location PH #2 By AR Date 11/90
Well Number #5 Measurement Datum mark on North side of casing

Pre-Development Information Time (Start):

Water Level: $9'\ 5\frac{1}{8}''$ Total Depth of Well: $10'\ 1\frac{5}{8}''$

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material none apparent
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Interim Water Characteristics

no measurements taken - only $8\frac{1}{2}''$ H_2O in well @ start.

Gallons Removed

pH

Temperature (°F °C)

Specific Conductance(µS/cm)

Post-Development Information Time (Finish):

Water Level: Total Depth of Well:

Approximate Volume Removed: 0.5gal → bailed dry

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Comments:

$8\frac{1}{2}''$ in well to start -
Bailed dry after 0.5 gal removed

Figure A.4
Well Development Record

Job Number 725525.03000 Job Name: Malmstrom Risk Based
Location PH #12 By ASR Date 11/9
Well Number #6 Measurement Datum mark on N. side of casing

Pre-Development Information Time (Start): 1:30

Water Level: 5' 3½" Total Depth of Well: 9' 8⅛"

Water Characteristics

Color Brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material none apparent
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Interim Water Characteristics

	0 g	5 g	10 g	15 g
Gallons Removed				
pH	7.030	7.090	7.142	7.157
Temperature (°F (°C))	12.8	13.0	12.7	12.7
Specific Conductance (µS/cm)	1820	1900	1911	1918

Post-Development Information Time (Finish): 2:25

Water Level: Total Depth of Well:

Approximate Volume Removed: 15 gal

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Comments:

Figure A.4
Well Development Record

Page 1 of 1

Job Number 725525.03000 Job Name Malmstrom Risk Based
Location PH #2 By AdR Date 11/9
Well Number #7 Measurement Datum mark on north side of casing

Pre-Development Information

Time (Start): 9:30a

Water Level: 6' 2 3/4" Total Depth of Well: 10'4"

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material no Film apparent
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Interim Water Characteristics

Gallons Removed	0 g	4 g	8 g	12 gal
pH	7.105	7.250		
Temperature (°F (°C))	11.7	11.2/11.4		
Specific Conductance ~~(µS/cm)~~ mS/cm	4.39	4.33		

* note: after removing 4 gal. → bailed dry
Total volume removed ≈ 4 gal.

Post-Development Information

Time (Finish): 10:10

Water Level: Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Comments:

Bailed dry after 4gal removed

Figure A.4
Well Development Record (purge)

Page 1 of 1

Job Number 725525.03000 MAL-MW12 Job Name Malmstrom AFB
Location PH #2, Malmstrom AFB By DRT Date 11/13/94
Well Number MAL-MW12 Measurement Datum

Pre-Development Information Time (Start):

Water Level: 3' 1 3/8" Total Depth of Well: 9' 8"

Water Characteristics

Color yellowish Clear (Cloudy)
Odor: None (Weak) Moderate Strong
Any Films or Immiscible Material no
pH Temperature(°F °C)
Specific Conductance(µS/cm)

Interim Water Characteristics

Gallo	MW 8, 9, + 11	0	4g	10g - dry
pH	DRY	7.4	7.5	7.405
Temp		15.4	15.4	16.2
Speci		4.03 ms/cm	4.04 ms/cm	4.02 ms/cm

Post-Development Information Time (Finish):

Water Level: Final H_2O level: 9'5" Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material
pH Temperature(°F °C)
Specific Conductance(µS/cm)

Comments: * - cold & windy so temp cooling rapidly once water removed from well. Third reading (16.2) taken immediately after water removed. First & second temp readings taken approx 5 min after H_2O removed from hole ∴ colder

Figure A.4
Well ~~Development~~ Purge Record

Job Number 725525.03000 Job Name Malmstrom AFB
Location PH #7 By DBT Date 11/14/94
Well Number MW-18 Measurement Datum N side of TOC
across Street

Pre-Development Information Time (Start): 0930

Water Level: 3'4 1/8" Total Depth of Well: 8'4"

Water Characteristics

Color gray-black Clear (Cloudy)
Odor: None Weak (Moderate) Strong
Any Films or Immiscible Material yes
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Interim Water Characteristics

Gallons Removed	0	2	5 DRY
pH	7.1	6.8	6.9
Temperature (°F (°C))	12.6	13.1	12.6
Specific Conductance(µS/cm)	1890	3.45 ms/cm	2.85 ms/cm
	Clear, colorless sl. odor	cldy, gray u. strong odor	cldy, gray u. strong odor

Purge
Post-Development Information Time (Finish): 1000

Water Level: DRY Total Depth of Well:

Approximate Volume Removed: 5 gallons

Water Characteristics

Color Gray Clear (Cloudy)
Odor: None Weak Moderate (Strong)
Any Films or Immiscible Material _____
pH ~7 Temperature(°F (°C)) ~ 12.8
Specific Conductance(µS/cm) Not constant

Comments:

3 casing vol = 0.40 gal

MONITORING POINT DEVELOPMENT RECORD

Job Number: 7252 Job Name: Malmstrom
Location Pump House 2 by Slayman Date: 10-13, 1996
Well Number ~~MW-9~~ MW-13 Measurement Datum TOC

Pre-Development Information Time (Start): _____

Water Level: ~~13.19~~ 13.73 Total Depth of Well: 14.55
(0.82' water)

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material NO
pH 7.4 Temperature(°C) 17.0
Specific Conductance(µS/cm) 5480
Disolved Oxygen (mg/L) _____

bailed dry 1/2 gallon

Interim Water Characteristics

Gallons Removed 1/8
pH 7.7
Temperature (°C) 14.0
Specific Conductance(µS/cm) 5480
Disolved Oxygen (mg/L) dry

Post-Development Information Time (Finish): 1015

Water Level: dry Total Depth of Well: 14.56
Approximate Volume Removed: 1/2 gallon

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material NO
pH 7.7 Temperature(°C) 14.0
Specific Conductance(µS/cm) 5480
Disolved Oxygen (mg/L) _____

Comments:

slow recharge

3 casing vol = 2.6 gal

MONITORING POINT DEVELOPMENT RECORD

Job Number: 72552 Job Name: Melmstrom
Location Pump House 2 - ditch by Slayman Date: 10-13, 1996
Well Number MW-14 Measurement Datum _____

Pre-Development Information Time (Start): 1455

Water Level: 4.41 Total Depth of Well: 9.70
(5.29' water)

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material No
pH 7.1 Temperature(°C) 18.2
Specific Conductance(µS/cm) 7020
Disolved Oxygen (mg/L) —

baited dry 2.5 gallons

Interim Water Characteristics WL = 8.36 10/14/96

Gallons Removed 1/8
pH malfunctioning
Temperature (°C) 14.9
Specific Conductance(µS/cm) 7450
Disolved Oxygen (mg/L) _____

Post-Development Information Time (Finish): ~~9.70~~ 1105 10/14/96

Water Level: dry Total Depth of Well: 9.70'
Approximate Volume Removed: 3 gallons (3½ casing volumes)

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material _____
pH not available Temperature(°C) 14.9
Specific Conductance(µS/cm) 7450
Disolved Oxygen (mg/L) _____

Comments:

slow recharge

3 CV = 1.6 gal

MONITORING POINT DEVELOPMENT RECORD

Job Number: 725525 Job Name: Malmstrom
Location Pump house 2 - ditch by ~~[illegible]~~ Slayman Date: 10-13, 1996
Well Number MW-16 Measurement Datum TOC

Pre-Development Information Time (Start): _____

Water Level: 6.28' Total Depth of Well: 9.53' (3.25' water)

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material No
pH 7.5 Temperature(°C) 24.1
Specific Conductance(µS/cm) 1220
Disolved Oxygen (mg/L) _____ bailed dry at 2.5 gallon

Interim Water Characteristics 10/14/96 (6.32' wl)

Gallons Removed ¼ 1 2

pH not available

Temperature (°C) 20.7 21.0 20.9

Specific Conductance(µS/cm) 1250 1280 1350

Disolved Oxygen (mg/L) _____ dry at 2.5 gal.

Post-Development Information Time (Finish): 1125 10/14/96

Water Level: dry Total Depth of Well: 9.54

Approximate Volume Removed: 5 gallons (9 CV)

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material no
pH not avail Temperature(°C) 20.9
Specific Conductance(µS/cm) 1350
Disolved Oxygen (mg/L) _____

Comments:

3 casing = 1.8 gal

MONITORING POINT DEVELOPMENT RECORD

Job Number: 725525 Job Name: Malmstrom
Location Pump House 2 by Slayman Date: 10-12 , 1996
Well Number MW-17A Measurement Datum TOC

Pre-Development Information Time (Start): 1735

Water Level: 5.88' Total Depth of Well: 9.56'

Water Characteristics

Color black Clear (Cloudy)
Odor: None Weak Moderate Strong
Any Films or Immiscible Material NO
pH 7.2 Temperature(°C) 15.2
Specific Conductance(µS/cm) 3630
Disolved Oxygen (mg/L)

Interim Water Characteristics

Gallons Removed 7	9	11.5	15
pH 7.01	6.9	6.9	7.0
Temperature (°C) 15.0	14.9	14.8	14.8
Specific Conductance(µS/cm) 3670	3680	3670	3670
Disolved Oxygen (mg/L)			

Post-Development Information Time (Finish): 1755

Water Level: 6.27' Total Depth of Well: 9.56'

Approximate Volume Removed: 15 gallons (2.5 casing vol)

Water Characteristics

Color murky brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material no
pH 7.0 Temperature(°C) 14.8
Specific Conductance(µS/cm) 3670
Disolved Oxygen (mg/L)

Comments: good recharge

3 casing vol = 4.8 gal

MONITORING POINT DEVELOPMENT RECORD

Job Number: 725525 Job Name: Malmstrom
Location Pump House 2 by Slayman Date: 10/12, 1996
Well Number MW-17B Measurement Datum TOC

Pre-Development Information Time (Start): 1635

Water Level: 6.02 Total Depth of Well: 14.41

Water Characteristics

Color black Clear (Cloudy)
Odor: None Weak (Moderate) Strong
Any Films or Immiscible Material NO
pH 7.4 Temperature(°C) 16.2
Specific Conductance(µS/cm) 3630
Disolved Oxygen (mg/L)

Interim Water Characteristics bailed 5 gallons went dry 10/14/96

Gallons Removed	day 2 1/2	2	1/2	1	2
pH	8.0	7.5	8.0	7.7	7.7
Temperature (°C)	14.5	15.5	12.6	12.0	12.0
Specific Conductance(µS/cm)	2720	2980	2450	2660	2880
Disolved Oxygen (mg/L)		dry at 2.5 gal			dry at 3.5 gallon

Post-Development Information Time (Finish): 0935 10/14/96

Water Level: dry Total Depth of Well: 14.41

Approximate Volume Removed: 10 gallons total (7 casing vol.)

Water Characteristics

Color black Clear (Cloudy)
Odor: None Weak (Moderate) Strong
Any Films or Immiscible Material NO
pH 7.7 Temperature(°C) 12.0
Specific Conductance(µS/cm) 2880
Disolved Oxygen (mg/L)

Comments:

3 casing vol = 1.0 gal

MONITORING POINT DEVELOPMENT RECORD

Job Number: 725525 Job Name: Malmstrom
Location Pump House 2 by Slayman Date: 10/13, 1996
Well Number MW-19 Measurement Datum TOC

Pre-Development Information Time (Start):

Water Level: 12.19 Total Depth of Well: 14.35
(2.16' watr)

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material ND
pH 7.2 Temperature(°C) 17.0
Specific Conductance(µS/cm) 5950
Disolved Oxygen (mg/L)

bailed dry after 1.5 gallons

Interim Water Characteristics

	10/14/96	
Gallons Removed	1/4	1/2
pH	7.7	7.6
Temperature (°C)	12.1	12.8
Specific Conductance(µS/cm)	5930	6150
Disolved Oxygen (mg/L)	dry	

Post-Development Information Time (Finish): 10/14/96 10:00

Water Level: dry Total Depth of Well: 14.40'

Approximate Volume Removed: 2 gallons (6 of casing volumes)

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material ND
pH 7.6 Temperature(°C) 12.8
Specific Conductance(µS/cm) 6150
Disolved Oxygen (mg/L)

Comments:

Slow recharge

3 casing Vol = 2.2 gal

MONITORING POINT DEVELOPMENT RECORD

Job Number: 725525
Location Pump House 2
Well Number MW-20

Job Name: Malmstrom
by ~~[illegible]~~ Layman Date: 10-12, 1996
Measurement Datum TOC

Pre-Development Information

Time (Start): 1540

Water Level: 9.61

Total Depth of Well: 14.11

Water Characteristics

Color light brown Clear (Cloudy)
Odor: None (Weak) Moderate Strong
Any Films or Immiscible Material NO
pH 7.1 Temperature(°C) 15.2
Specific Conductance(µS/cm) 5240
Disolved Oxygen (mg/L)

10/14/96

Still murky after 3.5 gallons, bailed dry

Interim Water Characteristics

				1/2	1	2
Gallons Removed	1/2	2.5	3.0			
pH	7.3	7.3	7.3	7.7	7.5	7.5
Temperature (°C)	13.3	13.0	12.8	12.2	12.5	12
Specific Conductance(µS/cm)	5520	5670	5890	5490	5460	5
Disolved Oxygen (mg/L)			dry			

avg of 3.5

Post-Development Information

Time (Finish): 9:15 10/14/96

Water Level: dry

Total Depth of Well: 14.11

Approximate Volume Removed: 10 gallons total (13 casing vol)

Water Characteristics

Color brown Clear (Cloudy)
Odor: None Weak (Moderate) Strong
Any Films or Immiscible Material NO
pH 7.5 Temperature(°C) 11.9
Specific Conductance(µS/cm) 5730
Disolved Oxygen (mg/L)

Comments:

~~Good recharge~~ Water not as silty, parameters pretty much within 10%, consider well developed

3 casing Vol = ~~3 gal~~ 2.5 gal

MONITORING POINT DEVELOPMENT RECORD

Job Number: 725525 Pump House 2 Job Name: Malmstrom Risk-based
Location ~~MW-21 Risk Based~~ by Layman Date: 10/12, 1996
Well Number MW-21 Measurement Datum TOC

Pre-Development Information Time (Start): ~~1400~~ 1440

Water Level: 4.48' Total Depth of Well: 9.41'

Water Characteristics

Color murky, brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material no
pH 7.5 Temperature(°C) 19.5
Specific Conductance(µS/cm) 2690
Disolved Oxygen (mg/L)

Interim Water Characteristics

	5	day 2 1	2	3	4
Gallons Removed 3					
pH 7.1	7.1	7.5	7.2	7.2	7.3
Temperature (°C) 18.5	18.4	16.4	16.7	16.4	16.
Specific Conductance(µS/cm) 2980	3120	3370	3370	3370	33
Disolved Oxygen (mg/L)					

dry

Post-Development Information Time (Finish): 1020 10/13/96

Water Level: 8.53' Total Depth of Well: 9.48'

Approximate Volume Removed: 10 gallons (12 casing vol)

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material ND
pH 7.2 Temperature(°C) 16.7
Specific Conductance(µS/cm) 3390
Disolved Oxygen (mg/L) —

Comments:

3 casing Vol = 2.4 gal

MONITORING POINT DEVELOPMENT RECORD

Job Number: 72552 Job Name: Malmstrom
Location Pumphouse 2 by Slaymaker Date: 10-13, 1996
Well Number MW-22 Measurement Datum TOC

Pre-Development Information Time (Start): 1400

Water Level: 3.07 Total Depth of Well: 7.91 (4.84' water)

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material
pH 7.1 Temperature(°C) 18.4
Specific Conductance(µS/cm) 2110
Disolved Oxygen (mg/L)

Interim Water Characteristics — bailed dry at 4 gallons

Gallons Removed	10/14/96 1/2	1	2	3	4
pH	malfunctioning				
Temperature (°C)	13.9	15.6	15.7	14.9	15.4
Specific Conductance(µS/cm)	2100	2080	2310	2250	2250
Disolved Oxygen (mg/L)					

Post-Development Information Time (Finish): 10/14/96 1045

Water Level: 6.22' Total Depth of Well: 7.91

Approximate Volume Removed: 9 gallons total (11 casing volumes)

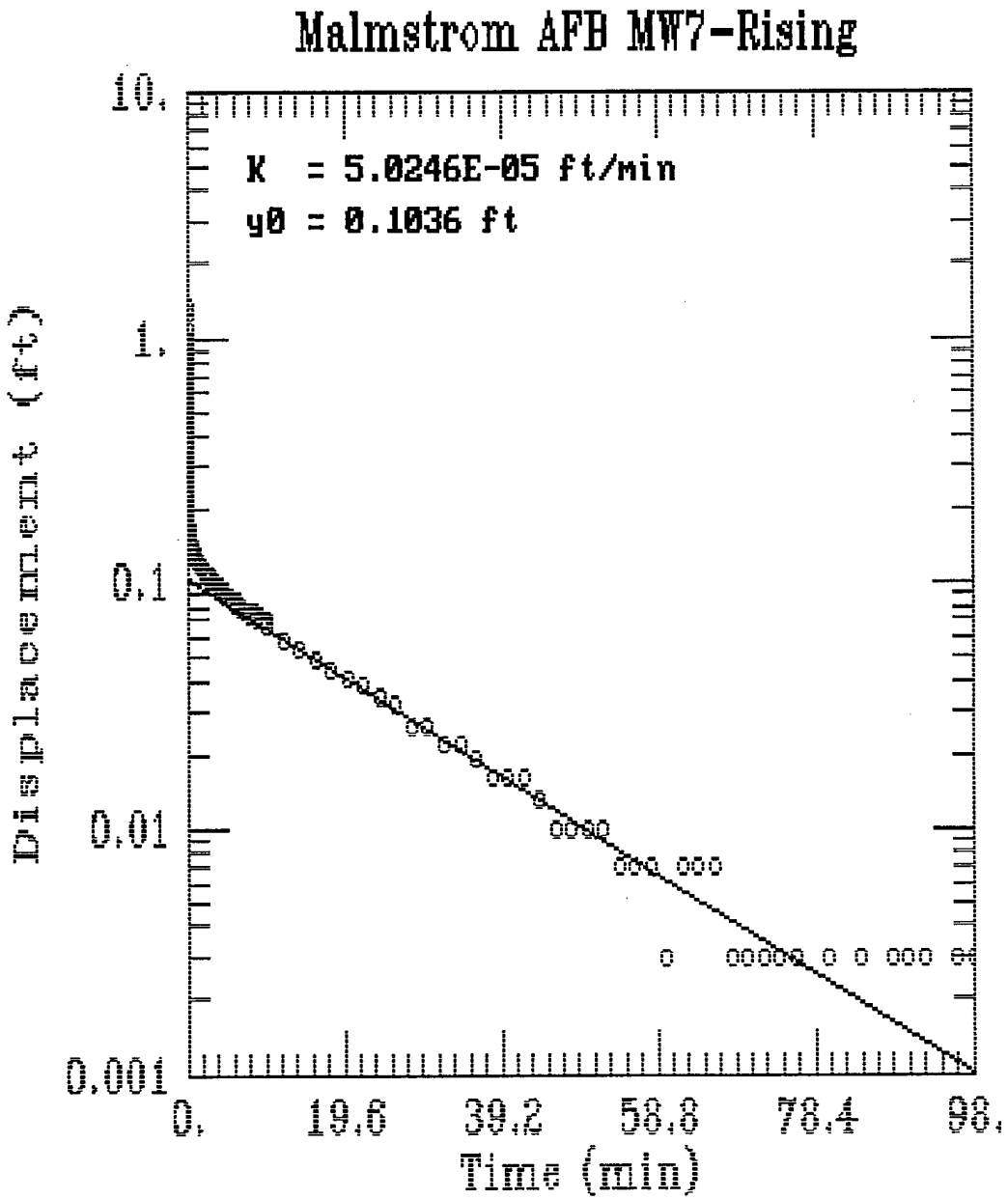
Water Characteristics

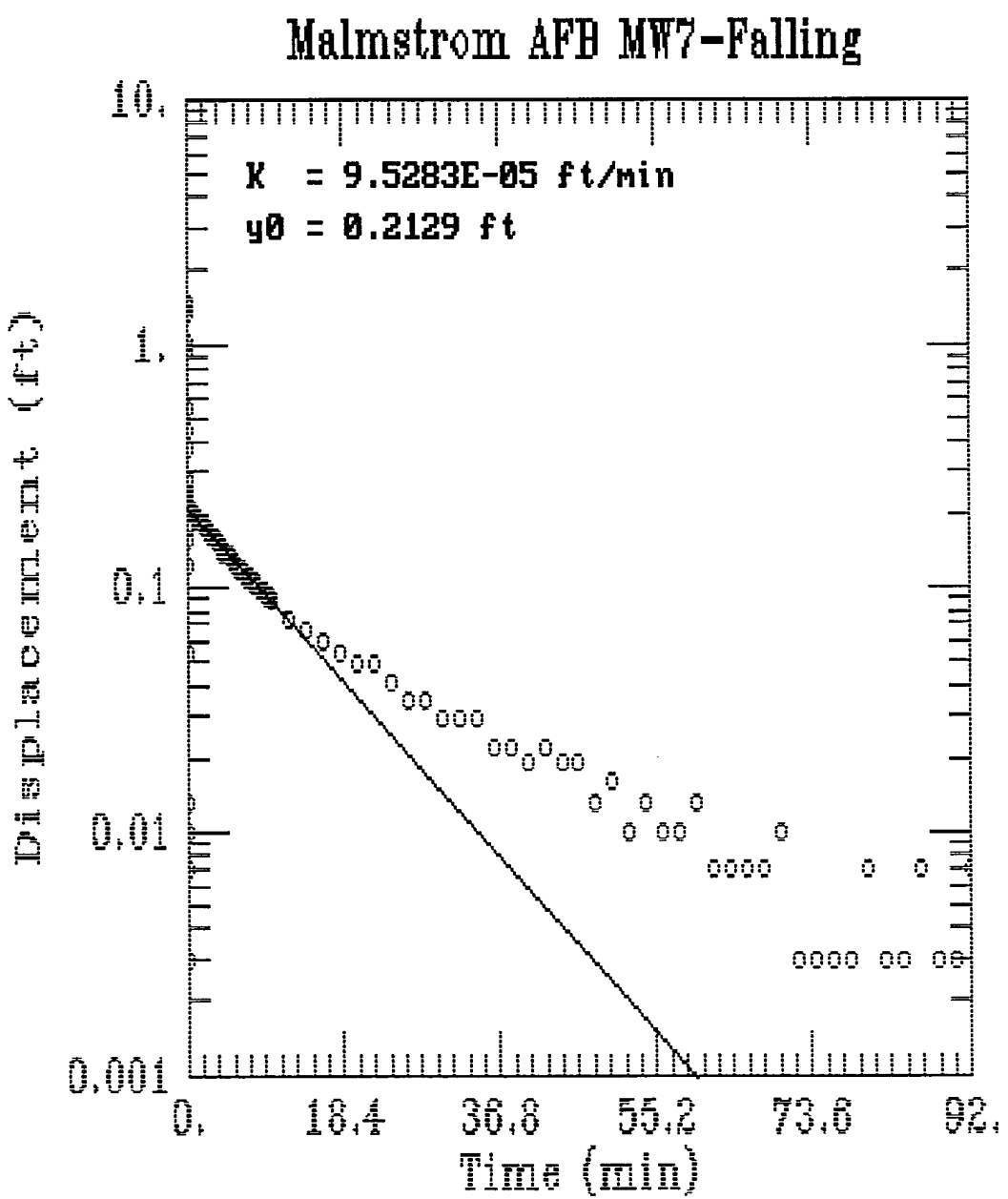
Color brown Clear Cloudy
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material ND
pH not available Temperature(°C) 15.4
Specific Conductance(µS/cm) 2250
Disolved Oxygen (mg/L)

Comments:

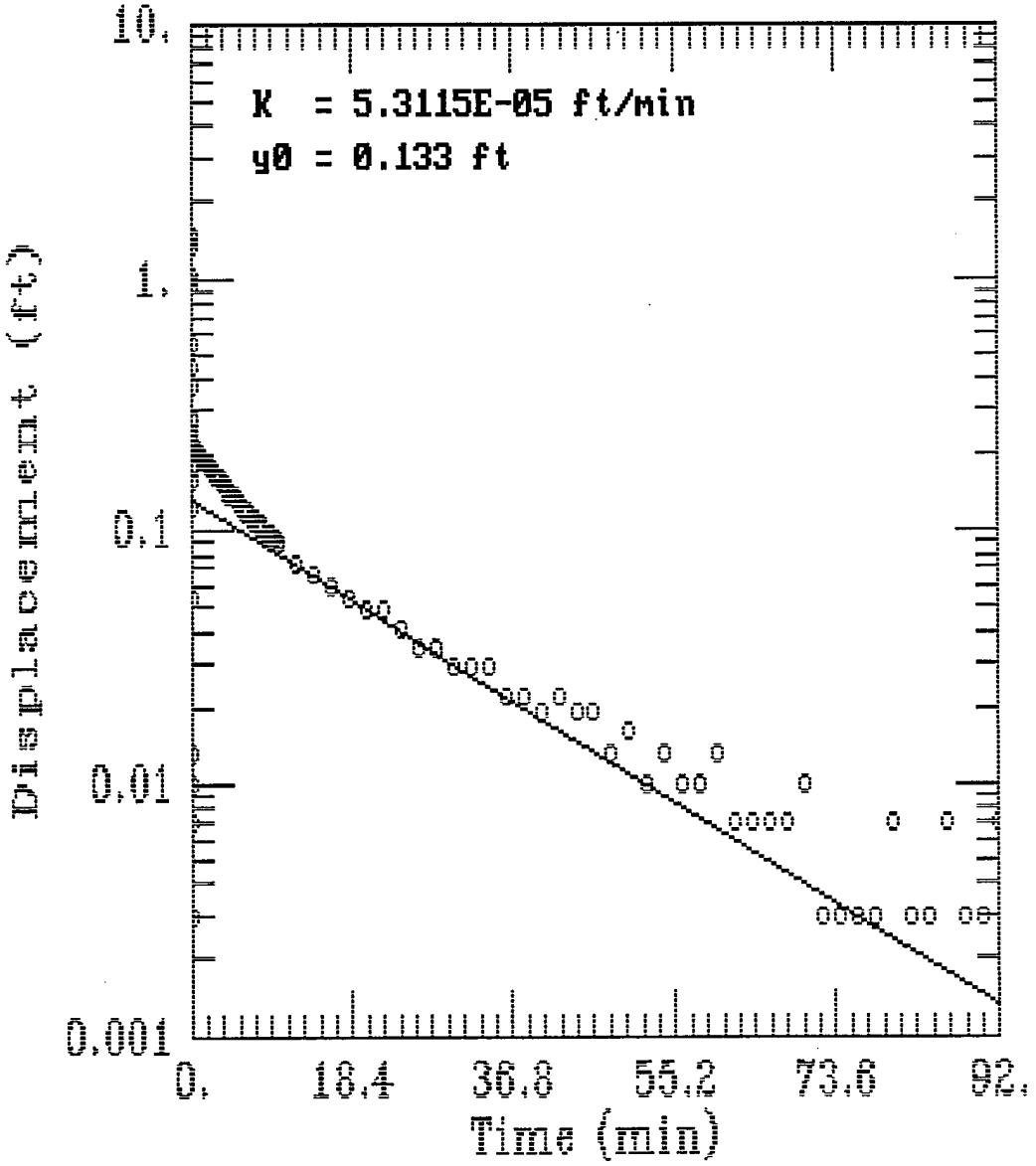
APPENDIX C

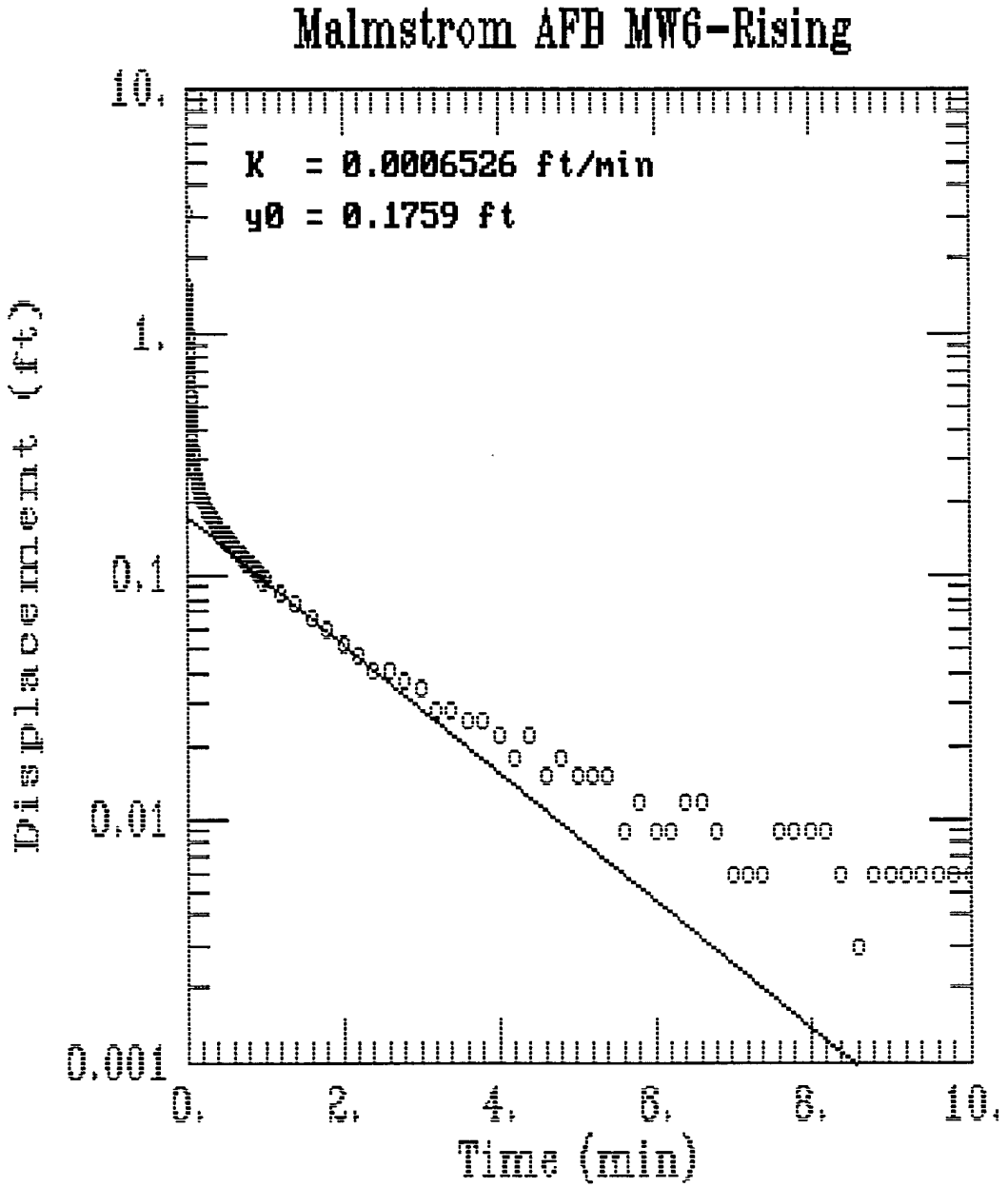
AQUIFER TEST DATA


Malmstrom AFB MW7-Rising
K = 5.0246E-05 ft/min
y0 = 0.1036 ft
10.
1.
0.1
0.01
0.001
Displacement (ft)
0.
19.6
39.2
58.8
78.4
98.
Time (min)

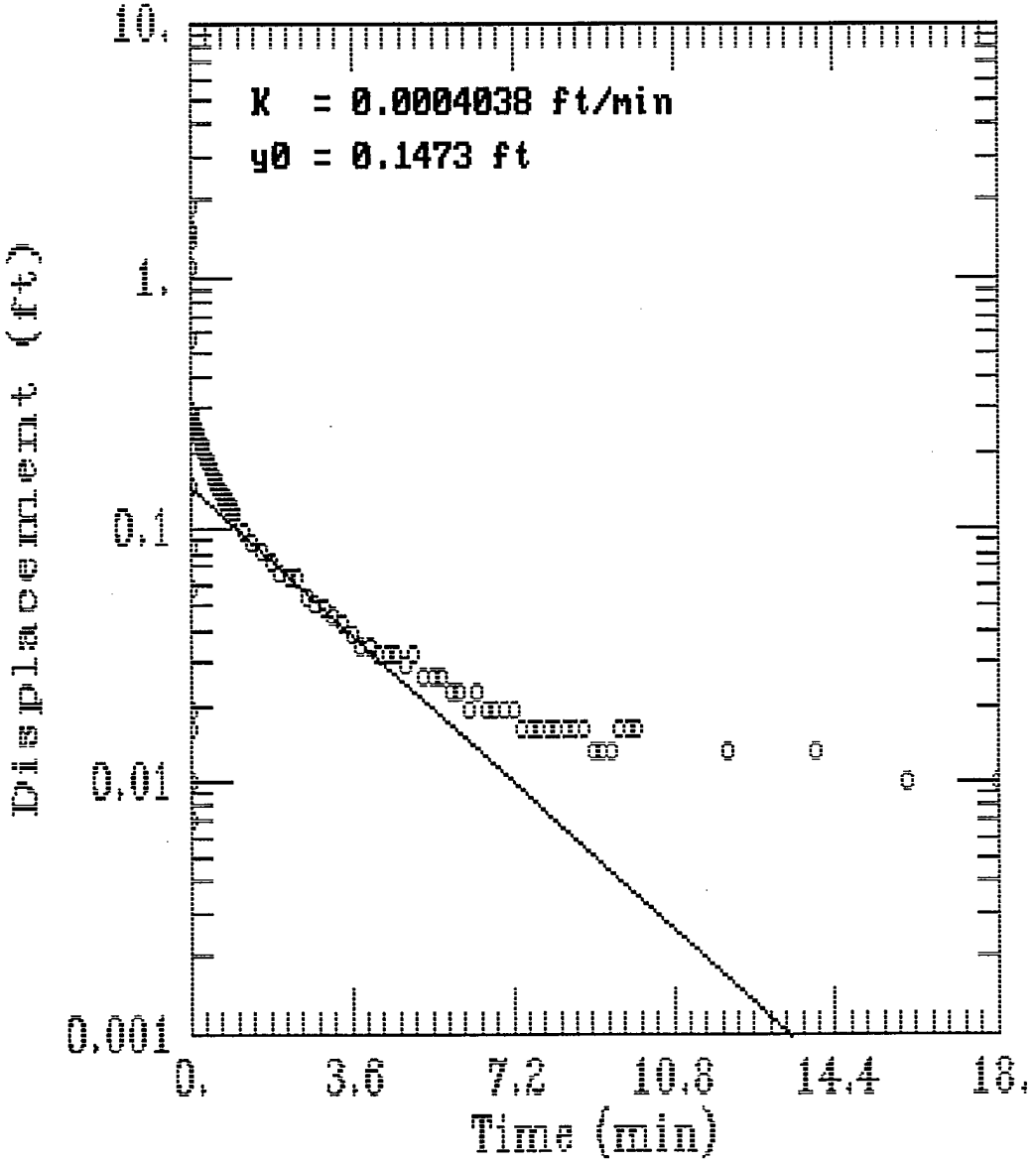

Malmstrom AFB MW7-Falling
K = 9.5283E-05 ft/min
y0 = 0.2129 ft
10.
1.
0.1
0.01
0.001
Displacement (ft)
0.
18.4
36.8
55.2
73.6
92.
Time (min)

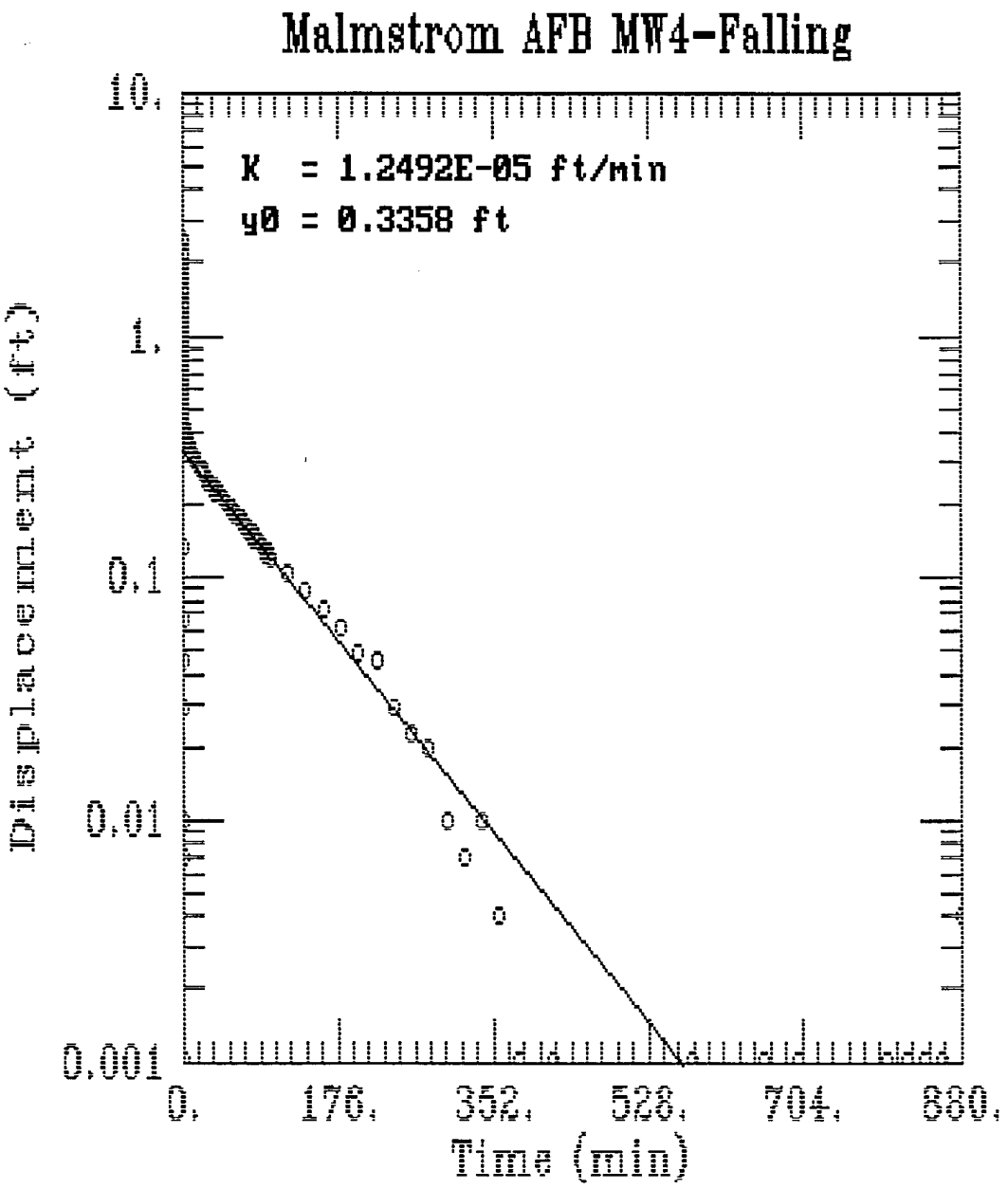
Malmstrom AFB MW7-Falling

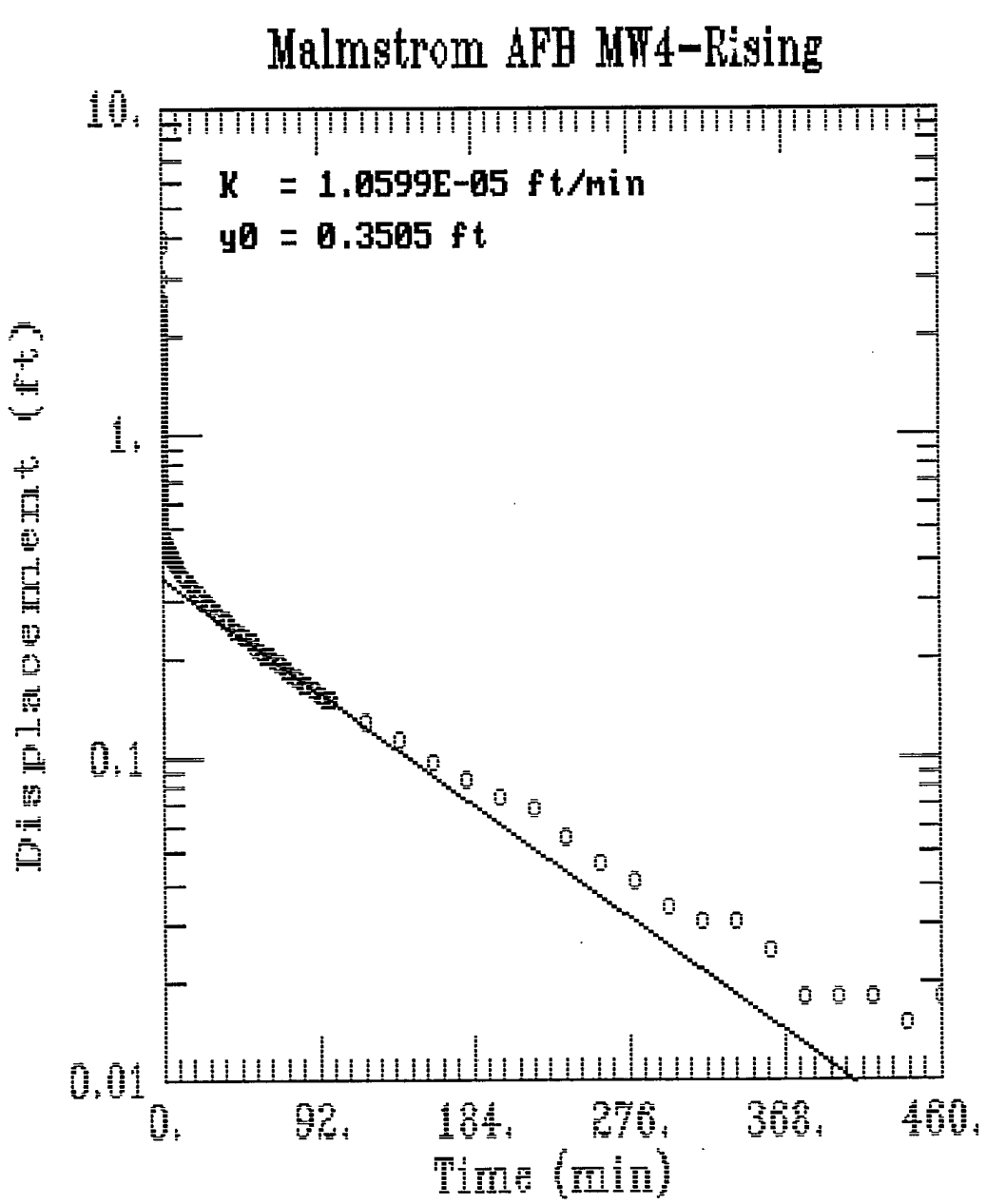


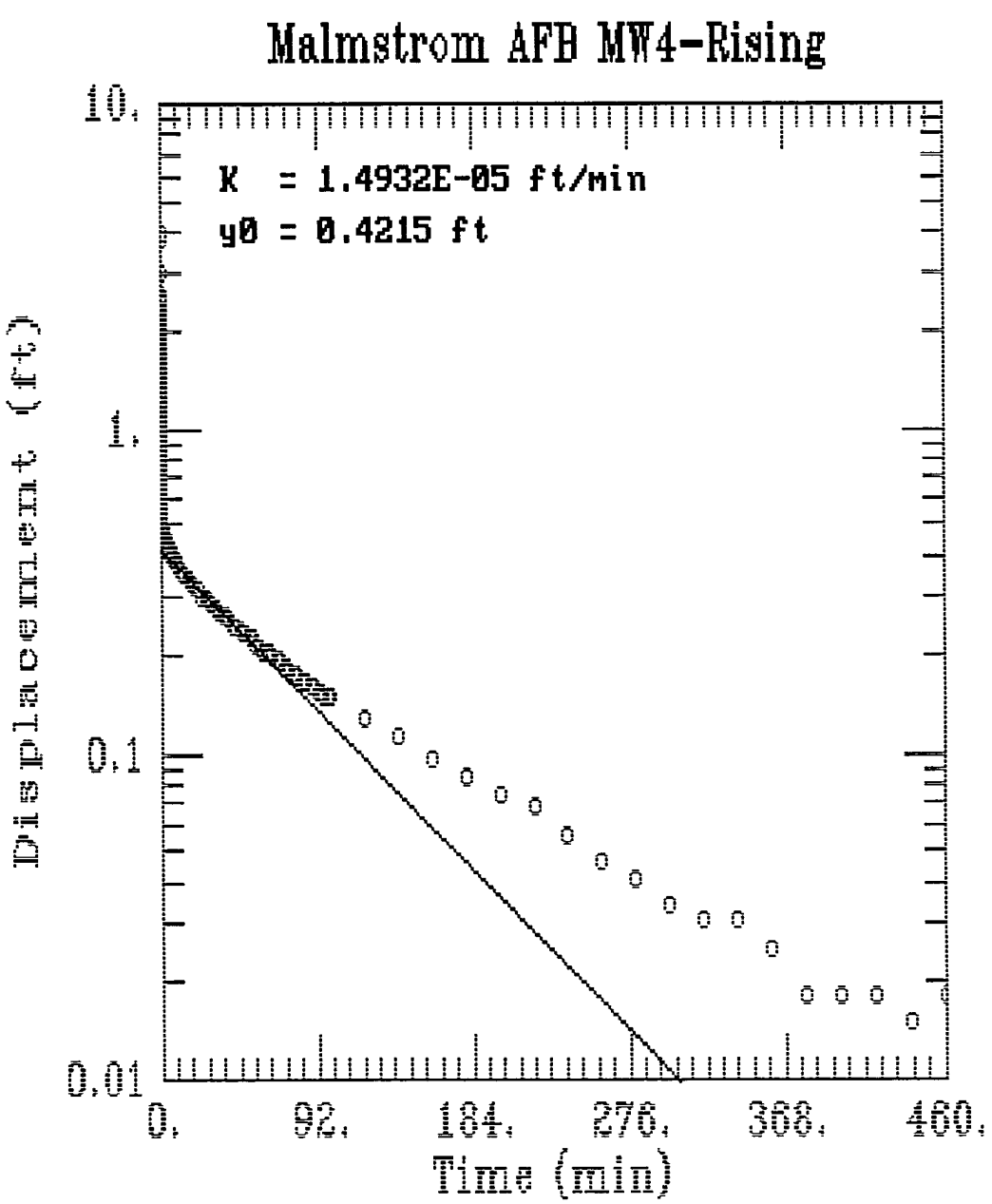

Malmstrom AFB MW6-Rising
K = 0.0006526 ft/min
y0 = 0.1759 ft
Displacement (ft)
10.
1.
0.1
0.01
0.001
0.
2.
4.
6.
8.
10.
Time (min)

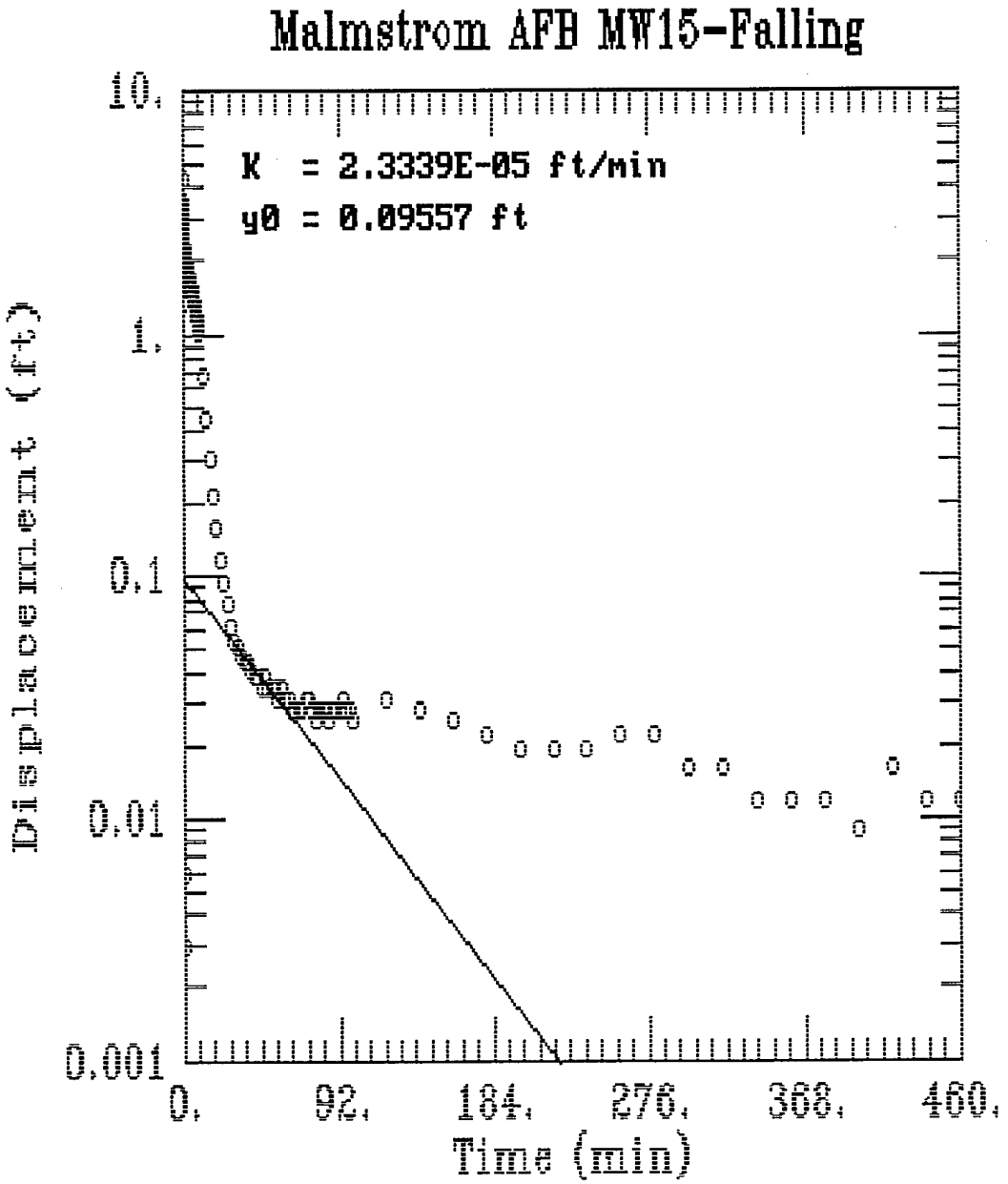
Malmstrom AFB MW6-Falling

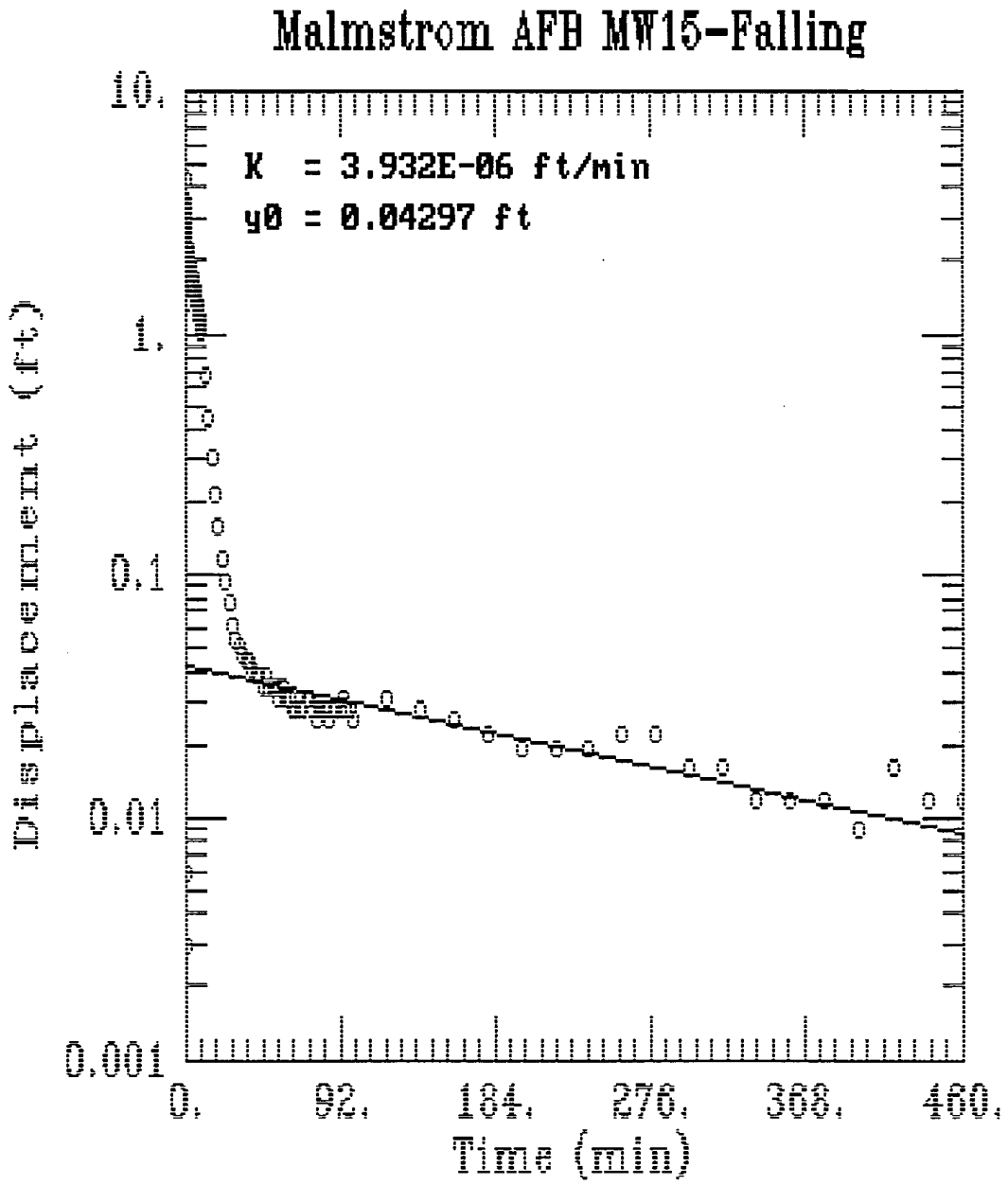


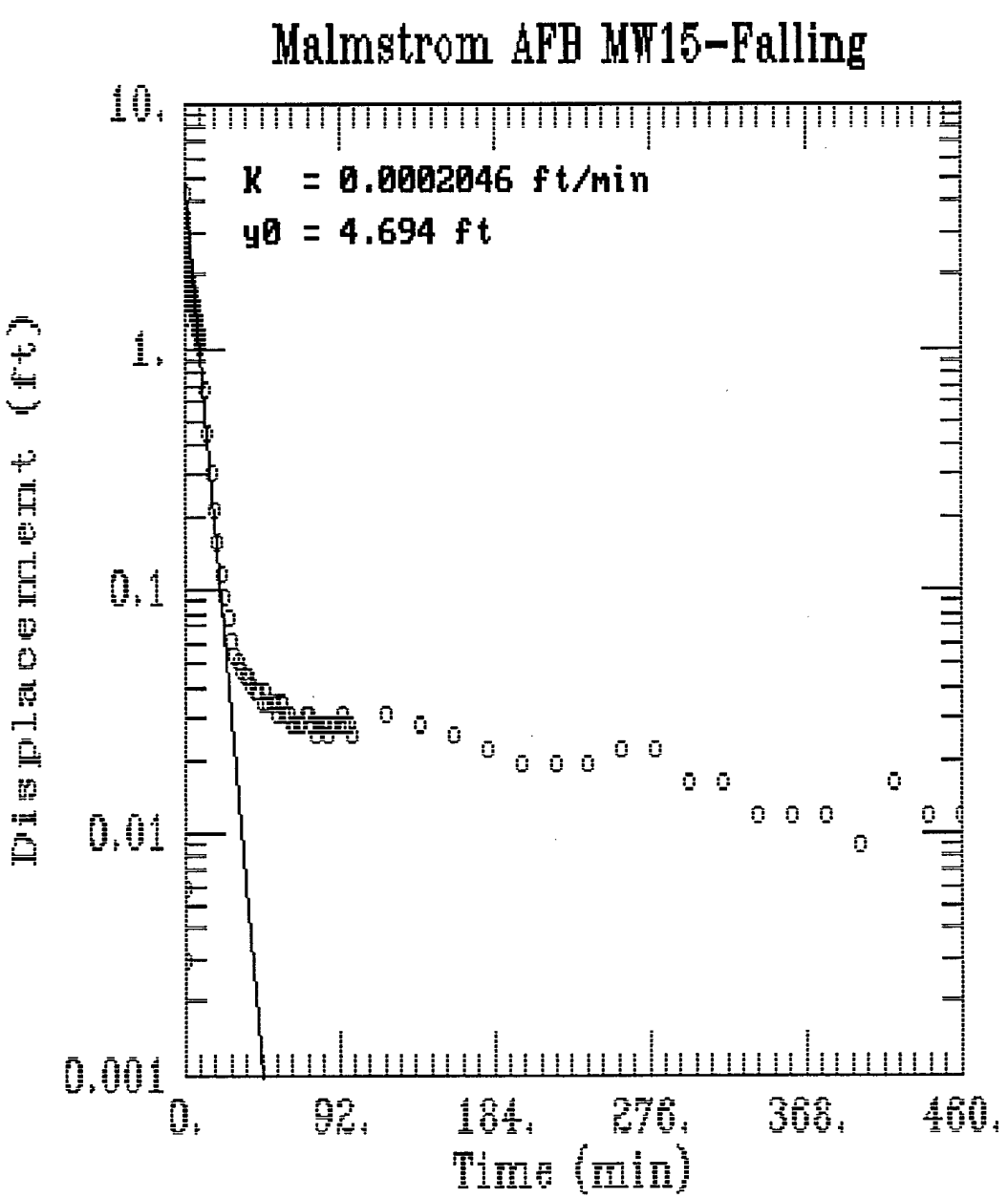

Malmstrom AFB MW4-Falling
K = 1.2492E-05 ft/min
y0 = 0.3358 ft
10.
1.
0.1
0.01
0.001
Displacement (ft)
0.
176.
352.
528.
704.
880.
Time (min)

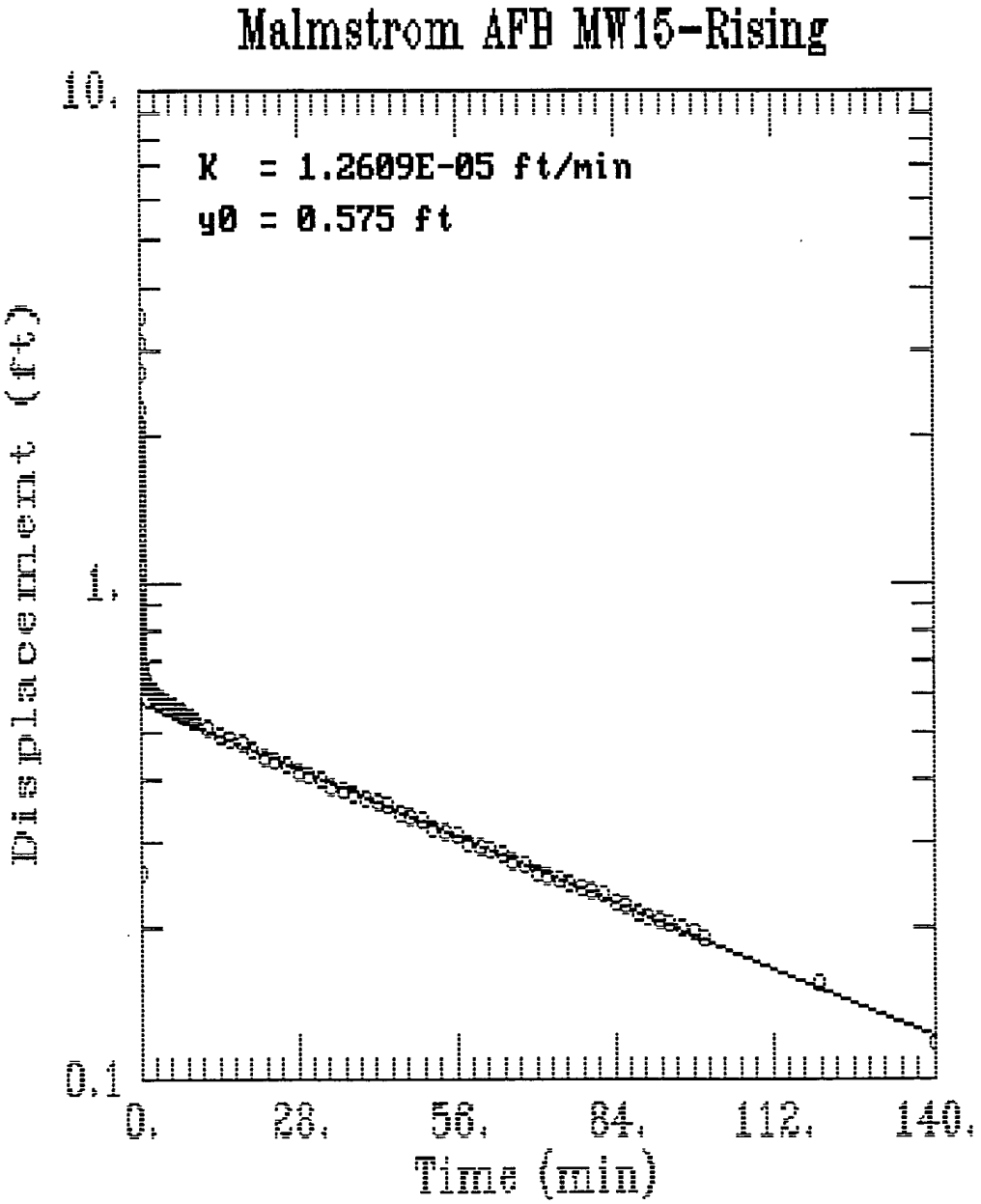

Malmstrom AFB MW4-Rising
K = 1.0599E-05 ft/min
y0 = 0.3505 ft
10.
1.
0.1
0.01
Displacement (ft)
0.
92.
184.
276.
368.
460.
Time (min)


Malmstrom AFB MW4-Rising
K = 1.4932E-05 ft/min
y0 = 0.4215 ft
10.
1.
0.1
0.01
Displacement (ft)
0.
92.
184.
276.
368.
460.
Time (min)


Malmstrom AFB MW15-Falling
K = 2.3339E-05 ft/min
y0 = 0.09557 ft
10.
1.
0.1
0.01
0.001
Displacement (ft)
0.
92.
184.
276.
368.
460.
Time (min)


Malmstrom AFB MW15-Falling
K = 3.932E-06 ft/min
y0 = 0.04297 ft
10.
1.
0.1
0.01
0.001
Displacement (ft)
0.
92.
184.
276.
368.
460.
Time (min)


Malmstrom AFB MW15-Falling
K = 0.0002046 ft/min
y0 = 4.694 ft
10.
1.
0.1
0.01
0.001
Displacement (ft)
0.
92.
184.
276.
368.
460.
Time (min)


Malmstrom AFB MW15-Rising
K = 1.2609E-05 ft/min
y0 = 0.575 ft
Displacement (ft)
10.
1.
0.1
0.
28.
56.
84.
112.
140.
Time (min)

APPENDIX D

DEVELOPMENT OF SSTLS

The site-specific target concentration goals developed herein were calculated using site-specific exposure assumptions based on the current and planned future use of the site. Relevant EPA guidance (i.e., EPA 1989a, 1989b, 1991b-c, 1992, 1993, 1994a, and 1994c) were used to develop health-protective target concentration goals. The following summarizes the exposure assumptions, toxicity data, and algorithms.

(a) Summary of potentially completed exposure pathways:

- exposure of current and future on-site workers engaged in non-disruptive site activities to contaminated sediments and ephermal surface water
  - direct contact w/ sediments & surface water
  - incidental ingestion and inhalation of volatilizing chemicals emitted from dried, exposed sediments

- exposure of current and future on-site workers engaged in disruptive site activities to soil gas, subsurface soils, sediments, surface water, and groundwater
  - direct contact w/ sediments and ephermal surface water
  - incidental ingestion and inhalation of volatilizing contaminants from dried, exposed sediments & disturbed subsurface soils
  - dermal contact with subsurface soils & groundwater

- migration of contaminated groundwater to areas beyond Base property controls
  [Note: this is not really a potentially complete exposure pathway since no receptor, no exposure point, or exposure route has been identified. Rather, this has been included to ensure state-defined MCLs are not exceeded @ points beyond exposure controls.]

APPENDIX G
SITE-SPECIFIC TARGET LEVELS (SSTLs) - SOILS AND SEDIMENTS
ONSITE WORKERS - NONDISRUPTIVE CONDITIONS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Exposure Assumptions			Source
Receptor	Current/future onsite worker		
Target risk (TR)	10^{-4} to 10^{-6}		
Target hazard quotient (THQ)	1		
Body weight (BW)	70	kg	EPA, 1990, 1991a
Averaging Time (AT)	70	years	EPA, 1991a
Exposure frequency (EF)	90	days/year	Site-specific
Exposure duration (ED)	10	years	Site-specific
Skin surface area (SA)	5800	cm^2	EPA, 1992
Soil/skin adherance (AF)	1	$mg/cm^2/day$	EPA 1989a, 1990
Dermal absorption factor (DABS)	0.25		Ryan et al., 1989
Inhalation rate, air (IRair)	24	m^3/day	EPA, 1992
Soil ingestion rate, incidental (IRsoil)	100	mg/day	EPA, 1990, 1993
Soil-to-air volatilization factor (VF)	chem-specific	m^3/kg	EPA, 1991a
Oral absorption factor (Oabs)	chem-specific		ATSDR Profiles, 1989-1992
VF = [(LS*V*DH)/A]*[(3.14*AS*T)^0.5/(2*Dei*porosity*KAS*0.001)]			
Length of contaminated area (LS)	6	meters	Site-specific
Wind speed in mixing zone (V)	3.6	m/sec	Site-specific
Diffusion height (DH)	2	m	EPA, 1991a
Area of soil contamination (A)	90000	cm^2	Site-specific
Diffusivity*(porosity)^1.33 (Dei)	chem-specific	cm^2/sec	
Porosity (n)	0.35		Site-specific
Density (ds)	1.7	g/cm^3	Site-specific
Soil/air partition coefficient (KAS)	chem-specific	g/cm^3	
AS = (Dei*n)/(n+ds*(1-n)/KAS)	chem-specific	cm^2/sec	
Exposure interval (T)	7.78E+07	sec	Site-specific; see ED*EF

Chemical-specific Values and Algorithms

Effective diffusivity

Benzene	0.0659	cm^2/sec
Toluene	0.0593	cm^2/sec
Ethylbenzene	0.0529	cm^2/sec
Xylenes	0.0523	cm^2/sec

Soil/air partition coefficient (KAS)

Benzene	0.138	g/cm^3
Toluene	0.0435	g/cm^3
Ethylbenzene	0.012	g/cm^3
Xylenes	0.0601	g/cm^3

Soil-to-air volatilization factor (VF)

Benzene	1.24E+05	m^3/kg
Toluene	2.37E+05	m^3/kg
Ethylbenzene	4.80E+05	m^3/kg
Xylenes	2.14E+05	m^3/kg

SSTL for Carcinogens in Soils and Sediments

$=[TR*BW*AT*365]/[(EF*ED)*[(SFo/Oabs*SA*AF*10^{-6}*DABS)+(SFi*IRair*(1/VF)) + (SFo*10^{-6}*IRsoil)]]$

SSTL for Noncarcinogens in Soils and Sediments

$=[THQ*BW*ED*365]/[(EF*ED)*(1/(RfDo*Oabs)*SA*AF*10^{-6}*DABS)+(1/RfDi*IRair*(1/VF)) + (1/RfDo*10^{-6}*IRsoil)]$

RfDo = oral reference dose (mg/kg-day)
RfDi = inhalation reference dose (mg/m^3)
SFo = oral slope factor (mg/kg-day)
SFi = inhalation slope factor (mg/m^3)

Chemical	RfDo	RfDi	SFo	SFi	Oabs	SSTL/ HQ=1 (mg/kg)	SSTL/10^{-6} (mg/kg)	SSTL/10^{-4} (mg/kg)
Benzene	--	--	0.029	8.30E-03	0.95	--	4.08E+01	4.08E+03
Toluene	0.2	0.4	--	--	0.9	3.22E+04	--	--
Ethylbenzene	0.1	1	--	--	0.85	1.57E+04	--	--
Xylenes	2	--	--	--	0.9	3.32E+05	--	--

APPENDIX G
SITE-SPECIFIC TARGET LEVELS (SSTLs) - SOILS AND SEDIMENTS
ONSITE WORKERS - DISRUPTIVE CONDITIONS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Exposure Assumptions			Source
Receptor	Current/future onsite worker		
Target risk (TR)	10^{-4} to 10^{-6}		
Target hazard quotient (THQ)	1		
Body weight (BW)	70	kg	EPA, 1990, 1991a
Averaging Time (AT)	70	years	EPA, 1991a
Exposure frequency (EF)	90	days/year	Site-specific
Exposure duration (ED)	10	years	Site-specific
Skin surface area (SA)	5800	cm^2	EPA, 1992
Soil/skin adherance (AF)	1	$mg/cm^2/day$	EPA 1989a, 1990
Dermal absorption factor (DABS)	0.25		Ryan et al., 1989
Inhalation rate, air (IRair)	31.2	m^3/day	EPA, 1990, 1991a, 1991c, 1993
Soil ingestion rate, incidental (IRsoil)	480	mg/day	EPA, 1990, 1993
Soil-to-air volatilization factor (VF)	chem-specific	m^3/kg	EPA, 1991a
Oral absorption factor (Oabs)	chem-specific		ATSDR Profiles, 1989-1992
VF = [(LS*V*DH)/A]*[(3.14*AS*T)^0.5/(2*Dei*porosity*KAS*0.001)]			
Length of contaminated area (LS)	6	meters	Site-specific
Wind speed in mixing zone (V)	3.6	m/sec	Site-specific
Diffusion height (DH)	2	m	EPA, 1991a
Area of soil contamination (A)	270000	cm^2	Site-specific
Diffusivity*(porosity)^1.33 (Dei)	chem-specific	cm^2/sec	
Porosity (n)	0.35		Site-specific
Density (ds)	1.7	g/cm^3	Site-specific
Soil/air partition coefficient (KAS)	chem-specific	g/cm^3	
AS = (Dei*n)/(n+ds*(1-n)/KAS)	chem-specific	cm^2/sec	
Exposure interval (T)	7.78E+07	sec	Site-specific; see ED*EF

Chemical-specific Values and Algorithms

Effective diffusivity

Benzene	0.0659	cm^2/sec
Toluene	0.0593	cm^2/sec
Ethylbenzene	0.0529	cm^2/sec
Xylenes	0.0523	cm^2/sec

Soil/air partition coefficient (KAS)

Benzene	0.138	g/cm^3
Toluene	0.0435	g/cm^3
Ethylbenzene	0.012	g/cm^3
Xylenes	0.0601	g/cm^3

Soil-to-air volatilization factor (VF)

Benzene	4.15E+04	m^3/kg
Toluene	7.90E+04	m^3/kg
Ethylbenzene	1.60E+05	m^3/kg
Xylenes	7.14E+04	m^3/kg

<u>SSTL for Carcinogens in Soils and Sediments</u>

=[TR*BW*AT*365]/[(EF*ED)*[(SFo/Oabs*SA*AF*10^{-6}*DABS)+ (SFi*IRair*(1/VF)) + (SFo*10^{-6}*IRsoil)]]

<u>SSTL for Noncarcinogens in Soils and Sediments</u>

=[THQ*BW*ED*365]/[(EF*ED)*(1/(RfDo*Oabs)*SA*AF*10^{-6}*DABS)+ (1/RfDi*IRair*(1/VF)) + (1/RfDo*10^{-6}*IRsoil)]

RfDo = oral reference dose (mg/kg-day)
RfDi = inhalation reference dose (mg/m^3)
SFo = oral slope factor (mg/kg-day)
SFi = inhalation slope factor (mg/m^3)

Chemical	RfDo	RfDi		SFo	SFi	Oabs	SSTL/ HQ=1 (mg/kg)	SSTL/10^{-6} (mg/kg)	SSTL/10^{-4} (mg/kg)
Benzene	--	--		0.029	8.30E-03	0.95	--	3.08E+01	3.08E+03
Toluene	0.2	0.4		--	--	0.9	2.48E+04	--	--
Ethylbenzene	0.1	1		--	--	0.85	1.29E+04	--	--
Xylenes	2	--		--	--	0.9	2.72E+05	--	--

APPENDIX G
SITE-SPECIFIC TARGET LEVELS (SSTLs) - EPHERMAL SURFACE WATER AND GROUNDWATER
ONSITE WORKERS - NONDISRUPTIVE AND DISRUPTIVE CONDITIONS
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Exposure Assumptions			Source	Algorithms
Receptor	Current/future onsite worker			SSTL for Carcinogens in Groundwater
Target risk (TR)	10^{-4} to 10^{-6}			=[TR*BW*AT*365]/[(EF*ED*ET*10^{-3}*PC*SFo*SA)]
Target hazard quotient (THQ)	1			
Body weight (BW)	70	kg	EPA, 1990, 1991a	
Averaging Time (AT)	70	years	EPA, 1991a	SSTL for Noncarcinogens in Groundwater
Exposure frequency (EF)	90	days/year	Site-specific	=[THQ*BW*ED*365]/(EF*ED*ET*10^{-3}*PC*1/RfDo*SA)
Exposure duration (ED)	10	years	Site-specific	
Exposure Time (ET)	8	hours/day	EPA, 1989a, 1990	
Skin surface area (SA)	5800	cm^2	EPA, 1989a, 1990	RfDo = oral reference dose (mg/kg-day)
Permeability Constant (PC)	chem-specific	cm/hour		SFo = oral slope factor (mg/kg-day)
Benzene	2.10E-02	cm/hour		
Toluene	4.50E-02	cm/hour		
Ethylbenzene	7.40E-02	cm/hour		
Xylenes	8.00E-02	cm/hour		

Chemical	RfDo	SFo	SSTL/ HQ=1 (mg/L)	SSTL/10^{-6} (mg/L)	SSTL/10^{-4} (mg/L)
Benzene	--	0.029	--	7.03E-02	7.03E+00
Toluene	0.2	--	2.72E+01	--	--
Ethylbenzene	0.1	--	8.27E+00	--	--
Xylenes	2	--	1.53E+02	--	--

APPENDIX G
SITE-SPECIFIC TARGET LEVELS (SSTLs) - SOILS AND SEDIMENTS
PROTECTION OF WATER QUALITY
ENGINEERING EVALUATION/COST ANALYSIS
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Leaching Algorithm				Source
Receptor		Current/future onsite worker		
Target groundwater concentration (Ct)		chem-specific		Groundwater SSTLs - see
	Benzene (10^{-6})	7.03E-02	mg/L	previous calculations
	Benzene (10^{-4})	7.03E+00	mg/L	
	Toluene	2.72E+01	mg/L	
	Ethylbenzene	8.27E+00	mg/L	
	Xylenes	1.53E+02	mg/L	
Target groundwater concentration (Ct)		chem-specific		Groundwater MCLs
	Benzene	0.005	mg/L	
	Toluene	1	mg/L	
	Ethylbenzene	0.7	mg/L	
	Xylenes	10	mg/L	
Bulk density of soil (ds)		1.7	kg/L	Site-specific
Soil/water partition coefficient (Kd)		chem-specific	L/kg	Site-specific based on
	Benzene	11.2	L/kg	measured soil/measured water data
	Toluene	43.5	L/kg	from MW-18 (HDR, 1994)
	Ethylbenzene	95.4	L/kg	
	Xylenes	43.5	L/kg	
Soil/water partition coefficient (Kd)		chem-specific	L/kg	Literature-based values based on
	Benzene	0.12	L/kg	Koc*foc (which is 0.0024)
	Toluene	0.28	L/kg	
	Ethylbenzene	0.23	L/kg	
	Xylenes	0.31	L/kg	
Water-filled porosity (n)		0.3		Site-specific
Air-filled porosity (na)		0.05		Assume soils essentially saturated
Dimensionless Henry's Law (H')		chem-specific		EPA, 1986
	Benzene	0.23		EPA, 1986
	Toluene	0.265		EPA, 1986
	Ethylbenzene	0.267		EPA, 1986
	Xylenes	0.293		

$SSTL = Ct(ds*Kd + n + (na*H'))/ds$

Chemical	Site-specific Kd Values				Literature-based Kd Values			
	SSTL/ HQ=1 (mg/kg)	SSTL/10^{-6} (mg/kg)	SSTL/10^{-4} (mg/kg)	MCL (mg/kg)	SSTL/ HQ=1 (mg/kg)	SSTL/10^{-6} (mg/kg)	SSTL/10^{-4} (mg/kg)	MCL (mg/kg)
Benzene	--	8.01E-01	8.01E+01	5.69E-02	--	2.12E-02	2.12E+00	1.50E-03
Toluene	1.19E+03	--	--	4.37E+01	1.25E+01	--	--	4.60E-01
Ethylbenzene	7.90E+02	--	--	6.69E+01	3.42E+00	--	--	2.89E-01
Xylenes	6.68E+03	--	--	4.37E+02	7.56E+01	--	--	4.94E+00

BENZENE

CAS NUMBER

71-43-2

COMMON SYNONYMS

None.

ANALYTICAL CLASSIFICATION

Volatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: 1,791 mg/L [1]
Vapor Pressure: 95.19 mm Hg at 25°C [1]
Henry's Law Constant: 5.43 x 10^{-3} atm-m^3/mole (temperature not given) [1]
Specific Gravity: 0.879 at 15/5°C [2]
Organic Carbon Partition Coefficient: 31 - 143 [1]

FATE DATA: HALF-LIVES

Soil: 5 - 16 days [3]
Air: 2.09 - 20.9 days [3]
Surface Water: 5 - 16 days [3]
Groundwater: 10 days to 2 years [3]

NATURAL SOURCES

Crude oil, volcanoes, forest fires, plants [1].

ARTIFICIAL SOURCES

Gasoline, fuel oils, chemical industry, coke ovens, mining, manufacturing, cigarette smoke [1].

FATE AND TRANSPORT

Benzene will rapidly volatilize from surface soil and water. That which does not volatilize from permeable surface and subsurface soils will be highly to very highly mobile, and can be expected to leach to nearby groundwater which is not protected by a confining layer. It is fairly soluble, and will be carried with the groundwater to discharge points. It may be subject to biodegradation in soils, shallow groundwater, and surface water. Benzene will not be expected to significantly adsorb to sediment, bioconcentrate in aquatic organisms, or hydrolyze. Photodegradation may be a significant removal mechanism in surface waters which are not conducive to microbial degradation. Benzene will undergo significant photodegradation in air, but may be washed out with rain [1].

HUMAN TOXICITY

General. Benzene is absorbed into the body following ingestion, inhalation, and dermal contact, and must undergo metabolic transformation to exert its toxic effects. Metabolism occurs primarily in the liver, and to a lesser extent in the bone marrow [4]. The primary targets of benzene toxicity are the central nervous system and the blood [4,5]. Benzene is genotoxic to humans and the USEPA has placed it in weight-of-evidence cancer Group A, indicating that it is a human carcinogen [6].

Oral Exposure. A chronic oral RfD for benzene is currently under review by the USEPA [6]. Benzene is readily absorbed following oral exposure. The lowest reported fatal dose in humans is 50 mg/kg [5]. Acute oral LD_{50} values in animals include 930 to 5600 mg/kg in rats, 2000 mg/kg in dogs and 4700 mg/kg in mice [4,5]. Data regarding the ingestion of benzene in humans are limited to acute overexposure. Ingestion of 2 ml (29 mg/kg) has resulted in depression of the central nervous system, while ingestion of 10 ml (143 mg/kg) has been fatal [5]. The cause of death was usually respiratory arrest, central nervous system depression or cardiac collapse [4]. In animals, longer-term oral exposure has resulted in toxic effects on the blood (cytopenia: decrease in various cellular elements of the blood) and the immunological system (decreased white blood cells) [4]. There is no evidence that oral exposure to benzene causes effects on reproduction and development, but studies in animals suggest that benzene may affect fetal development [4]. There is no information regarding carcinogenic effects in humans following oral exposure to benzene, but studies in animals indicate that benzene ingestion causes cancer in various regions of the body [4]. An oral Slope Factor of 0.029 $(mg/kg/day)^{-1}$ is based on an increase in the incidence of leukemia in occupationally-exposed workers [6]. The oral Slope Factor was extrapolated from the inhalation data.

Inhalation Exposure. A chronic inhalation RfC for benzene is currently under review by the USEPA [6]. Benzene is readily absorbed following inhalation exposure. The lowest reported fatal concentration in humans is 6380 mg/m^3 for a 5 minute exposure [5]. Acute inhalation LC_{50} values in rats ranged from 10,000 ppm for 7 hours to 13,700 ppm for 4 hours [4,5]. Most of the available data regarding benzene exposure involve workers exposed in the workplace. The acute effects of benzene exposure involve the central nervous system. Brief exposure to concentrations of 700 to 3000 ppm can cause drowsiness, dizziness, headaches and unconsciousness, and exposure to concentrations of 10,000 to 20,000 ppm can result in death [4]. In most cases, the effects will end when exposure ceases. The hematopoietic system is the primary target of toxicity following long-term exposure: exposure for several months to years results in pancytopenia (reduction in red blood cells, platelets and white blood cells), while continued exposure for many years results in anemia or leukemia. The lowest concentration resulting in the hematological effects is approximately 10 to 50 ppm [5]. Benzene has been shown to cause chromosomal aberrations in bone marrow and lymphocytes in workers exposed to concentrations > 100 ppm [5]. Chromosomal damage has been found in animals at concentrations as low as 1 ppm [5]. Benzene is not known to be teratogenic (cause birth defects) in humans, but has been found to cause various problems in the developing fetus of animals (low birth weight, delayed

bone formation) [4,5]. Occupational exposure to benzene has resulted in leukemia in exposed workers [4,5]. An inhalation Unit Risk of 8.3×10^{-6} $(ug/m^3)^{-1}$ is based on the incidence of leukemia in occupationally-exposed workers [6].

Dermal Exposure. Dermal exposure to benzene may cause redness and dermatitis [4,5]. Systemic effects have not been reported following dermal exposure to benzene.

REFERENCES

1. Howard, P.H., 1990. Handbook of Environmental Fate and Exposure Data For Organic Chemicals, Vol. II: Solvents. Lewis Publishers, Inc. Chelsea, Michigan. 546 pp.
2. Merck, 1989. The Merck Index. Eleventh Edition. Merck & Company, Inc. Rahway, NJ.
3. Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko, 1991. Handbook of Environmental Degradation Rates. Lewis Publishers. Chelsea, Michigan.
4. ATSDR, 1991. Toxicological Profile for Benzene (Draft). Agency for Toxic Substances and Disease Registry. USPHS/USEPA. October 1991.
5. Arthur D. Little, Inc., 1989. The Installation Restoration Program Toxicology Guide. Volume 2. Cambridge, MA. July 1989.
6. USEPA, 1994. Integrated Risk Information System (IRIS). Data base. Online. February, 1994.

TOLUENE

CAS NUMBER

108-43-2

COMMON SYNONYMS

Methylbenzene.

ANALYTICAL CLASSIFICATION

Volatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: 534.8 mg/L at 25°C [1]
Vapor Pressure: 28.4 mm Hg at 25°C [1]
Henry's Law Constant: 5.94 x 10^{-3} atm-m^3/mole (temperature not given) [1]
Specific Gravity: 0.866 at 20/4°C [2]
Organic Carbon Partition Coefficient: 37 to 178 [1]

FATE DATA: HALF-LIVES

Soil: 4 to 22 days [3]
Air: 10 hours to 4.3 days [3]
Surface Water: 4 to 22 days [3]
Groundwater: 1 to 4 weeks [3]

NATURAL SOURCES

Volcanoes, forest fires, and crude oil [1].

ARTIFICIAL SOURCES

Gasoline, fuel oils, automobile exhaust, chemical industry, paints and lacquers [1].

FATE AND TRANSPORT

Much of the toluene released to surface soil will be lost to volatilization. It is mobile in soils and will leach to groundwater. Biodegradation occurs slowly in soil and groundwater, but is inhibited by high concentrations. Under ideal conditions of low concentration and acclimated microbial populations, rapid biodegradation may occur. Losses from surface water occur due to volatilization and biodegradation. It will not significantly adsorb to sediment or bioconcentrate in aquatic organisms. In the atmosphere it will degrade or be washed out with rain [1].

HUMAN TOXICITY

General. Toluene acts primarily on the central nervous system [4]. The USEPA has placed toluene in weight-of-evidence Group D; that is, it is not classifiable as to human carcinogenicity [5].

Oral Exposure. A chronic RfD of 0.2 mg/kg/day is based on a NOAEL of 223 mg/kg/day for changes in liver and kidney weights in a subchronic oral study in rats. The LOAEL in this study was a dose of 446 mg/kg/day [5]. Toluene is absorbed more slowly from the gastrointestinal tract than from the lungs [6]. The acute oral LD_{50} for adult rats is in the range of 5,000 to 7,300 mg/kg [4,6]. Brain damage was noted in mice receiving 1,250 mg/kg/day by gavage for 13 weeks [6].

Inhalation Exposure. The RfC of 0.4 mg/m^3 is based on a LOAEL of 88 ppm for central nervous system effects observed in humans following inhalation exposure [5]. Toluene is rapidly absorbed following inhalation by humans and animals [6]. The inhalation LC_{50} in mice is 5,300 ppm for an 8-hour exposure. Exposure of humans by inhalation to 200 ppm for 8 hours produced mild fatigue, weakness, confusion, lacrimation, and tingling of the skin. At 600 ppm, additional effects included euphoria, headache, dizziness, dilated pupils, convulsions, and nausea. After 8 hours at 800 ppm, symptoms were more pronounced; effects included nervousness, muscular fatigue, and insomnia persisting for several days. Exposure to concentrations of 10,000 to 30,000 ppm could lead to narcosis and death. Chronic abusive inhalation of toluene vapors by humans produces central nervous system impairment and emotional and intellectual disturbances. Uptake in the various brain regions is widespread due to the high lipid solubility of toluene and the high lipid content of the brain. Effects on animals following high levels of exposure include hearing loss, kidney effects, and lung lesions. High level oral intake by animals has resulted in weight increases in the liver and kidney, and brain tissue damage [4].

Dermal Exposure. The absorption of toluene through human skin is slow, falling within the range of 14 to 23 mg/cm^2/hour. Dermal contact with toluene by humans may cause skin damage. Application of toluene to the eyes of rabbits reportedly resulted in moderately severe injury [6].

REFERENCES

1. Howard, P.H., 1990. Handbook of Environmental Fate and Exposure Data For Organic Chemicals, Vol. II: Solvents. Lewis Publishers, Inc. Chelsea, Michigan. 546 pp.
2. Merck, 1989. The Merck Index. Eleventh Edition. Merck & Company, Inc. Rahway, NJ.
3. Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko, 1991. Handbook of Environmental Degradation Rates. Lewis Publishers. Chelsea, Michigan.
4. Arthur D. Little, Inc., 1989. The Installation Restoration Program Toxicology Guide. Volume 2. Cambridge, MA. July 1989.
5. USEPA, 1994. Integrated Risk Information System (IRIS). On-line data base. February, 1993.

6. ATSDR, 1989. Toxicological Profile for Toluene. Agency for Toxic Substances and Disease Registry. USPHS/USEPA. December 1989.

ETHYLBENZENE

CAS NUMBER

100-41-4

COMMON SYNONYMS

None noted.

ANALYTICAL CLASSIFICATION

Volatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: 161 mg/l at 25°C [1]
Vapor Pressure: 9.53 mm Hg at 25°C [1]
Henry's Law Constant: 8.44 x 10^{-3} atm-m^3/mole [1]
Specific Gravity: 0.87 at 25/25°C [2]
Organic Carbon Partition Coefficient: 871 [1]

FATE DATA: HALF-LIVES

Soil: 3 to 10 days [3]
Air: 8.56 hours to 3.57 days [3]
Surface Water: 3 to 10 days [3]
Groundwater: 6 to 228 days [3]

NATURAL SOURCES

Coal tar and petroleum [4].

ARTIFICIAL SOURCES

Manufacture of styrene, solvent, petroleum refining, vaporization/spills of gasoline and diesel fuel, auto emissions, paints, inks, insecticides, and cigarette smoke [1,2,4].

FATE AND TRANSPORT

Ethylbenzene released to surface soils will probably undergo partial volatilization and, given its limited ability to sorb to soils (K_{oc} = 871), leach to groundwater. Evidence suggests that this material undergoes biodegradation in groundwaters, and may do so in soils if the initial loading doesn't prove toxic to soil-based microorganisms. If released to surface waters, ethylbenzene is expected to volatilize fairly readily. As with groundwaters, rapid biodegradation can be predicted after an initial acclimation period. Ethylbenzene shows only a slight to moderate tendency to adsorb to soils and sediments in waters. Bioconcentration in aquatic organisms is not expected to be significant (BCF for ethylbenzene = 145). Ethylbenzene is expected to exist in the atmosphere primarily as a vapor, based upon its vapor pressure value (9.53 mm Hg). Principally,

ethylbenzene will be removed from the atmosphere via reaction with hydroxyl radicals; some washout via rainfall may be expected. [1]

HUMAN TOXICITY

General. Humans exposed to ethylbenzene may experience eye and throat irritation, decreased movement, and dizziness. Studies in animals have shown liver and kidney damage, nervous system changes, and blood changes [4]. The USEPA has placed ethylbenzene in weight-of-evidence group D, indicating that it is not classifiable as to human carcinogenicity [5].

Oral Exposure. A chronic RfD of 0.1 mg/kg/day is based on a NOEL of 97.1 mg/kg/day and a LOAEL of 291 mg/kg/day determined for liver and kidney toxicity in a rat subchronic to chronic oral bioassay [5]. Studies in animals revealed that ethylbenzene is quickly and effectively absorbed following oral exposure. The oral (gavage) LD_{50} in rats is reported to be 4,728 mg/kg. No information was located regarding death or health effects in humans following oral exposure [4].

Inhalation Exposure. The RfC of 1 mg/m^3 is based on a NOAEL of 434 mg/m^3 determined for developmental toxicity in rats and rabbits exposed via inhalation [5]. Ethylbenzene is rapidly and efficiently absorbed via inhalation in humans and animals. A 4-hour LC_{50} of 4,000 ppm was reported for rats. Exposure-related adverse effects in animals included those to liver and kidney, eye irritation, profuse lacrimation, CNS depression and ataxia. No deaths were reported for humans following inhalation of ethylbenzene. The effects observed in humans included pulmonary and ocular irritation, profuse lacrimation, chest constriction, dizziness, vertigo, and possible hematological alterations. Exposure of pregnant rats to levels above 138 ppm for 24 hours/day for 9 days had adverse developmental effects [4].

Dermal Exposure. Liquid ethylbenzene is rapidly absorbed through the skin; however, absorption of vapors through the skin is minimal. The dermal LD_{50} in rabbits for liquid ethylbenzene was reportedly 15,415 mg/kg. Ethylbenzene appears to be a slight eye irritant in rabbits [4].

REFERENCES

1. Howard, P.H., 1989. Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Volume I: Large Production and Priority Pollutants. Lewis Publishers, Inc. Chelsea, MI. 574 pp.
2. Merck, 1989. The Merck Index, Eleventh Edition. Merck & Company, Inc. Rahway, NJ.
3. Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, E.M. Michalenko, 1991. Handbook of Environmental Degradation Rates. Lewis Publishers, Inc. Chelsea, MI. 725 pp.
4. ATSDR, 1990. Toxicological Profile for Ethylbenzene. Agency for Toxic Substances and Disease Registry. USPHS/USEPA. December 1990.
5. USEPA, 1992. Integrated Risk Information System (IRIS). On-line data base. August 3, 1992.

XYLENES

CAS NUMBER

1330-20-7

COMMON SYNONYMS

Xylene.

Note: There are three isomers (forms) of xylene: ortho, meta, and para, also known as 1,2-, 1,3-, and 1,4-xylene, respectively.

ANALYTICAL CLASSIFICATION

Volatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: 146 - 175 mg/L at 25°C [1]
Vapor Pressure: 6.6 - 8.7 mm Hg at 25°C [1]
Henry's Law Constant: 5.1×10^{-3} to 7.7×10^{-3} atm-m^3/mole at 25°C [2]
Specific Gravity: 0.880 at 20/4°C (*o*-xylene) [3]
Organic Carbon Partition Coefficient: 25.4 - 204 [1]

FATE DATA: HALF-LIVES

Soil: 1 - 4 weeks [4]
Air: 2.6 hours - 1.8 days [4]
Surface Water: 1 - 4 weeks [4]
Groundwater: 2 weeks - 1 year [4]

NATURAL SOURCES

All three isomers of xylene occur in petroleum. 1,2-Xylene is found additionally in coal tar, forest fire products, and plants [1].

ARTIFICIAL SOURCES

Gasoline, fuel oils, and their combustion products. Petroleum refining, chemical industry; aerosols of paints, varnishes, and shellacs. Wood-burning stoves and fireplaces [1].

FATE AND TRANSPORT

Xylenes are moderately mobile in soil and may leach to groundwater where they are known to persist for several years despite evidence of biodegradation in both soil and groundwater. The dominant removal process in surface water is volatilization, but this is not a rapid process. Some adsorption to sediment will occur. Once released to the atmosphere, xylenes will undergo photochemical degradation at a moderate rate [1].

HUMAN TOXICITY

General. The primary target of xylenes toxicity is the central nervous system [2,5]. Xylenes are considered to be nongenotoxic. The USEPA has placed xylenes in weight-of-evidence cancer Group D, indicating that they are not classifiable as to human carcinogenicity [6].

Oral Exposure. A chronic oral RfD of 2 mg/kg/day is based on a NOAEL of 250 mg/kg/day for hyperactivity, decreased body weight and increased male mortality in a chronic study in rats [6]. Acute oral LD_{50} values for xylenes ranged from 3523 to 8600 mg/kg in rats and 5251 to 5627 mg/kg in mice [2,5]. Death in humans has been reported following the ingestion of xylenes, but the fatal dose is not known [2]. Reports of the ingestion of xylenes in humans are generally lacking. In animals, oral exposure to xylenes results in effects on the liver (increased liver enzymes and weight), the kidenys (increased kidney weight), and the nervous system (impairment of visual function, hyperactivity) [4]. Information is not available regarding the effects of ingested xylene on reproduction or development in humans, and the results of developmental studies in animals are inconclusive [2]. There is no conclusive evidence that oral exposure to xylenes causes cancer in humans or animals, therefore, an oral slope factor is not available [6].

Inhalation Exposure. An inhalation RfC for mixed xylenes is considered non-verifiable by the USEPA [7]. Xylenes are readily absorbed following inhalation exposure. Acute inhalation LC_{50} values of 6350 to 6700 ppm (4-hour exposure) were reported in rats for mixed xylenes [2]. LC_{50} values for the separate isomers are comparable to the mixture. Cause of death was usually respiratory failure and/or sudden ventricular fibrillation. In humans, inhalation of approximately 10,000 ppm xylenes has been fatal [2]. Exposure of humans to 90 ppm xylene has produced impairment of reaction time, manual coordination and body balance [5]. Brief exposure to concentrations of 200 ppm has caused irritation of the eyes, nose and throat. and exposure to concentrations above 200 ppm has resulted in nausea, vomiting, abdominal pain and loss of appetite [5]. Long-term high-level occupational exposure to xylenes ($>$ 200 ppm) has resulted in central nervous system effects, incoordination, nausea, vomiting, and abdominal pain [5]. Studies in laboratory animals suggest that xylenes have a relatively low chronic toxicity. Some data in animals suggest possible kidney and liver impairment with high level inhalation exposures ($>$1000 ppm) [5]. Information regarding the effects of xylenes on human reproduction and development are not available, but teratogenicity, fetotoxicity, and maternal toxicity have been observed in animals [2,5]. Xylenes have been found to cross the human placenta, therefore, there is sufficient reason for concern for pregnant women who are exposed to xylenes [2,5]. It is not known whether inhaled xylenes cause cancer in humans or animals, therefore, an inhalation unit risk is not available [6].

Dermal Exposure. Acute dermal LD_{50} values in rabbits of 14.1 ml/kg and greater than 5.0 ml/kg are reported for m-xylene and mixed xylenes, respectively [5]. Xylene is a skin irritant and causes redness, defatting and dryness. Vesicles may form following prolonged skin contact [2,5].

ECOLOGICAL TOXICITY

General. Xylenes are not a priority pollutant because they have low acute and chronic toxicity. Xylenes move through the soil/groundwater system when present at low concentrations, dissolved in water and adsorbed on soil, or as a separate organic phase resulting from a spill of significant quantities. Xylenes readily volatilize from water, are moderately adsorbed on soil, and have a moderate potential for bioaccumulation [8]. No information on biomagnification of xylenes was available in the technical literature.

Vegetation. Nearly all xylenes (98.8 percent) are expected to be sorbed into the soil. For the portion of xylenes in the gaseous phase of soil (0.5 percent), diffusion through the soil/air pores up to the ground surface and removal by wind will be a significant loss pathway [8]. Review of the technical literature did not produce information regarding the phytotoxic effects of xylenes.

Aquatic Life. The half-life of xylenes in surface water has been calculated as 2.6 to 11.2 days [9]. Under normal environmental conditions, xylenes are not expected to undergo hydrolysis because they contain no hydrolyzable functional groups [8]. The LC_{50} value for freshwater fish was approximately 30 mg/L [9]. The 96-hour LC_{50} values for fathead minnows were 26.7 mg/L in soft water and 28.8 mg/L in hard water [10]. The 96-hour LC_{50} for bluegills was 20.9 mg/L in soft water [10]. There are no federal or state water quality standards established to protect aquatic life [11].

Wildlife. Xylenes are considered to be of low acute and chronic toxicity to birds and mammals [12]. No changes were found in rats, guinea pigs, dogs, and monkeys continuously exposed to 80 ppm for 127 days, nor in rats exposed to 700 ppm for 130 days [8]. Japanese quail showed no signs of toxicity at oral concentrations of 5,000 to 20,000 ppm (approximately 600 to 2,400 mg/kg body weight) [9]. Mallard eggs were immersed in xylene (10%) for 30 seconds and no significant effects on embryonic weight and length were observed when compared to controls [13]. Arthur D. Little, Inc. [8] reported an oral LD_{50} for rats at 4,300 mg/kg.

REFERENCES

1. Howard, P.H., 1990. Handbook of Environmental Fate and Exposure Data For Organic Chemicals, Vol. II: Solvents. Lewis Publishers, Inc. Chelsea, Michigan. 546 pp.
2. ATSDR, 1990. Toxicological Profile for Total Xylenes. Agency for Toxic Substances and Disease Registry. USPHS/USEPA. December 1990.
3. Merck, 1989. The Merck Index. Eleventh Edition. Merck & Company, Inc. Rahway, NJ.
4. Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko, 1991. Handbook of Environmental Degradation Rates. Lewis Publishers. Chelsea, Michigan.
5. Arthur D. Little, Inc., 1989. The Installation Restoration Program Toxicology Guide. Volume 2. Cambridge, MA. July 1989.
6. USEPA, 1994. Integrated Risk Information system (IRIS). Data base. Online. February, 1994.

7. USEPA, 1993. Health Effects Assessment Summary Tables (HEAST). Office of Emergency and Remedial Response. OHEA ECAO-CIN-909. March, 1993.
8. Arthur D. Little, Inc., 1985. The Installation Restoration Program Toxicology Guide. Volume 1. Cambridge, MA.
9. CH2M Hill, Inc., 1989. Preliminary Endangerment Assessment for Lowry Landfill. Prepared for USEPA. Denver, Colorado.
10. Sax, N.I. (ed.), 1984. Dangerous Properties of Industrial Materials. 6th ed. Van Nostrand Reinhold, New York. p 2728.
11. USEPA, 1991. Water Quality Criteria Summary. Washington, D.C.
12. Clement Associates, Inc., 1985. Chemical, Physical, and Biological Properties of Compounds Present a Hazardous Waste Sites. Prepared for USEPA. September 27, 1985.
13. Micromedex, Inc., 1992. Tomes Plus System. Toxicology, Occupational Medicine and Environmental Series. Volume 14. Denver, Colorado.

APPENDIX E

NATURAL CHEMICAL ATTENUATION CALCULATIONS

APPENDIX E

Engineering Evaluation/Cost Analysis
Risk-Based Approach to Remediation
Pumphouse #2, Malmstrom AFB, Montana

Electron Donor and Electron Acceptor Half Cell Reactions

HALF-CELL REACTIONS	$\Delta G°_r$ (kcal/ equiv)*	$\Delta G°_r$ (kJ/ equiv)*	E° (mV)	Eh (mV)	pe	Conditions for Eh and pe §
ELECTRON-ACCEPTOR (REDUCTION) HALF CELL REACTIONS						
$5e^- + 6H^+ + NO_3^- \Rightarrow 0.5N_2 + 3H_2O$ *Denitrification*	-28.7	-120.	+1.24	+0.712	+12.0	pH = 7 $\Sigma[N]=10^{-3}$
$4e^- + 4H^+ + O_2 \Rightarrow 2H_2O$ *Aerobic Respiration*	-28.3	-119.	+1.23	+0.805	+13.6	pH = 7 $P_{O_2}=0.21$ atm
$2e^- + 4H^+ + MnO_3 \Rightarrow Mn^{2+} + 2H_2O$ *Pyrolusite Dissolution/Reduction*	-28.3	-119	+1.23	+0.550	+9.27	pH = 7 $\Sigma[Mn]=10^{-5}$
$e^- + H^+ + CO_2 + \underline{MnOOH} \Rightarrow \underline{MnCO_3} + H_2O$ *a Manganite Carbonation/Reduction*	-23.1	-96.8	+1.00	+0.412	+6.96	pH = 8 $P_{CO_2}=10^{-2}$
$e^- + H^+ + \underline{MnO_2} \Rightarrow \underline{MnOOH}$ *Pyrolusite Hydrolysis/Reduction*	-22.1	-92.5	+0.959	+0.545	+9.21	pH = 7
$e^- + 3H^+ + \underline{Fe(OH)_{3,amph.}} \Rightarrow Fe^{2+} + 3H_2O$ *Amorphous "Goethite" Dissolution/Reduction*	-21.5	-89.9	+0.932	+0.163	+2.75	pH = 6
$8e^- + 10H^+ + NO_3^- \Rightarrow NH_4^+ + 3H_2O$ *Nitrate Reduction*	-20.3	-84.9	+0.879	+0.362	+6.12	pH = 6 $\Sigma[Fe]=10^{-5}$
$2e^- + 2H^+ + NO_3^- \Rightarrow NO_2^- + H_2O$ *Nitrate Reduction*	-18.9	-78.9	+0.819	+0.404	+6.82	pH = 7
$1e^- + 3H^+ + \underline{FeOOH} \Rightarrow Fe^{2+} + 2H_2O$ *"Ferric oxyhydroxide" Dissolution/Reduction*	-15.0	-62.9	+0.652	-0.118	-1.99	pH = 6 Σ [Fe]=10^{-5}
$e^- + 3H^+ + \underline{Fe(OH)_{3,xline.}} \Rightarrow Fe^{2+} + 3H_2O$ *Crystallized "Goethite" Dissolution/Reduction*	-11.8	-49.2	+0.51 0	-0.259	-4.38	pH = 6 Σ [Fe]=10^{-5}
$e^- + H^+ + CO_{2,g} + \underline{Fe(OH)_{3,amph.}} \Rightarrow \underline{FeCO_3} + 2H_2O$ *Amorphous "Goethite" Carbonation/Reduction*	-11.0	-46.2	+0.479	-0.113	-1.90	pH = 8 $P_{CO_2}=10^{-2}$ atm
$8e^- + 9H^+ + SO_4^{2-} \Rightarrow HS^- + 4H_2O$ *Sulfate Reduction*	-5.81	-24.3	+0.252	-0.281	-4.74	pH = 8
$8e^- + 10H^+ + SO_4^{2-} \Rightarrow H_2S^o + 4H_2O$ *Sulfate Reduction*	-6.93	-28.9	+0.301	-0.143	-2.42	pH = 6
$8e^- + 8H^+ + CO_{2,g} \Rightarrow CH_{4,g} + 2H_2O$ *Methanogenesis*	-3.91	-16.4	+0.169	-0.259	-4.39	pH = 7 $P_{CO_2}=10^{-2}$ $P_{CH_4}=10^{0}$

HALF-CELL REACTIONS	$\Delta G°_r$ (kcal/ equiv)*	$\Delta G°_r$ (kJ/ equiv)*	E° (mV)	Eh (mV)	pe	Conditions for Eh and pe §
ELECTRON-DONOR (OXIDATION) HALF CELL REACTIONS						
$12H_2O + C_6H_6 \Rightarrow 6CO_2 + 30H^+ + 30e^-$ *Benzene Oxidation*	+2.83	+11.8	+0.122	-0.316	-5.34	pH = 7 $P_{CO_2}=10^{-2}$
$14H_2O + C_6H_5CH_3 \Rightarrow 7CO_2 + 36H^+ + 36e^-$ *Toluene Oxidation*	+2.96	+12.4	+0.128	-0.309	-5.22	pH = 7 $P_{CO_2}=10^{-2}$
$16H_2O + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42H^+ + 42e^-$ *Ethylbenzene Oxidation*	+2.95	+12.4	+0.128	-0.308	-5.21	pH = 7 $P_{CO_2}=10^{-2}$
$16H_2O + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 42H^+ + 42e^-$ *m-Xylene Oxidation*	+3.02	+12.7	+0.131	-0.305	-5.88	pH = 7 $P_{CO_2}=10^{-2}$

NOTES:

* = $\Delta G°_r$ for half cell reaction as shown divided by the number of electrons involved in reaction.

§ = Conditions assumed for the calculation of Eh and pe (pe = Eh/0.05916). Where two dissolved species are involved, other than those mentioned in this column, their activities are taken as equal. Note, this does not affect the free energy values listed.

Coupled Oxidation Reactions for BTEX Compounds

Coupled Benzene Oxidation Reactions	ΔG°_r (kcal/mole Benzene)	ΔG°_r (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5O_2 + C_6H_6 \Rightarrow 6CO_{2,g} + 3H_2O$ *Benzene oxidation /aerobic respiration*	-765.34	-3202	3.07:1
$6NO_3^- + 6H^+ + C_6H_6 \Rightarrow 6CO_{2,g} + 6H_2O + 3N_{2,g}$ *Benzene oxidation / denitrification*	-775.75	-3245	4.77:1
$30H^+ + 15\underline{MnO_2} + C_6H_6 \Rightarrow 6CO_{2,g} + 15Mn^{2+} + 18H_2O$ *Benzene oxidation / manganese reduction*	-765.45	-3202	10.56:1
$3.75\,NO_3^- + C_6H_6 + 7.5\,H^+ + 0.75\,H_2O \Rightarrow 6\,CO_2 + 3.75\,NH_4^+$ *Benzene oxidation / nitrate reduction*	-524.1	-2193	2.98:1
$60H^+ + 30\underline{Fe(OH)_{3,a}} + C_6H_6 \Rightarrow 6CO_2 + 30Fe^{2+} + 78H_2O$ *Benzene oxidation / iron reduction*	-560.10	-2343	21.5:1
$7.5H^+ + 3.75SO_4^{2-} + C_6H_6 \Rightarrow 6CO_{2,g} + 3.75H_2S^o + 3H_2O$ *Benzene oxidation / sulfate reduction*	-122.93	-514.3	4.61:1
$4.5H_2O + C_6H_6 \Rightarrow 2.25CO_{2,g} + 3.75CH_4$ *Benzene oxidation / methanogenesis*	-32.40	-135.6	0.77:1 [a]

Coupled Toluene Oxidation Reactions	ΔG°_r (kcal/mole Toluene)	ΔG°_r (kJ/mole Toluene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$9O_2 + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4H_2O$ *Toluene oxidation /aerobic respiration*	-913.76	-3823	3.13:1
$7.2NO_3^- + 7.2H^+ + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 7.6H_2O + 3.6N_{2,g}$ *Toluene oxidation / denitrification*	-926.31	-3875	4.85:1
$36H^+ + 18\underline{MnO_2} + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 18Mn^{2+} + 22H_2O$ *Toluene oxidation / manganese reduction*	-913.89	-3824	10.74:1
$72H^+ + 36\underline{Fe(OH)_{3,a}} + C_6H_5CH_3 \Rightarrow 7CO_2 + 36Fe^{2+} + 94H_2O$ *Toluene oxidation / iron reduction*	-667.21	-2792	21.86:1
$9H^+ + 4.5SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4.5H_2S^o + 4H_2O$ *Toluene oxidation / sulfate reduction*	-142.86	-597.7	4.7:1
$5H_2O + C_6H_5CH_3 \Rightarrow 2.5CO_{2,g} + 4.5CH_4$ *Toluene oxidation / methanogenesis*	-34.08	-142.6	0.78:1 [a]

Coupled Ethylbenzene Oxidation reactions	ΔG°_r (kcal/mole Ethylbenzene)	ΔG°_r (kJ/mole Ethylbenzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5O_2 + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5H_2O$ *Ethylbenzene oxidation /aerobic respiration*	-1066.13	-4461	3.17:1
$8.4NO_3^- + 8.4H^+ + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *Ethylbenzene oxidation / denitrification*	-1080.76	-4522	4.92:1
$46H^+ + 22\underline{MnO_2} + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 22Mn^{2+} + 28H_2O$ *Ethylbenzene oxidation / manganese reduction*	-1066.27	-4461	11.39:1
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *Ethylbenzene oxidation / iron reduction*	-778.48	-3257	22:1
$10.5H^+ + 5.25SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5.25H_2S^o + 5H_2O\ Eth$ *Ethylbenzene oxidation / sulfate reduction*	-166.75	-697.7	4.75:1
$5.5H_2O + C_6H_5C_2H_5 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *Ethylbenzene oxidation / methanogenesis*	-39.83	-166.7	0.79:1 [a]

Coupled m-Xylene Oxidation Reactions	$\Delta G°_r$ (kcal/mole *m*-xylene)	$\Delta G°_r$ (kJ/mole *m*-xylene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5O_2 + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 5H_2O$ *m-Xylene oxidation /aerobic respiration*	-1063.25	-4448	3.17:1
$8.4NO_3^- + 8.4H^+ + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *m-Xylene oxidation / denitrification*	-1077.81	-4509	4.92:1
$46H^+ + 22\underline{MnO_2} + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 22Mn^{2+} + 28H_2O$ *m-Xylene oxidation / manganese reduction*	-1063.39	-4449	11.39:1
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *m-Xylene oxidation / iron reduction*	-775.61	-3245	22:1
$10.5H^+ + 5.25SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 5.25H_2S^o + 5H_2O$ *m-Xylene oxidation / sulfate reduction*	-163.87	-685.6	4.75:1
$5.5H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *m-Xylene oxidation / methanogenesis*	-36.95	-154.6	0.79:1 [1]

Gibbs Free Energy of Formation forSpecies used in Half Cell reactions and Coupled Oxidation-Reduction Reactions

Species	State	$\Delta G^{0}_{f,298.15}$ (kcal/mole)	Source
e^-	i	0	std
H^+	i	0	std
O_2	g	0	std
H_2O	l	-56.687	Dean (1972)
Carbon Species			
CO_2	g	-94.26	Dean (1972)
CH_2O, formalydehyde	aq	-31.02	Dean (1972)
C_6H_6, benzene	l	+29.72	Dean (1972)
CH_4, methane	g	-12.15	Dean (1972)
$C_6H_5CH_3$, toluene	l	+27.19	Dean (1972)
$C_6H_5C_2H_5$, Napthalene	l	+28.61	Dean (1972)
$C_6H_4(CH_3)_2$, o-xylene	l	+26.37	Dean (1972)
$C_6H_4(CH_3)_2$, m-xylene	l	+25.73	Dean (1972)
$C_{10}H_8$, napthalene	l	+46.03	Dean (1972)
$C_{14}H_{10}$, phenanthrene	l	+64.12	Dean (1972)
$C_6H_4(CH_3)_2$, p-xylene	l	+26.31	Dean (1972)
Nitrogen Species			
NO_3^-	i	-26.61	Dean (1972)
N_2	g	0	std
NO_2^-	i	-7.7	Dean (1972)
NH_4^+	i	-18.82	Dean (1972)
Sulfur Species			
SO_4^{2-}	i	-177.97	Dean (1972)
H_2S	aq	-6.66	Dean (1972)
H_2S	g	-7.9	Dean (1972)
HS^-	i	+2.88	Dean (1972)
Iron Species			
Fe^{2+}	i	-18.85	Dean (1972)
Fe^{3+}	i	-1.1	Dean (1972)
αFe_2O_3, hematite	c	-177.4	Dean (1972)
$\alpha FeOOH$, ferric oxyhydroxide	c	-117.2	Naumov *et al.* (1974)
$Fe(OH)_3$, goethite	a	-167.416	Langmuir and Whittemore (1971)
$Fe(OH)_3$, goethite	c	-177.148	Langmuir and Whittemore (1971)
$FeCO_3$, siderite	c	-159.35	Dean (1972)
Manganese Species			
Mn^{2+}	i	-54.5	Dean (1972)
MnO_2, pyrolusite	c	-111.18	Stumm and Morgan (1981)
MnOOH, manganite	c	-133.29	Stumm and Morgan (1981)
$MnCO_3$, rhodochrosite	p	-194	Dean (1972)

NOTES:

c = crystallized solid

a = amorphous solid (may be partially crystallized - dependant on methods of preparation)

p = freshly precipitated solid

i = dissociated, aqueous ionic species (concentration = 1 m)

aq = undissociated aqueous species

g = gaseous

l = liquid

std = accepted by convention

Wherever possible multiple sources were consulted to eliminate the possibility of typographical error.

APPENDIX F

SOURCE-REDUCTION TEST DATA

TABLE 1
PUMPHOUSE 2
RESPIRATION AND DEGRADATION RATES
MALMSTROM AFB, MT

Location–Depth	Initial			6–Month			1–Year[b/]		
	K_o (% O_2/min)	Degradation Rate (mg/kg/year)[a/]	Soil Temperature (°C)	K_o (% O_2/min)	Degradation Rate (mg/kg/year)	Soil Temperature (°C)	K_o (% O_2/min)	Degradation Rate (mg/kg/year)	Soil Temperature (°C)
MPA–4	0.049	2100	16.9	0.0051	220	NS	NS[d/]	NS	16.4
MPB–4	0.05	2600	NS[c/]	0.0034	180	NS	NS	NS	NS
MPC–4	0.063	5300	NS	0.0058	490	NS	NS	NS	NS

[a/] Milligrams of hydrocarbons per kilogram of soil per year.
[b/] The 1-Year respiration tests were not sampled due to ~~flooding and/or low oxygen~~ content.
[c/] NS = Not sampled.
[d/] ~~Not sampled, monitoring points below ground water surface~~ performed monitoring point flooding. All points were below the ground water surface.

TABLE 2
PUMPHOUSE 2
INITIAL AND 1-YEAR SOIL AND SOIL GAS ANALYTICAL RESULTS
MALMSTROM AFB, MT

Analyte (Units)[a]	Sample Location–Depth (feet below ground surface)									
	MPA–4		MPB–4		MPC–4					
Soil Gas Hydrocarbons	Initial[b]	1–Year[c]	Initial	1–Year	Initial	1–Year	Initial	1–Year	Initial	1–Year
TVH (ppmv)	5,400	NS[d]	6,900	65	14,000 1,400	NS				
Benzene (ppmv)	< 0.61	NS	< 0.69	< 0.002	19	NS				
Toluene (ppmv)	< 0.61	NS	< 0.69	< 0.002	< 0.57	NS				
Ethylbenzene (ppmv)	9	NS	5.2	0.150	13	NS				
Xylenes (ppmv)	11	NS	9.8	0.280	15	NS				

	MPA–2		MPB–3.5		MPC–5.5					
Soil Hydrocarbons	Initial[e]	1–Year[f]	Initial	1–Year	Initial	1–Year	Initial	1–Year	Initial	1–Year
TRPH (mg/kg)	300	146	270	33.5	150	74.4				
Benzene (mg/kg)	< 0.65	< 0.05	< 0.64	< 0.05	< 0.31	< 0.05				
Toluene (mg/kg)	0.71	< 0.05	< 0.64	0.12	1.1	0.057				
Ethylbenzene (mg/kg)	1.2	< 0.05	2.2	0.55	1.5	0.067				
Xylenes (mg/kg)	3.6	< 0.1	3.1	0.29	4.4	< 0.1				
Moisture (%)	23	NS	22	NS	20	NS				

CAN WE GET THESE ?

[a] TVH = total volatile hydrocarbons; ppmv = parts per million, volume per volume;
TRPH = total recoverable petroleum hydrocarbons; mg/kg = milligrams per kilogram.
[b] Initial soil gas samples collected on 10/3/93.
[c] 1–Year soil gas samples collected on 10/19/94.
[d] NS = Not sampled.
[e] Initial soil samples collected on 10/2/93.
[f] 1–Year soil samples collected on 10/23/94.

Malmstrom AFB – Pumphouse 2 – Initial
Biodegradation Rate Calculations

enter data | calculated data

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPA–4

K_o = max. observed rate	0.049	%/min.
w = moisture content	23	%

Assume: Soil properties for mixed grained sand Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	n =	0.40
Unit weight (dry):	^{g}d =	1.59
Void ratio:	$e = n/1-n$ =	0.67
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.

Solving for 1 liter of soil

a) $V_v = n * 1$ L

V_v = 0.4 liters V_v = void volume

b) $S_r = Gw/e$

S_r = 0.91 S_r = degree of saturation

c) $V_w = S_r \times V_v$

V_w = 0.36 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$

V_a = 0.04 liters V_w = volume of water

e) Bulk density = ^{g}d + ($V_w \times {}^g$w) = 1.9 kg/l soil

f) A = V_a/Bulk density = 0.021 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 2070.7 mg TPH/year

Malmstrom AFB – Pumphouse 2 – Initial
Biodegradation Rate Calculations | enter data | calculated data |

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPB–4

K_o = max. observed rate: 0.05 %/min.

w = moisture content: 22 %

Assume: Soil properties for mixed grained sand Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	*n* =	0.40
Unit weight (dry):	^{g}d =	1.59
Void ratio:	*e = n/1–n* =	0.67
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.

Solving for 1 liter of soil

a) $V_v = n * 1$ L

V_v = 0.4 liters V_v = void volume

b) $S_r = Gw/e$

S_r = 0.87 S_r = degree of saturation

c) $V_w = S_r \times V_v$

V_w = 0.35 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$

V_a = 0.05 liters V_w = volume of water

e) Bulk density = ^{g}d + ($V_w \times {}^g$w) = 1.9 kg/l soil

f) A = V_a/Bulk density = 0.026 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 2616 mg TPH/year

Malmstrom AFB – Pumphouse 2 – Initial Biodegradation Rate Calculations

enter data | calculated data

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPC–4

K_o = max. observed rate 0.063 %/min.

w = moisture content 20 %

Assume: Soil properties for mixed grained sand Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	*n* =	0.40
Unit weight (dry):	^{g}d =	1.59
Void ratio:	*e* = *n*/1–*n* =	0.67
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.

Solving for 1 liter of soil

a) $V_v = n * 1$ L

V_v = 0.4 liters V_v = void volume

b) $S_r = Gw/e$

S_r = 0.79 S_r = degree of saturation

c) $V_w = S_r \times V_v$

V_w = 0.32 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$

V_a = 0.08 liters V_w = volume of water

e) Bulk density = ^{g}d + ($V_w \times {}^g$w) = 1.9 kg/l soil

f) A = V_a/Bulk density = 0.042 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 5324.5 mg TPH/year

Malmstrom AFB – Pumphouse 2 – 6 Month
Biodegradation Rate Calculations | enter data | calculated data |

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPA–4 K_o = max. observed rate 0.0051 %/min.
w = moisture content 23 %

Assume: Soil properties for mixed grained sand Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	*n* =	0.40
Unit weight (dry):	^{g}d =	1.59
Void ratio:	*e* = *n*/1–*n* =	0.67
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.
Solving for 1 liter of soil

a) $V_v = n * 1$ L
V_v = 0.4 liters V_v = void volume

b) $S_r = Gw/e$
S_r = 0.91 S_r = degree of saturation

c) $V_w = S_r \times V_v$
V_w = 0.36 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$
V_a = 0.04 liters V_w = volume of water

e) Bulk density = ^{g}d + ($V_w \times {}^g$w) = 1.9 kg/l soil

f) A = V_a/Bulk density = 0.021 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 215.5 mg TPH/year

Malmstrom AFB – Pumphouse 2 – 6 Month
Biodegradation Rate Calculations | enter data | calculated data |

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPB–4 K_o = max. observed rate 0.0034 %/min.
w = moisture content 22 %

Assume: Soil properties for mixed grained sand Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	n =	0.40
Unit weight (dry):	^{g}d =	1.59
Void ratio:	$e = n/1-n$ =	0.67
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.
Solving for 1 liter of soil

a) $V_v = n * 1$ L
V_v = 0.4 liters V_v = void volume

b) $S_r = Gw/e$
S_r = 0.87 S_r = degree of saturation

c) $V_w = S_r \times V_v$
V_w = 0.35 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$
V_a = 0.05 liters V_w = volume of water

e) Bulk density = ^{g}d + ($V_w \times {}^g$w) = 1.9 kg/l soil

f) A = V_a/Bulk density = 0.026 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 177.9 mg TPH/year

Malmstrom AFB – Pumphouse 2 – 6 Month
Biodegradation Rate Calculations | enter data | calculated data |

Formula: $K_b = K_o \times 1/100\% \times A \times D_o \times C$ Where:

K_b = fuel biodegradation rate

K_o = O_2 utilization rate (%/min.)

A = volume of air/kg soil

D_o = O_2 density 1340 mg/L

C = Carbon/O_2 ratio for hexane mineralization = 1/3.5

Test Results: MPC–4 K_o = max. observed rate 0.0058 %/min.
w = moisture content 20 %

Assume: Soil properties for mixed grained sand Specify from Table 1.4 (Ref. Foundation Engineering, Peck, Hanson, and Thornburn, John Wiley Press, 1974)

Porosity:	*n* =	0.40
Unit weight (dry):	^{g}d =	1.59
Void ratio:	*e* = *n*/1–*n* =	0.67
Specific gravity:	G =	2.65

Calculate A = Air filled volume (V_a)/unit wt.
Solving for 1 liter of soil

a) $V_v = n * 1$ L
V_v = 0.4 liters V_v = void volume

b) $S_r = Gw/e$
S_r = 0.79 S_r = degree of saturation

c) $V_w = S_r \times V_v$
V_w = 0.32 liters V_w = volume of water

d) $V_a = V_v - V_{vw}$
V_a = 0.08 liters V_w = volume of water

e) Bulk density = ^{g}d + ($V_w \times {}^{g}$w) = 1.9 kg/l soil

f) A = V_a/Bulk density = 0.042 l air/kg soil

$K_b = K_o \times 1/100\% \times A \times D_o \times C \times$ 525,600 min/yr = 490.2 mg TPH/year

Initial Respiration Test

Pumphouse 2

Malmstrom AFB, MT

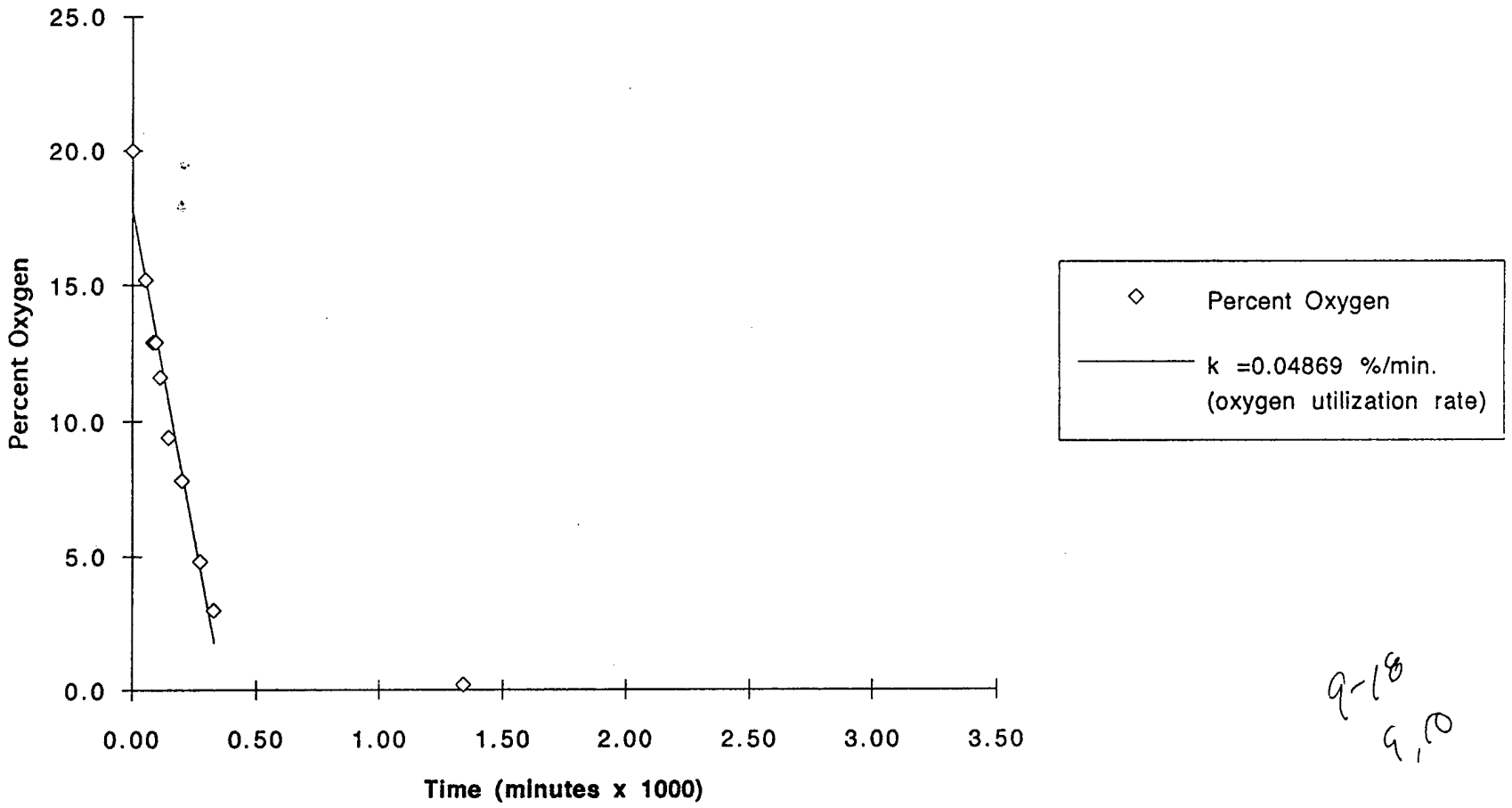
Monitoring Point	Date	Days Elapsed (frac. days)	Time	Hrs elapsed (fractional days)	Days Elapsed	Elapsed Time (min. x 1000)	O2%	CO2%	Total Hydro-carbon	Helium	Comments	Trend of O2/ Time	New x-values	k
MPA-4	10/04/93	0.00	11:00	0.00	0.00	0.00	20.0	0.10	700	NS	30 second purge. Sample collected by egg.	17.81306659	0	0.04869379
MPA-4	10/04/93	0.00	11:53	0.04	0.04	0.05	15.2	0.25	2000	NS	30 second purge. Sample collected by egg.	1.744116456	0.33	
MPA-4	10/04/93	0.00	12:23	0.06	0.06	0.08	12.9	0.30	2400	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	12:34	0.07	0.07	0.09	12.9	0.30	2300	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	12:52	0.08	0.08	0.11	11.6	0.25	2600	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	13:27	0.10	0.10	0.15	9.4	0.55	3100	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	14:19	0.14	0.14	0.20	7.8	0.60	3400	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	15:33	0.19	0.19	0.27	4.8	0.6	4100	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	16:27	0.23	0.23	0.33	3.0	0.7	4800	NS	30 second purge. Sample collected by egg.			
MPA-4	10/05/93	1.00	09:21	-0.07	0.93	1.34	0.2	0.9	11200	NS	30 second purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	10:44	0.00	0.00	0.00	20.2	0.07	320	NS	1 minute purge. Sample collected by egg.	19.81066995	0	0.05018663
MPB-4	10/04/93	0.00	11:44	0.04	0.04	0.06	17.2	0.10	940	NS	1 minute purge. Sample collected by egg.	5.256546015	0.29	
MPB-4	10/04/93	0.00	12:18	0.07	0.07	0.09	14.8	0.10	1200	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	12:50	0.09	0.09	0.13	13.0	0.10	1800	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	13:24	0.11	0.11	0.16	11.2	0.10	2000	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	14:13	0.15	0.15	0.21	9.4	0.10	2300	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	15:31	0.20	0.20	0.29	5.9	0.10	3200	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	16:23	0.24	0.24	0.34	4.7	0.10	3600	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/05/93	1.00	09:15	-0.06	0.94	1.35	0.3	0.10	8000	NS	1 minute purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	10:51	0.00	0.00	0.00	20.5	0.15	540	NS	25 second purge. Sample collected by egg.	18.95682915	0	0.06300657
MPC-4	10/04/93	0.00	11:51	0.04	0.04	0.06	15.1	0.40	2700	NS	25 second purge. Sample collected by egg.	1.314990763	0.28	
MPC-4	10/04/93	0.00	12:15	0.06	0.06	0.08	11.9	0.40	3800	NS	25 second purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	12:47	0.08	0.08	0.12	10.6	0.40	4000	NS	25 second purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	13:22	0.10	0.10	0.15	10.5	0.60	3700	NS	25 second purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	14:08	0.14	0.14	0.20	6.1	0.60	5100	NS	25 second purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	15:27	0.19	0.19	0.28	2.3	0.70	6600	NS	25 second purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	16:18	0.23	0.23	0.33	1.0	0.70	8000	NS	Hydrocarbon analyzer with dilluter.			
MPC-4	10/05/93	1.00	09:30	-0.05	0.95	1.38	0.0	1.40	19000	NS	Hydrocarbon analyzer with dilluter.			

CAL RAF 11/6/93

Respiration Test
Pumphouse 2
Malmstrom AFB, MT

Monitoring Point	Date	Days Elapsed (frac. days)	Time	Hrs elapsed (fractional days)	Days Elapsed	Elapsed Time (min. x 1000)	O2%	CO2%	Total Hydro-carbon	Helium	Comments	Trend of O2/ Time	New x-values	k
MPA-4	10/04/93	0.00	11:00	0.00	0.00	0.00	20.0	0.10	700	NS	30 second purge. Sample collected by egg.	17.8130666	0	0.04869
MPA-4	10/04/93	0.00	11:53	0.04	0.04	0.05	15.2	0.25	2000	NS	30 second purge. Sample collected by egg.	1.74411646	0.33	
MPA-4	10/04/93	0.00	12:23	0.06	0.06	0.08	12.9	0.30	2400	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	12:34	0.07	0.07	0.09	12.9	0.30	2300	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	12:52	0.08	0.08	0.11	11.6	0.25	2600	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	13:27	0.10	0.10	0.15	9.4	0.55	3100	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	14:19	0.14	0.14	0.20	7.8	0.60	3400	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	15:33	0.19	0.19	0.27	4.8	0.6	4100	NS	30 second purge. Sample collected by egg.			
MPA-4	10/04/93	0.00	16:27	0.23	0.23	0.33	3.0	0.7	4800	NS	30 second purge. Sample collected by egg.			
MPA-4	10/05/93	1.00	09:21	-0.07	0.93	1.34	0.2	0.9	11200	NS	30 second purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	10:44	0.00	0.00	0.00	20.2	0.07	320	NS	1 minute purge. Sample collected by egg.	19.81067	0	0.00088
MPB-4	10/04/93	0.00	11:44	0.04	0.04	0.06	17.2	0.10	940	NS	1 minute purge. Sample collected by egg.	5.25654601	0.29	
MPB-4	10/04/93	0.00	12:18	0.07	0.07	0.09	14.8	0.10	1200	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	12:50	0.09	0.09	0.13	13.0	0.10	1800	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	13:24	0.11	0.11	0.16	11.2	0.10	2000	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	14:13	0.15	0.15	0.21	9.4	0.10	2300	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	15:31	0.20	0.20	0.29	5.9	0.10	3200	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/04/93	0.00	16:23	0.24	0.24	0.34	4.7	0.10	3600	NS	1 minute purge. Sample collected by egg.			
MPB-4	10/05/93	1.00	09:15	-0.06	0.94	1.35	0.3	0.10	8000	NS	1 minute purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	10:51	0.00	0.00	0.00	20.5	0.15	540	NS	25 second purge. Sample collected by egg	18.9568292	0	0.0047
MPC-4	10/04/93	0.00	11:51	0.04	0.04	0.06	15.1	0.40	2700	NS	25 second purge. Sample collected by egg	1.31499076	0.28	
MPC-4	10/04/93	0.00	12:15	0.06	0.06	0.08	11.9	0.40	3800	NS	25 second purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	12:47	0.08	0.08	0.12	10.6	0.40	4000	NS	25 second purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	13:22	0.10	0.10	0.15	10.5	0.60	3700	NS	25 second purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	14:08	0.14	0.14	0.20	6.1	0.60	5100	NS	25 second purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	15:27	0.19	0.19	0.28	2.3	0.70	6600	NS	25 second purge. Sample collected by egg.			
MPC-4	10/04/93	0.00	16:18	0.23	0.23	0.33	1.0	0.70	8000	NS	Hydrocarbon analyzer with dilluter.			
MPC-4	10/05/93	1.00	09:30	-0.05	0.95	1.38	0.0	1.40	19000	NS	Hydrocarbon analyzer with dilluter.			

Figure 3.8
Respiration Test -MPA-4
Oxygen Concentrations
Pumphouse 2
Malmstrom AFB, Montana



9-18
9.10

RECORD SHEET FOR IN SITU RESPIRATION TEST

SITE MAF13 - PH2
DATE 10/3/93
LOCATION PH-2
SAMPLER(S) RAF/DBT

MONITORING POINTS MPA-4
O2 METER NO. _____ CO2 METER NO. _____
HYDROCARBON METER NO. Not Calibrated HE METER NO. _____
SHUT DOWN DATE _____ TIME _____

Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Helium	Comments
10/3/93 0838	16.2	0.5	>20,000	—	INIT-SEAL GAS IN WELL
10/3/93 1148		START	INJECTING		
10/4/93 1058		END	INJECTING		
1100	0.10 ~~0.01~~ PPT	20.0	700	—	"
1153	0.25	15.2	2,000	—	"
1223	0.30	12.9	2,400	—	" "
1230					Recalibrated O2/CO2 meter.
1234	0.30	12.9	2,300	—	30 sec purge sample collected w/ syg.
1252	0.25	11.6	2,600	—	"
1327	0.55	9.4	3,100	—	"

TEST DATA ORIGINALS

Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Helium	Comments
14/9	0.6	7.8	3,400	—	"
-3	0.6	4.8	4,100	—	"
7	3.0	4,800	—		"
7	0.2	11,200	—		"

RECORD SHEET FOR IN SITU RESPIRATION TEST

SITE MAFB - PH2
DATE 10/3/93
LOCATION PH-2
SAMPLER(S) RAF/DBT

MONITORING POINTS MPB-4
O2 METER NO. CO2 METER NO.
HYDROCARBON METER NO. Not Calibrated HE METER NO.
SHUT DOWN DATE TIME

Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Helium	Comments
10/3/93 1057	7.2	8.1	~~>20,000~~ NS DST	—	Initial ~~He set/filled~~
1105	12.2	1.7	>20,000		Resample Initial Soil gas Analysis
1148		START	INJECTING		
10/4/93 1034		END	INJECTION		
1044	0.07	20.2	320	—	1 min purge Sample collected by Cgg.
1144	0.10	17.2	940	—	"
1218	0.10	14.8	1,200	—	"
1250	0.10	13.0	1,800	—	"
1324	0.10	11.2	2,000	—	"
1413	0.10	9.4	2,300	—	"

Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Helium	Comments
1531	0.1	5.9	3,200	—	"
1623	0.1	4.7	3,600	—	"
10/5/93 ~~0921~~	~~0.9~~	~~0.2~~	~~11,200~~		" PRST 10/5/93
10/5/93 0915	0.7	0.3	8,000	—	"
10/6/93 1732	1.2	11.3	—	—	Oxygen influence 7hrs 53 minutes after injection
10/7/93 0822	1.8	16.9	—	—	27hrs 43 min

RECORD SHEET FOR IN SITU RESPIRATION TEST

SITE MAFB - PH2
DATE 10/3/93
LOCATION PH-2
SAMPLER(S) RAF/DAS

MONITORING POINTS mpc-4
O2 METER NO. 9J0100S8 CO2 METER NO. SAA
HYDROCARBON METER NO. DT035 Not Calibrated HE METER NO. NA
SHUT DOWN DATE 10/4/93 TIME 1050

Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Helium	Comments
10/3/93 1130	12.7	0.6	720,000	—	Init. soil gas Hc w/ dilluter
1148		START	AIR INJECTION		
10/4/93 1050		END	Air Injection		
1051	0.15	20.5	540	—	25 sec purge Sample collected by Egg.
1151	0.40	15.1	2700		" "
1215	0.40	11.9	3800		" "
1247	0.40	10.6	4000		" "
1322	0.60	10.5	3700		" "
1408	0.60	6.1	5,100		" "
1527	0.70	2.3	6,600		" "

Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Helium	Comments
1618	0.7	1.0	8,000		" " Hc w/ dilluter
10/5 ~~0915~~	~~0.7~~	~~0.3~~	~~8,000~~		" " Hc w/ dilluter DAS 10/5/93
10/5/93 0930	1.4	0.0	19,000		" Hc w/ dilluter
10/6/93 1755	3.0	7.0	—		O2 Influence 7hrs 50 minutes after injection
10/7/93 0915	3.8	11.0	—		22hrs 35 min.

Record Sheet for Air Permeability Test.

SITE Malmstrom AFB Pumphouse 2 (PH2)
DATE 10-6-93
SAMPLER(S) DBT / RAF

TYPE OF TEST Injection
TEST DATE
TIME

Pressure/Vacuum ("H_2O)

Distance from Vent Well (ft)		MPA-4	MPA-6.5	MPB-4	MPB-6.5
Time (min)	In(t)		BGW		BGW
1		>100	Groundwater purging		
2		"	"		
3		"	"		
4		~~>100~~	—		
5		~~>100~~	—		
6		—	—		
7		—	—		
8		—	—		
9		—	—		
10		~~>100~~ 115 RAF	—		
12		115	—		

Distance from Vent Well		P	V	T_{IN}	FLOW	T_{OUT}
Time	In(t)					
		5.2	Gauge Broken	50	15	
		4.8	—	48	15	100
		4.6	—	48	15.5	110
		4.8		48	15.5	
		4.6	—	"	16.0	120
		—	—	—	—	
		4.6	—	—	16.0	120
		—	—	—	~~16.0~~ — RAF	
		4.5	—	48	16.0	122
		4.4	—	48	16.1	125
		4.3	—	—	16.5	125

BGW = below ground water surface

Record Sheet for Air Permeability Test.

SITE Malmstrom PH2 — TYPE OF TEST _____

DATE _____ — TEST DATE _____

SAMPLER(S) _____ — TIME _____

Pressure/Vacuum ("H_2O)

Distance from Vent Well (ft)		MPA-4	MPA-65	MPB-4	MPB-65	Distance from Vent Well		P	T_{OUT}	T_{IN}	FLOW
Time	ln(t)		Blow		Blow	Time	ln(t)				
14		107	Purging GW					4.3	128	—	16.5
16		107	—					4.2	128	—	16.5
18		107	-					4.2	—	—	17.0
20		107	-					4.2	-	—	17.0
25		107	—					4.1	—	—	17.0
30		105	—					4.0	—	—	17.0
35		105	—					4.0	128	48	17.0
40		105	—					3.9	—	—	17.0
45		105	—					3.9	/	—	17.2
60		102	—					3.7	—	—	17.5
75		101						3.6	136	51	17.8

Record Sheet for Air Permeability Test.

SITE Malmstrom PH2 TYPE OF TEST _____

DATE _____ TEST DATE _____

SAMPLER(S) _____ TIME _____

Pressure/Vacuum ("H_2O)

Distance from Vent Well (ft)		MPA-4	FLOW	P		Distance from Vent Well					
Time	ln(t)					Time	ln(t)				
90		100	18.0	3.5							
180		94	19.0	2.9							
263		90	19.0	2.5							
300		89	19.5	2.4							
393		87	20.0	2.2							
465		85	20.0	2.1							
1017 CBC			20.1	0.8							

Record Sheet for Air Permeability Test.

SITE Malmstrom PH2 — TYPE OF TEST Injection

DATE — TEST DATE

SAMPLER(S) — TIME

Pressure/Vacuum ("H_2O)

Distance from Vent Well (ft)		MPB-4	MPB-6.5	MPC-4	MPC-6.5
Time	ln(t)		Blow		
0		ϕ	+9.1 (rising)	ϕ	<0
1		0.5	>10	0.1	0
2		+8	—	0.7	0.11
3		17.5	—	2	0.26
4		>20	—	3.25	0.38
4 30 5		24 26	—	4.4	0.45
6		29	—	5.0	0.47
7		30	—	5.8	0.49
8		31	—	6.1	0.50
9		31	—	6.4	0.50
to 12		31.25	—	6.6	0.55

Distance from Vent Well		MPB-4	MPB-6.5	MPC-4	MPC-6.5
Time	ln(t)				
14		31.4	~~6.7~~ DNT	6.7	0.60
16		31.4	—	6.8	0.70
18		31.3	16.0	6.8	0.79
20		31.2	22.0	6.8	0.84
26		31.0	35.0	6.7	>1 (Assume) switched gauge
30		30.4	42.7	6.7	>1 Assume
35		30.2	48.0	6.7	switched gauge back
40		30.2	w/ new gauge 42.5	6.8	0
45		30.2	42.0	6.8	0.04
60		30.0	40.3	6.8	0.42
75		30.0	40.0	6.7	0.9

Readings at MPC-6.5 may be due to pressure input from weather

Record Sheet for Air Permeability Test.

SITE Malmstrom PH2 TYPE OF TEST Injection

DATE TEST DATE

SAMPLER(S) TIME

Pressure/Vacuum ("H_2O)

Distance from Vent Well (ft)		mPB-4	mPB-6.5	mPC-4	mPC-6.5
Time	ln(t)				
90		29.8	39.6	6.7	>1
180		28.2	34.3	6.6	0.84
4hrs 23min		27.3	4.0	6.6	>1
5hrs 0min		27.3	2.1	6.1	0.98
6hrs 32min		27.3	1.1	8.2	0.21
7hrs 45min		27.3	1.3	9.5	0.13
22hrs 30min		25.0	ϕ	13.7	ϕ

Distance from Vent Well					
Time	ln(t)				

6-Month Respiration Test

PH-2

Malmstrom AFB, MT

Monitoring Point	Date	Days Elapsed (frac. days)	Time	Hrs elapsed (fractional days)	Days Elapsed	Elapsed Time (min. x 1000)	O2%	CO2%	Total Hydro-carbon	Comments	Trend of O2/ Time	New x-values	k
MPA-4	04/19/94	0.00	09:25	0.00	0.00	0.00	20.9	0.20	60		21.084506	0	0.0050653
MPA-4	04/20/94	1.00	08:24	-0.04	0.96	1.38	14.5	0.40	90		4.1664446	3.34	
MPA-4	04/20/94	1.00	16:07	0.28	1.28	1.85	11.5	0.50	180	Purge w/meters.			
MPA-4	04/21/94	2.00	08:09	-0.05	1.95	2.81	7.0	0.50	160	Purge w/meters.			
MPA-4	04/21/94	2.00	17:02	0.32	2.32	3.34	4.0	0.50	280	Purge w/meters.			
MPA-6.5	04/19/94	0.00	09:29	0.01	0.01	0.01	20.9	0.20	58				
MPA-6.5	04/20/94	1.00	08:30	-0.04	0.96	1.39				POINT FLOODED			
MPB-4	04/19/94	0.00	09:33	0.01	0.01	0.01	20.0	1.50	250		19.988733	0	0.0034361
MPB-4	04/20/94	1.00	08:31	-0.03	0.97	1.39	15.0	1.50	300	Pulled 2 tedlars to get enough sample.	8.5122813	3.34	
MPB-4	04/20/94	1.00	16:16	0.29	1.29	1.86	13.5	1.50	360	Purge w/meters.			
MPB-4	04/21/94	2.00	08:13	-0.05	1.95	2.81	11.1	1.60	380	Purge w/meters.			
MPB-4	04/21/94	2.00	17:05	0.32	2.32	3.34	8.0	1.50	490	Purge w/meters.			
MPB-6.5	04/19/94	0.00	09:37	0.01	0.01	0.02				POINT FLOODED.			
MPC-4	04/19/94	0.00	09:40	0.01	0.01	0.02	17.5	3.50	280		15.240659	0	0.0057981
MPC-4	04/20/94	1.00	08:37	-0.03	0.97	1.40	4.0	3.60	480	Pulled 2 tedlars to get enough sample.	-1.1099939	2.82	
MPC-4	04/20/94	1.00	16:23	0.29	1.29	1.86	2.2	3.50	500	Purge w/meters.			
MPC-4	04/21/94	2.00	08:23	-0.04	1.96	2.82	1.9	3.50	1,000	Purge w/meters.			
MPC-6.5	04/14/94	0.00	09:43	0.02	0.02	0.02				POINT FLOODED.			

6-Month Respiration Test

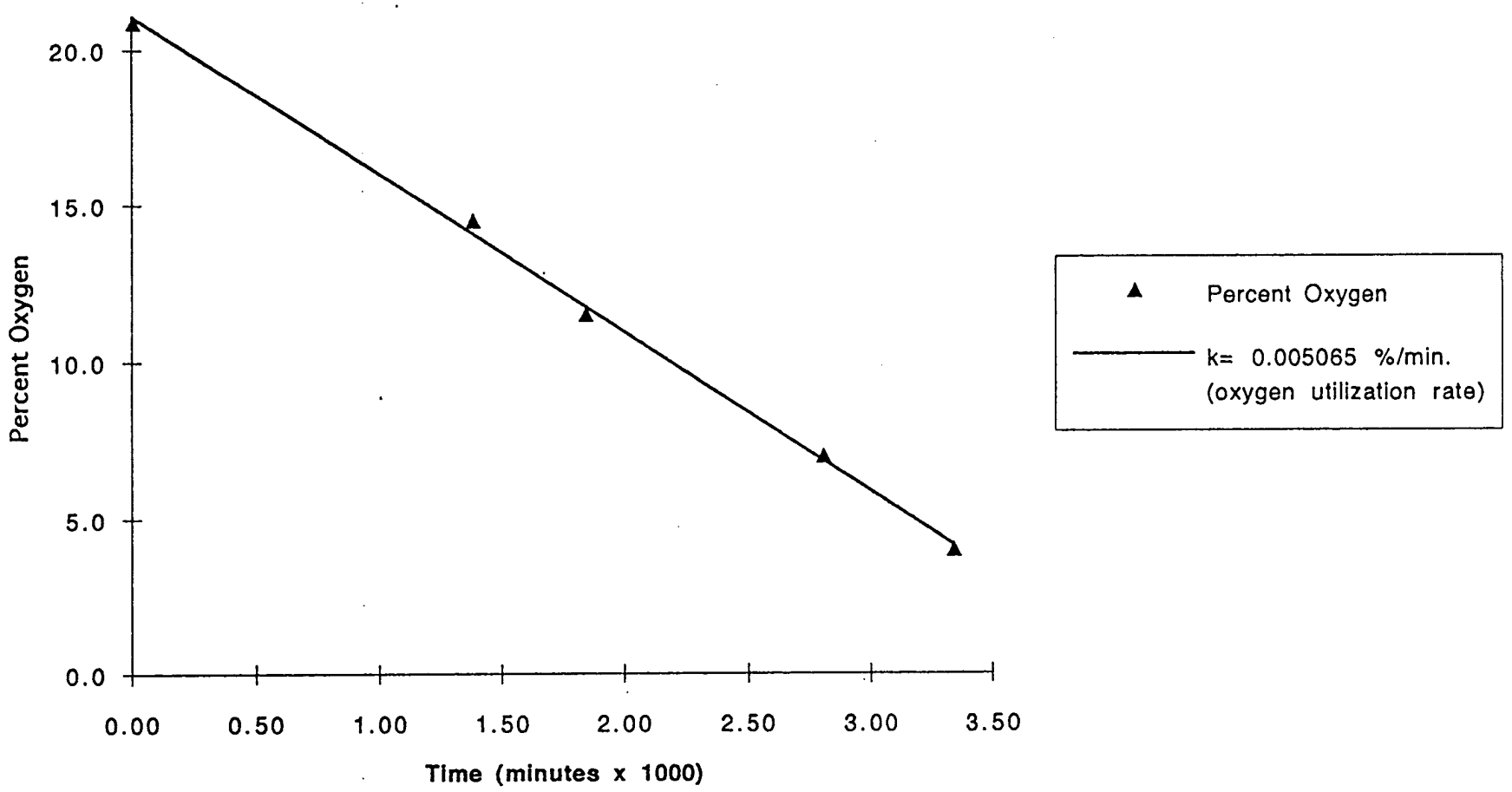
PH-2

Malmstrom AFB, MT

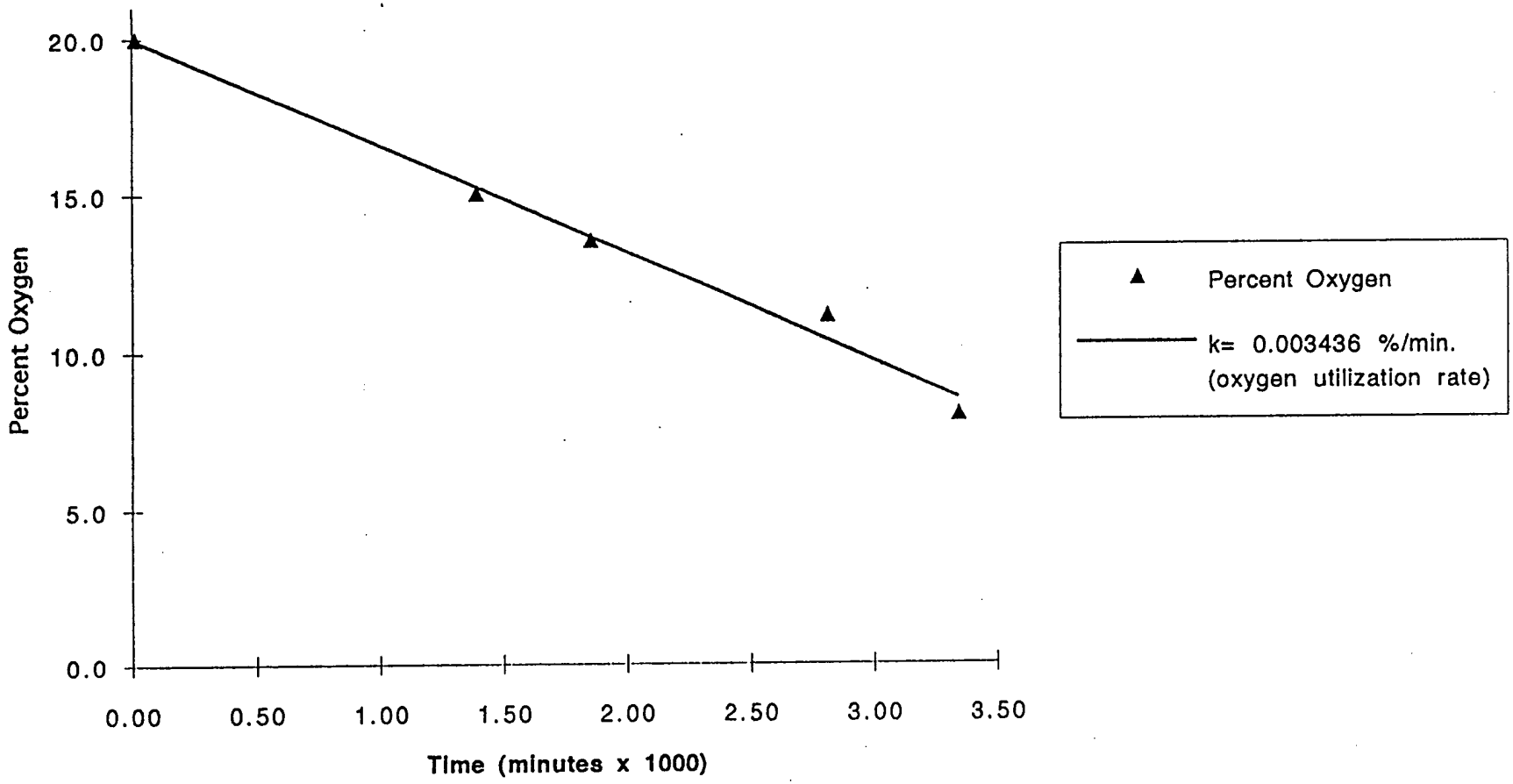
Monitoring Point	Date	Days Elapsed (frac. days)	Time	Hrs elapsed (fractional days)	Days Elapsed	Elapsed Time (min. x 1000)	O2%	CO2%	Total Hydro-carbon	Comments	Trend of O2/ Time	New x-values	k
MPA-4	04/19/94	0.00	09:25	0.00	0.00	0.00	20.9	0.20	60		21.084506	0	0.00
MPA-4	04/20/94	1.00	08:24	-0.04	0.96	1.38	14.5	0.40	90		4.1664446	3.34	
MPA-4	04/20/94	1.00	16:07	0.28	1.28	1.85	11.5	0.50	180	Purge w/meters.			
MPA-4	04/21/94	2.00	08:09	-0.05	1.95	2.81	7.0	0.50	160	Purge w/meters.			
MPA-4	04/21/94	2.00	17:02	0.32	2.32	3.34	4.0	0.50	280	Purge w/meters.			
MPA-6.5	04/19/94	0.00	09:29	0.01	0.01	0.01	20.9	0.20	58				
MPA-6.5	04/20/94	1.00	08:30	-0.04	0.96	1.39				POINT FLOODED			
MPB-4	04/19/94	0.00	09:33	0.01	0.01	0.01	20.0	1.50	250		19.988733	0	0.00
MPB-4	04/20/94	1.00	08:31	-0.03	0.97	1.39	15.0	1.50	300	Pulled 2 tedlars to get enough sample.	8.5122813	3.34	
MPB-4	04/20/94	1.00	16:16	0.29	1.29	1.86	13.5	1.50	360	Purge w/meters.			
MPB-4	04/21/94	2.00	08:13	-0.05	1.95	2.81	11.1	1.60	380	Purge w/meters.			
MPB-4	04/21/94	2.00	17:05	0.32	2.32	3.34	8.0	1.50	490	Purge w/meters.			
MPB-6.5	04/19/94	0.00	09:37	0.01	0.01	0.02				POINT FLOODED.			
MPC-4	04/19/94	0.00	09:40	0.01	0.01	0.02	17.5	3.50	280		15.240659	0	0.00
MPC-4	04/20/94	1.00	08:37	-0.03	0.97	1.40	4.0	3.60	480	Pulled 2 tedlars to get enough sample.	-1.1099939	2.82	
MPC-4	04/20/94	1.00	16:23	0.29	1.29	1.86	2.2	3.50	500	Purge w/meters.			
MPC-4	04/21/94	2.00	08:23	-0.04	1.96	2.82	1.9	3.50	1,000	Purge w/meters.			
MPC-6.5	04/14/94	0.00	09:43	0.02	0.02	0.02				POINT FLOODED.			

QC'd
5/6/94
RAF

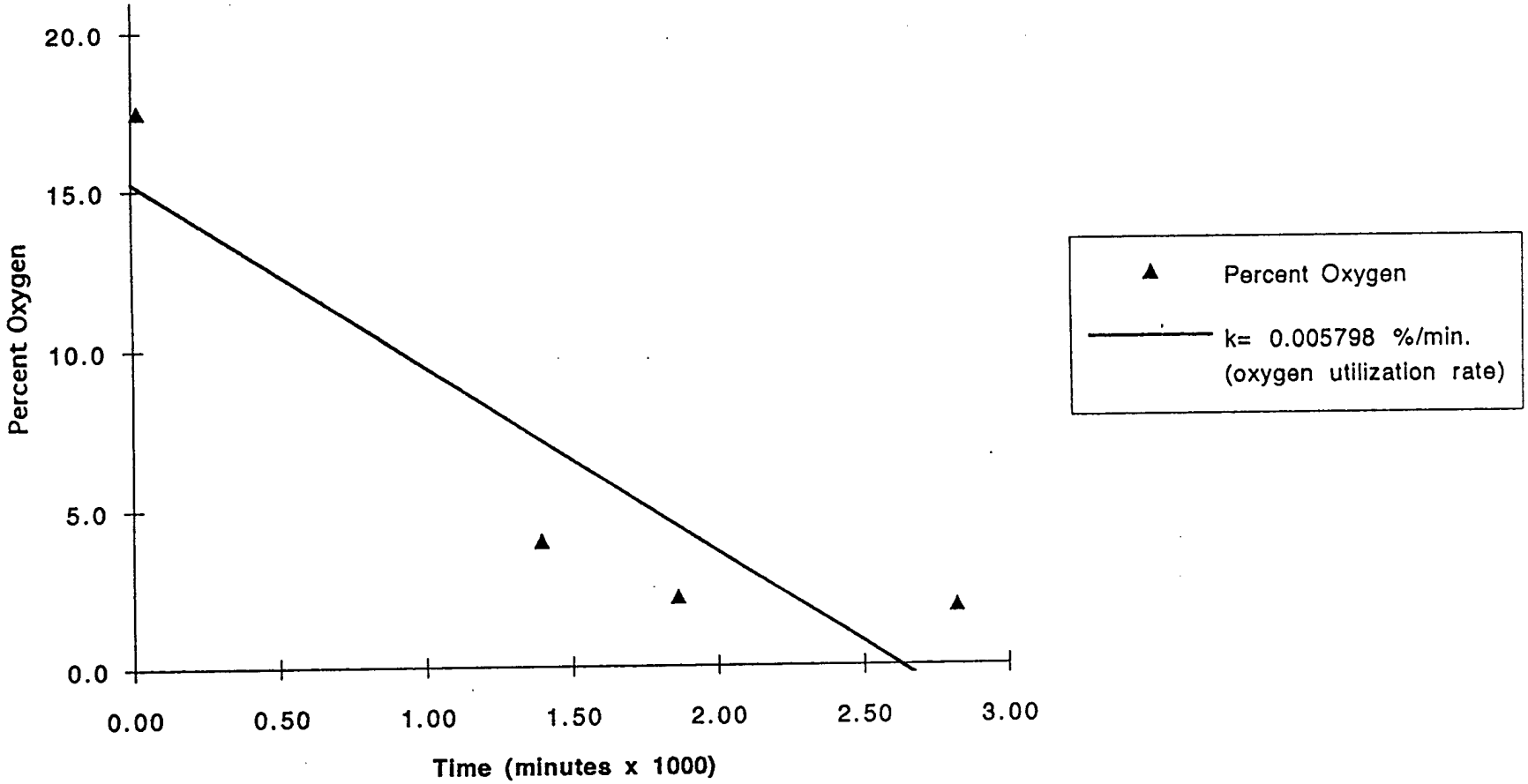
Respiration Test
Oxygen Concentrations
PH-2, MPA-4
Malmstrom AFB, Montana



Respiration Test
Oxygen Concentrations
PH-2, MPB-4
Malmstrom AFB, Montana



Respiration Test
Oxygen Concentrations
PH-2, MPC-4
Malmstrom AFB, Montana



RECORD SHEET FOR LONG-TERM BIOVENTING TEST
(6-MONTH) (1-YEAR) RESPIRATION TEST

SITE PH 2
DATE 4/19/94
LOCATION MALMSTROM AFB
SAMPLER(S) RAE
MONITORING POINTS MPA-4
O2 METER NO. _____ CO2 METER NO. _____
HYDROCARBON METER NO. _____
SHUT DOWN DATE 4/19/94 TIME 0921

	Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments	Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments
	4/19/94 0925	0.2	20.9	60						
23	4/20/94 0824	0.4	14.5	90						
30.75	1607 4/20/94	0.6	11.5	180	PURGE W/METERS					
46.75	4/21/94 0809	0.5	7.0	160	"					
	4/21/94 1702	0.5	4.0	280	" END TEST					

RECORD SHEET FOR LONG-TERM BIOVENTING TEST
(6-MONTH) (1-YEAR) RESPIRATION TEST

SITE PH 2
DATE 4/19/94
LOCATION MALMSTROM AFB
SAMPLER(S) RAF
MONITORING POINTS MPA-6,5
O2 METER NO. CO2 METER NO.
HYDROCARBON METER NO.
SHUT DOWN DATE 4/19/94 TIME 0921

Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments	Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments
04/19/94 0929	0.2	20.9	58						
4/20/94 0830	POINT FLOODED								

RECORD SHEET FOR LONG-TERM BIOVENTING TEST
(6-MONTH) (1-YEAR) RESPIRATION TEST

SITE PH-2 MONITORING POINTS MPB-4
DATE MAMSTROM AFB ↑ O2 METER NO. CO2 METER NO.
LOCATION 4/19/94 ← HYDROCARBON METER NO.
SAMPLER(S) RAF SHUT DOWN DATE 4/19/94 TIME 0921

	Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments	Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments
	04/19/94 0933	RAF 20 1.5	20.0	250						
23	04/20/94 0831	RAF 20 1.5	RAF ~~19.0~~ 15.0	300	PULLED 2 TEDLARS TO GET ENOUGH SAMPLE					
30.75	04/20/94 1614 ~~0416~~	1.5	13.5	360	PURGED W/METERS					
46.75	04/21/94 0813	1.6	11.1	380	"					
	4/21/94 1705	1.5	8.0	490	" END TEST ✓					

RECORD SHEET FOR LONG-TERM BIOVENTING TEST
~~(6-MONTH)~~ (1-YEAR) RESPIRATION TEST

SITE PH-2
DATE 4/19/94
LOCATION MALMSTROM AFB
SAMPLER(S) RAF

MONITORING POINTS MPB-6.5
O2 METER NO. _____ CO2 METER NO. _____
HYDROCARBON METER NO. _____
SHUT DOWN DATE 4/19/94 TIME 0921

Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments	Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments
4/19/94 0937	POINT FLOODED								

RECORD ~~SHEET~~ FOR LONG-TERM BIOVENTING TEST
(6-MONTH) (1-YEAR) RESPIRATION TEST

SITE PH-2
DATE 4/19/94
LOCATION MALMSTROM AFB
SAMPLER(S) RAF

MONITORING POINTS MPC-4
O2 METER NO. _____ CO2 METER NO. _____
HYDROCARBON METER NO. _____
SHUT DOWN DATE 4/19/94 TIME 0921

Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments	Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments
4/19/94 0940	3.5	17.5	280						
4/20/94 0837	3.6	~~9.8~~ 4.0 ~~6.2~~ RAF	480	PULLED 2 TEDLARS TO GET ENOUGH SAMPLE					
4/20/94 1623	3.5	2.2	600	PURGED W/ METERS					
04/21/94 0823	3.5	1.9	1000	" END TEST					

23
30.75
46.25

RECORD SHEET FOR LONG-TERM BIOVENTING TEST
(6-MONTH) (2-YEAR) RESPIRATION TEST

SITE P17-2 MONITORING POINTS MPC-6.5
DATE 4/5/94 O2 METER NO. CO2 METER NO.
LOCATION MALMSTROM AFB HYDROCARBON METER NO.
SAMPLER(S) RAF SHUT DOWN DATE 4/19/94 TIME 0921

Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments	Date/ Time	CO2 (%)	O2 (%)	Total Hydrocarbon	Comments
04/14/94 0943	POINT FLOODED								

1657 MW-6:S = 4.40 mg/L DO
1700 SWB OUT @ MW-15 SEL'd, A_2O=

3/16/95 725525.03000 DOT

0805 Arrive at Dan's office
1000 Arrive at PHZ after setting car unlocked.

Water Levels

Date/Time	Well	DTW (ft btoc)	Comments
3/16/95 1040	MW15	5.41	from N. side mark
1130	MW7	6.81	" " "
1230	MW4	2.39	" " "
1305	MW12	0.70	below lid (grnd elev)
			above TOC

1030 PHZ: Biospage point is an Artesian well; water is spewing from lid
Blower: was turned on 3/15 by Bennie - No readings, blower full flow - shut off at 1035 on 3/16/95
1055 Complete bailing MW15 - 3 gl. purge water slightly cloudy, petroleum odor

11/16/94 7Z5525.03000 RAP/DBT

0800	ON-BASE CAN TO CE TO TALK TO DAN DURR ABOUT IDW.
0830	H_2O ON TRANSDUCER IN MW-15 = 4.78'
0833	FLOW VELOC. IN BIOSPARGE = 800 FPM, 1.6 psi
	BACK OFF BLEED OF VALVE
0843	MW-12 H_2O @ 2'7"; DO = 5.0 mg/L @ 5'
0848	VW H_2O @ 4' 1/2" DO = 3.2 mg/L @ 8'
0910	START SLUG IN ON MW-15, SEL 8, H_2O = 4.41
0912	TAPPED TRANSDUCER W/ SLUG GOING INTO WELL, DON'T THINK TRANSDUCER MOVED TO MUCH WILL LET TEST RUN
0920	CALIBRATE PID FOR FLUX TESTING
0933	START CALIBRATION OF CHAMBER
1003	START TEST #1
1033	END TEST, MOVE TO #2
1041	START #2
1111	END #2, MOVE TO #3
1117	START #3
1147	END #3, GO TO LUNCH + BUY WELL LOCKS
1325	RETURN TO BASE, CALL WASTE MGMT. TO CHECK ON DUMPSTER
1405	BACK TO SITE, SETUP FLUX #4

FINAL WATER LEVELS

WELL #	DEPTH BTOC (ft)
1	DRY
2	6' 4 1/2"
3	DRY 9' 9 1/4" TD = 10' 3/4"
4	2' 11 1/2"
5	9' 11 3/8"
6	5' 3 7/8"
7	6' 2"
8	DRY
9	8' 10 7/8"
10	7' 3/8"
11	DRY
12	IN USE - BIOSPARGE
15	IN USE - SLUG TEST
18	3' 2"
VW	IN USE - BIOSPARGE

1605	BLOWER VELOC. = 800 FPM @ .9 PSI
1607	MW-12 H_2O = 2' 6 3/4" DO = 5.2 mg/L @ 5'
1612	VW H_2O = 4' 1/8" DO = 1.6 mg/L @ 8'
1642	MPC 05 DO = 1.15 mg/L
1648	MPB 6 3 = 0.5 mg/L DO

11/15/94 725525.03000 RAF/DBT

0930 AJR + DBT SET UP TO SAMPLE MW-10 RIGHT NEXT TO STREET

0940 DROP TRANSDUCER INTO MW-15, WILL WAIT FOR WELL TO STABILIZE BEFORE STARTING SLUG TEST

0950 RAF STARTS DECONNING EQUIPMENT AS AJR + DBT FINISH W/ IT.

1020 RAF TO HARDWARE STORE

1125 RAF RETURNS, DBT RUNNING AACA ON MW-9

1140 INSTALL FITTING FOR THERMAL ANEMOMETER IN BIOSPARGE PLUMBING

1155 FLOW = 750 FPM ~~FAS~~ ≈ 15 CFM WILL WAIT FOR IT TO STABILIZE THEN LOWER FLOW TO 10 CFM

1201 H_2O ON TRANSDUCER IN MW-10 = 4.25'

1220 FINISH AACA ON MW-9, GO TO LUNCH

1315 BACK TO BASE, STOP BY CE TO CHECK IN

1400 BLOWER @ 1420 FPM, BACK OFF TO 450 FPM.

1402 WAIT FOR BLOWER TO STABILIZE

1403 H_2O ON TRANSDUCER = 4.39'

1406 BEGIN PACKING SAMPLES, CLEANING UP

1449 BLOWER INTERIM VELOCITY = 480 FPM

1451 H_2O ON TRANSDUCER = 4.43'

1522 VELOCITY = 500 FPM 10.91 SCFM

1523 H_2O ON TRANSDUCER = 4.46'

11/15/94 725525.03000 RAF/DBT

1604 H_2O ON TRANSDUCERS 4.49'

1644 H_2O ON TRANSDUCERS 4.52'

1650 MW-12 H_2O = 2'8 3/8" DO = 6.56'

1652 BLOWER VELOCITY = 550 FPM

1653 VW H_2O = 4'1 1/2" DO = 4.1 mg/L 6.8'

11/14/94 725525.03000 RAF/DBT

1536 STOP SLUG OUT TEST IN MW-4. WILL DO MW-15 → MW-18 TOMORROW.

1615 START LABELLING & PACKING SAMPLES

1720 FINISH PACKING, GET READY TO LEAVE

1730 MW-12 DO = 7.0 mg/L

1757 VW DO = 1.1 mg/L

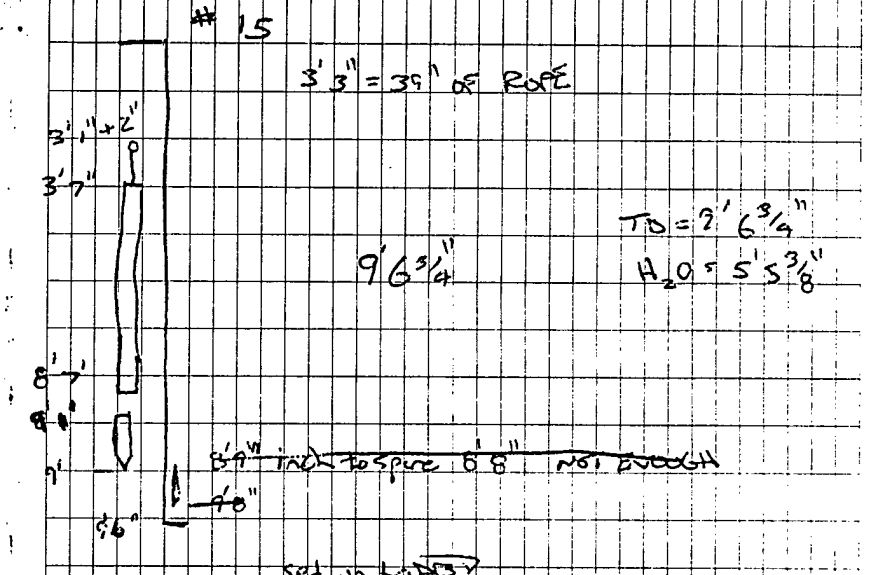
1803 LEAVE SITE FOR FED EX, LEAVE FOR DAY.

11/14/94 [signature]

11/15/94 725525.03000 RAF / DBT

0802 - ON SITE

0805 - SET UP FOR SLUG TEST @ MW-15



0810 AJR + DBT set up to sample MW #9 (4" IN CENTER ACROSS STREET)

0812 CHECK H_2O LEVEL IN MW-10, STILL NOT ENOUGH WATER FOR A NAPTHALENE SAMPLE

0830 AJR + DBT sample MW-9. Due to little amount of water (~6") and slow recharge the well was not developed or purged prior to sampling.

0836 H_2O @ MW-12 = 2' 8 3/8" DO = 7.1 mg/L

0855 H_2O @ VW = 9' 2" AND DROPPING DO = 5.2 mg/L

11/14/94 725525.0300 RAF/DBT

0805 ON-SITE

0813 SLUG OUT G MW-4, SEL 7, H_2O = 3.22'

0815 FORGET CONDUCTIVITY METER G HOUSE
DBT GOES BACK TO GET IT.

0820 PRESSURE G SPARGE POINT = 3.0 psi

0840 SAMPLE MW-5

0855 DBT RETURNS, STARTS BAILING MW-16

0940 H_2O IN MW-12 = 4' 10 5/4" BTOC
H_2O IN VW = 5' 10" AND DROPPING AFTER BLOWER WAS SHUT OFF. BOTH WELLS WERE ALLOWED TO EQUILIBRATE W/ THE ATMOSPHERE BEFORE READINGS WERE TAKEN.

0945 MW-16 BAILS DRY

950 CALIBRATE DO METER

1010 CHECK DO IN BIOSPARGE WELLS, MW-12 IS BUBBLING VERY RAPIDLY, WILL BACK OFF INSERTION PRESSURE TO 1 PSI. THIS SEEMS TO HELP, WELL IS NOW ONLY A LITTLE BUBBLY.

1026 DO IN MW-12 = 7.2 mg/L

1033 DO IN VW = 0.05 mg/L

1038 RAF GOES TO CE TO CALL OFFICE

1059 NO ANSWER IN DENVER, WILL CALL LATER.

11/14/94 725525.0300 RAF/DBT

1105 DBT+ AJR COME TO CE, THEY'VE RUN THE STANDARD ADDITIONS IN THE HACH KIT, NITRATE IS OUT OF WHACK!

1108 TRY LAB AGAIN, GET THROUGH, TALK TO LAB, DLD, AND BEB ABOUT DBT+ EQUIPMENT

1130 LUNCH

1220 BACK ON-SITE, DBT+AJR SAMPLE MW-15

1230 RAF LABELS WELLS AND DRUMS

1330 DBT+AJR SAMPLE MW-16

1410 RAF CHECKS H_2O LEVELS IN WELLS ON-SITE. RESULTS IN TABLE BELOW.

WELL	H_2O BTOC	TD BTOC
1	—	10' 2"
2	7' 7 1/8"	10' 2 1/4"
3	9' 9 7/8"	10' 5/8"
8	—	9' 6 5/8"
9	9' 1 1/8"	9' 6 1/2"
11	—	9' 6 7/8"
10	3' 5 7/8"	

11/13/94 725525.03000 RAF/DBT

1505 MW-4 HAD NOT FULLY RECHARGED, ASR+DBT SET UP TO SAMPLE MW-12

RAF SLUGS IN 6 MW-6 SEL=4 H_2O = 5.35' BTOC

1538 SLUG OUT 6 MW-6, SEL 5, H_2O = 5.35

1612 SLUG IN 6 MW-4, SEL 6, H_2O = 3.24

WAIT FOR WELL TO STABILIZE BEFORE INSERTING SLUG.

1645 DBT TO HARDWARE STORE TO GET PVC TO FINISH PLUMBING BIOSPARGE

1716 WELL FINALLY STABILIZES, INSERT SLUG INTO MW-4

1720 DBT RETURNS, FINALLY FINISH BIOSPARGE PORT PLUMBING.

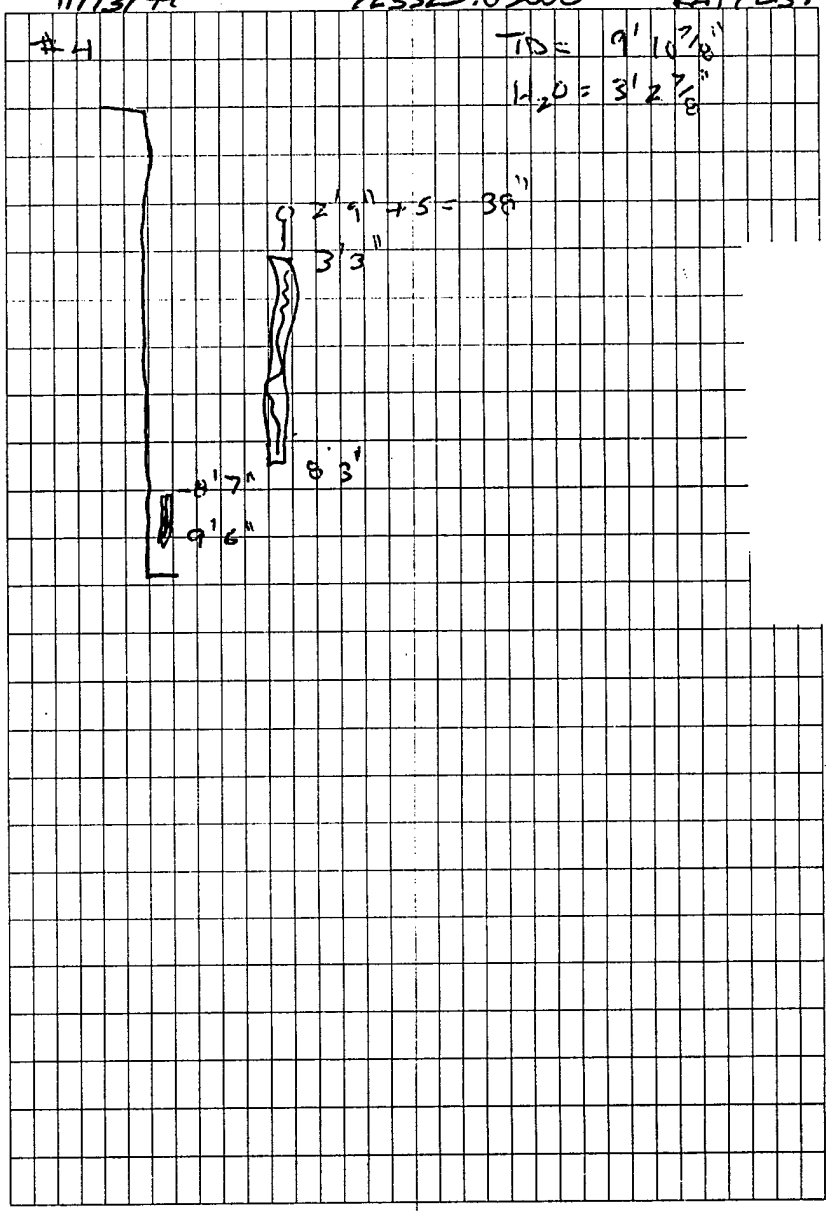
1740 START SPARGE INJECTION, INJECT @ 3.6 PSI

1755 CHECK ON SLUG IN TEST MW-4.

1805 OFF-SITE

11/13/94 Russell Site

11/13/94 725525.03000 RAF/DBT



APPENDIX G

SCREENING AND DEVELOPMENT OF REMEDIAL ALTERNATIVES

TABLE OF CONTENTS

Page

1.1 Overview 1
2.1 Screening of Remedial Technologies 1
2.1.1 Long-Term Soil, Soil Gas, and Groundwater Monitoring 1
2.1.1.1 Soil and Soil Gas Monitoring 1
2.1.1.2 Groundwater Monitoring 1
2.1.2 Land and Groundwater Use Control 2
2.1.2.1 Land Use Control 2
2.1.2.2 Groundwater Use Control 2
2.1.3 Public Education 2
2.1.4 Containment of the Groundwater Plume 2
2.1.4.1 Hydraulic Controls 3
2.1.4.2 Physical Groundwater Barriers 3
2.1.4.3 Reactive/Semipermeable Barriers 3
2.1.5 *In situ* Groundwater Treatment 3
2.1.5.1 Natural Chemical Attenuation 3
2.1.5.2 Enhanced/Active Biological Groundwater Treatment 4
2.1.6 Aboveground Groundwater Treatment 4
2.1.7 Soil Remediation Technologies 4
2.1.7.1 Soil Vapor Extraction 5
2.1.7.2 Bioventing 5
2.1.7.3 Soil Excavation and Treatment 5
3.1 Summary of Retained Remedial Technologies 6
4.1 References 7

LIST OF TABLES

No.	Title	Page
1	Initial Technical Implementability Screening of Technologies and Process Options for Soil and Groundwater Remediation	8

SCREENING AND DEVELOPMENT OF REMEDIAL ALTERNATIVES

1.1 OVERVIEW

This appendix identifies a variety of remedial approaches and technologies that were considered in developing remedial alternatives for Pumphouse #2. This initial screening was based on three primary evaluation criteria: effectiveness in meeting target risk-based remedial goals which are protective of human health and the environment, technical and administrative implementability, and relative cost. The purpose of this screening was to quickly focus the remedial action plan on the most promising and cost-effective methods for remediating Pumphouse #2. This appendix focuses on how selected active remedial technologies could be combined with intrinsic remediation to achieve an effective site cleanup.

2.1 SCREENING OF REMEDIAL TECHNOLOGIES

Table 1 provides a summary of the remedial approaches and technologies considered for Pumphouse #2. All of these technologies are appropriate for the remediation of fuel-contaminated soils or groundwater. Technologies which are used for non-fuel contaminants have been purposely deleted from this focused initial screening. Several of the most promising technologies considered during screening have been retained as candidates for the development of remedial alternatives and evaluated in Section 8 of the EE/CA. The following paragraphs provide a brief description of each approach or technology group and its site-specific applicability for this site.

2.1.1 Long-Term Soil, Soil Gas, and Groundwater Monitoring

Long-term monitoring of soils, soil gas, and groundwater is essential in evaluating the progress of intrinsic and engineered remediation and for ensuring that cleanup criteria are achieved over a specified time interval.

2.1.1.1 Soil and Soil Gas Monitoring

Soil and soil gas monitoring provides information for assessing the effectiveness of an implemented soil remedial technology. Extensive soil sampling at the Pumphouse #2 has revealed moderate contamination in unsaturated soils in the source area and very limited contamination in saturated soils outside of the source area. Soil gas is used as an indicator of VOC reduction, and oxygen and carbon dioxide concentrations can indicate the level of hydrocarbon biodegradation occurring in the soil. Long-term soil and soil gas monitoring was retained for further evaluation.

2.1.1.2 Groundwater Monitoring

Groundwater monitoring is essential for evaluating the effectiveness of implemented groundwater remediation technologies, particularly natural attenuation processes. Sentry or model verification wells can be utilized to monitor COCs and their attenuation within and near the existing plume. The predictions of fate and transport

models are often verified using sentry wells within the plume. POA wells can be established at downgradient locations to ensure that contaminants do not advance beyond an area of exposure control or present an unacceptable risk to downgradient human or ecological receptors. Sufficient sentry wells are now available at this site to assess both vertical and horizontal contaminant transport and attenuation. The suitability of existing wells for POA monitoring is addressed in Section 10 of the EE/CA, the Long-Term Monitoring Plan. Long-term groundwater monitoring was retained as a key component of the remedial alternatives for this site.

2.1.2 Land and Groundwater Use Control

Some degree of land and groundwater use control will be required if contaminant concentrations in groundwater at Pumphouse #2 are going to exceed state promulgated groundwater quality standards for a period of time before natural chemical attenuation lowers contaminant concentrations to acceptable levels. Land and groundwater use controls can be enacted to minimize the potential for direct receptor contact with site contamination.

2.1.2.1 Land Use Control

Physical barriers and deed restriction/easements can be used to control land use. Access to the site may be limited by fencing around the site itself in addition to the restrictions imposed by Base perimeter fencing and guard gates. Physical barriers and deed restrictions on land and resource uses were retained for further evaluation.

2.1.2.2 Groundwater Use Control

Groundwater use controls can eliminate the possibility of direct exposure of site workers to contaminated groundwater. Groundwater use can be controlled by regulating well permits, minimizing excavations below the water table, and when no other source of drinking water is available, installing point-of-use treatment systems. Contaminated groundwater at this site remains within an area under base control, and no active drinking water wells exist on or near the site. The regulation of future well permits in the vicinity of Pumphouse #2 was retained for further evaluation.

2.1.3 Public Education

At many hazardous waste sites, public education is required to inform the public of the risks associated with site contamination and to provide the necessary warnings to prevent unintentional contact with site soils or groundwater. Any future release of this property to private citizens or business should be accompanied with a clear understanding of where jet fuel contamination exists and the appropriate land uses that will prevent exposure to site workers. Public education was retained for further evaluation as a remedial approach.

2.1.4 Containment of the Groundwater Plume

Plume containment uses either hydraulic controls, such as limited groundwater pumping, or physical barriers such as slurry walls, to minimize downgradient plume

migration. This strategy is most often used to halt the advance of highly contaminated groundwater before it impacts downgradient drinking waters or surface waters.

2.1.4.1 Hydraulic Controls

Hydraulic controls extract contaminated groundwater to prevent further migration of the plume. Hydraulic controls considered for this site include a groundwater interceptor trench and extraction wells. Hydrogeology at the site is very discontinuous as discussed in Section 3 of the EE/CA. Areas yielding large amounts of groundwater are isolated, thus, a traditional pump and treat systems is not an appropriate remedial technology for Pumphouse #2. Additionally, groundwater appears to be migrating very slowly if at all at the site. Because of this, an interceptor trench would not be a cost effective method of either containing or collecting contaminated groundwater at the site. No hydraulic control technologies were retained as potential remedial alternatives.

2.1.4.2 Physical Groundwater Barriers

Slurry walls, grout curtains, and sheet pilings are physical structures capable of limiting downgradient contaminant migration. However, contaminants are not removed by such physical barriers, they are only contained. When compared to an interceptor trench or pump and treat system where contaminants are contained and removed, containment alone is a less effective option. Additionally, the large amount of infrastructure and facilities in the vicinity of the site would make installation of any large scale barrier highly impractical. Physical groundwater barriers were not retained for further consideration.

2.1.4.3 Reactive/Semipermeable Barriers

Reactive, semipermeable barriers are an emerging technology which uses a downgradient chemically reactive wall or biologically active treatment zone to intercept and treat groundwater contaminants as they pass through the treatment zone. This technology has the advantage over simple physical barriers in that contaminants are actually destroyed and groundwater flow is uninterrupted. As with the other remedial options requiring large amounts of ground disturbance, this alternative is not practical for installation at Pumphouse #2 due to surrounding buildings, roads, and utilities. Reactive walls and biological active zones were not retained for further evaluation.

2.1.5 *In situ* Groundwater Treatment

In situ treatment includes both engineered and natural processes which are capable of destroying or immobilizing dissolved contamination in place. *In situ* treatment is generally less expensive than aboveground treatment because there is no need to extract, treat, and then dispose of groundwater.

2.1.5.1 Natural Chemical Attenuation

As thoroughly discussed in Section 6 of the EE/CA, natural chemical attenuation takes advantage of destructive and nondestructive attenuation mechanisms to bring about a net reduction in groundwater contaminant concentrations. Destructive

attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include sorption, dilution, and volatilization (Wiedemeier, *et. al.*, 1994). At this site, the decrease in dissolved contamination with time, geochemical evidence, and lack of plume migration all confirm that natural chemical attenuation is a significant and ongoing cleanup process at this site. Therefore, this remedial approach was retained from the screening process.

2.1.5.2 Enhanced/Active Biological Groundwater Treatment via Biosparging

Enhanced *in situ* biodegradation takes advantage of natural biological processes by providing enhanced electron acceptor conditions and, when required, enhanced nitrogen/phosphorus (i.e., nutrient) conditions, to stimulate microbial growth and more rapid biodegradation. Section 6 of the EE/CA provides geochemical evidence that a low oxygen concentrations in groundwater at Pumphouse #2 may be limiting the biodegradation of dissolved contaminants in the plume. Low flow-rate air injection into groundwater, known as biosparging, can be used to increase dissolved oxygen concentrations in groundwater and promote biodegradation. As discussed in Section 7, a biosparging pilot test performed at Pumphouse #2 indicated that biosparging may be an appropriate technology for the remediation of contaminated groundwater at the site. However, variable subsurface conditions make it very unlikely that oxygen could be uniformly introduced into groundwater at the site. Gravel and sand lenses would create preferential flow pathways that would effectively consume all oxygen injected into the subsurface. Additionally, groundwater contamination at Pumphouse #2 is limited to small isolated areas and contaminant concentrations have been shown to be decreasing without any engineered remedial actions. As a result of these potential problems, biosparging was not retained for evaluation as a method of enhancing natural biodegradation in the source area.

2.1.6 Aboveground Groundwater Treatment

Groundwater extraction and aboveground groundwater treatment offers the flexibility of more engineering controls than *in situ* remediation, and can usually treat a wider range of contaminants than *in situ* treatment. Groundwater extraction also provides greater control over plume migration and can be focused in areas of greatest contamination. As discussed in Section 2.1.4.1 of this appendix, no groundwater extraction technologies will be evaluated in detail for application at Pumphouse #2. As a result, no above ground treatment is needed and no potential remedial technologies were evaluated in this EE/CA

2.1.7 Soil Remediation Technologies

The removal or reduction of concentrated contaminants in the source area is normally an important element of a comprehensive site remediation. Two primary sources of contamination can exist at fuel contaminated sites: free-phase product (LNAPL) and residual fuels which are adsorbed of occluded within the soil matrix. Only residual fuel in soil are present at Pumphouse #2 and no technologies for the remediation of LNAPLs were evaluated.

Residual fuel contamination at this site appears to be isolated to three discrete areas, the site of a former surface spill (MW-15), fuel transfer lines (MW-18 and SED-6), and

immediately downgradient of the former location of USTs at the site (MW-3). Soil contamination did not exceed 10 feet bgs in any borehole installed at the site in 1994. MDHES has only promulgated cleanup standards for benzene in soils. No other compound-specific cleanup standards have been issued.

Common *in situ* soil remediation technologies such as soil vapor extraction and *in situ* bioventing, which depend on soil gas movement, will be effective due to the highly permeable nature of the coarse gravel and sand lenses found in the subsurface at Pumphouse #2. Bioventing, however, may not be implemented in several areas at Pumphouse #2 due to topography and/or subsurface utilities. The most contaminated soils discovered at the site during 1993 RFI and the 1994 risk-based investigations were found in or immediately adjacent to the drainage ditches on either side of Flightline Drive (MW-18, SED-6, and SED-9). Since these locations are in the bottom of drainage ditches and on top of several different subsurface utilities paralleling the road, bioventing is not a practical remedial alternative. For these areas, excavation and *ex situ* treatment is the only possible remedial alternative. The Base currently operates a landfarm for the treatment of petroleum contaminated soils that could accept contaminated soil from Pumphouse #2.

2.1.7.1 Soil Vapor Extraction

Soil vapor extraction mechanically withdraws soil gas from the vadose zone to the surface using vent wells. If necessary, offgas can be treated prior to discharge into the atmosphere, although treatment can easily double the cost of this technology. By extracting soil gas from the vadose zone, the desorption of VOCs from soils into soil gas is enhanced. Soil vapor extraction is highly effective in highly permeable soil such as the coarse gravels and sand lenses present at this site. Because soil vapor extraction also results in an influx of oxygenated soil gas from clean soils, it also enhances the biodegradation of less volatile hydrocarbons. Soil vapor extraction was not retained for further evaluation because bioventing would provide the same benefits without the transfer of VOCs to the atmosphere.

2.1.7.2 Bioventing

Bioventing is mechanically similar to soil vapor extraction except that this technology uses much lower rates of air injection to provide the necessary oxygen to sustain biological degradation, and does not create an undesirable discharge of VOCs into the atmosphere. Bioventing rates of air injection are typically one-tenth of vapor extraction rates for the same site. The effectiveness of this technology has been demonstrated in a major pilot testing program conducted at over 140 Air Force sites, including over 50 sites contaminated with JP-4 jet fuel (Downey, 1994). A bioventing pilot test conducted at Pumphouse #2 is described in Section 7 of the EE/CA. Bioventing proved to be effective in removing BTEX from vadose zone soils at Pumphouse #2 and was retained for further evaluation.

2.1.7.3 Soil Excavation and Treatment

As mentioned briefly in Section 2.1.8, excavation and *ex situ* treatment is the only possible method to remediate contaminated soils in and immediately adjacent to the drainage ditches on either side of Flightline Drive. Soil will need to be excavated to a

depth of approximately 4 feet bgs over approximately 30 linear feet on each side of the road. The exact amount of excavation required will be determined in the field at the time of excavation. The excavation will result in approximately 24 cubic yards of contaminated soil that will need to be remediated. Malmstrom AFB has an active landfarm for the treatment of petroleum contaminated soils. This landfarm could receive contaminated soils from Pumphouse #2 and treat them until contaminant concentrations are lowered to an acceptable level. Excavation and aboveground biological treatment were retained for further evaluation.

3.1 SUMMARY OF RETAINED REMEDIAL TECHNOLOGIES

Based on the initial technology screening discussed in Section 2 of this appendix and summarized in Table 1, several remedial approaches and technologies have been retained for the development of remedial alternatives and more detailed analysis. These technologies were selected to provide a range of passive to more active response actions, all of which can attain a risk-based closure of Pumphouse #2 and contaminant concentrations that are protective of human health and the environment. While attaining these goals, all of the presented alternatives will eventually remediate the site to state promulgated groundwater quality standards, though in different time frames and at different costs. The following remedial approaches and technologies have been retained :

- Long-term soil and groundwater monitoring;
- Limited land use controls;
- Groundwater use controls;
- Public education;
- Natural chemical attenuation of soil and groundwater contamination;
- Soil excavation;
- *Ex situ* soil treatment in a landfarm; and
- Air injection bioventing in source area.

Because natural chemical attenuation, and specifically biodegradation, has been effectively removing dissolved BTEX compounds from the groundwater and limiting downgradient migration, this ongoing remediation process can only be enhanced through a reduction of more concentrated dissolved BTEX in the vicinity of the source area at the site. One candidate source-reduction technology, bioventing, was retained for additional analysis. Each of these remediation approaches is described in greater detail, and their effectiveness is evaluated in Section 8 of this EE/CA.

4.1 REFERENCES

Downey, D.C. 1994. Bioventing Performance and Cost Summary. Proposal for Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas. July.

Wiedemeier, T.H., J.T. Wilson, D.H. Kambell, R.N. Miller. 1994. US Air Force Guidelines for Successfully Supporting Intrinsic Remediation with an Example from Hill AFB. Proceedings of Petroleum Hydrocarbons and Organic Chemicals in Groundwater Conference. Houston, TX. Pp 317-335.

TABLE 1
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL AND GROUNDWATER REMEDIATION PUMPHOUSE #2, MALMSTROM AFB, MONTANA

General Response Action	Technology Type	Process Option	Technical Implementability	Effectiveness in Attaining Target Remedial Goals	Relative Cost	Retain
Long-Term Monitoring	Periodic Groundwater Monitoring	Sentry Wells	Many existing wells are available to confirm the progress of remediation.	Necessary component of all remediation strategies	Low	Yes
		Point-of-Action Wells	Sufficient distance exists between the plume and point-of-action to locate two additional wells.	Necessary component of all remediation strategies	Low	Yes
	Periodic Soil/Soil Gas Monitoring	Installation of Additional Soil Borings	Extensive soil sampling indicates soil contamination above screening criteria. Soil gas monitoring useful for checking bioremediation.	Additional soil sampling may be necessary in future to document decrease in BTEX concentrations.	Low	Yes
Institutional Controls	Land and Ground Water Use Control	Land Use Control/Regulate Well Permits	Plume area is currently within the Base boundary. Land-use and ground water use are under Base jurisdiction.	Necessary component of risk-based cleanup	Low	Yes
		Seal/Abandon Existing Wells	No drinking water wells located within 1,000 feet of plume.	Not required at this site	Low	No
		Point-of-Use Treatment	No groundwater is extracted from the plume area for use. Other sources of drinking water are available at the site.	Poor	Moderate	No
	Public Education	Meetings/ Newsletters	Important to convey a clear understanding of acceptable land and groundwater use.	Necessary component of risk-based cleanup	Low	Yes
Containment of Plume	Hydraulic Controls	Interceptor Trench Collection	Extensive infrastructure in vicinity of site prohibits construction. Low groundwater velocity would result in low capture volumes.	Low	High	No
		Minimum Pumping/Gradient Control	A line or semicircle of vertical pumping wells could intercept and halt the advance of the plume. Nonhomogeneous hydrogeology would decrease efficiency.	Low	High	No

TABLE 1 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL AND GROUNDWATER REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

General Response Action	Technology Type	Process Option	Technical Implementability	Effectiveness in Attaining Target Remedial Goals	Relative Cost	Retain
Containment of Plumes (cont.)	Physical Controls	Slurry Walls/Grout Curtains	Requires significant disruption. Limited effectiveness.	Moderate	High	No
		Sheet Piling	Requires significant disruption. Limited effectiveness.	Moderate	High	No
	Reactive/Semi-Permeable Barriers	Biologically Active Zones	Natural biodegradation of BTEX/PAH compounds can be stimulated by allowing contaminated groundwater to flow through an aquifer zone which has enhanced oxygen and nutrient conditions.	Moderate	High	No
In Situ Groundwater Treatment	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Differs from biologically active zone in that oxygen (air) is injected upgradient of plume and allowed to migrate downgradient. In theory, this method can more rapidly reduce higher BTEX/PAHs concentrations in and immediately downgradient of the source. Nonhomogeneous hydrogeology will severely limit effectiveness.	Moderate	Low	No
	Chemical/Physical	Intrinsic Remediation	A combination of natural biological, chemical, and physical removal mechanisms which occur to varying degrees on every site. Groundwater sampling at Pumphouse #2 indicates that this is a major, ongoing remediation process.	High	Low	Yes

TABLE 1 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL AND GROUNDWATER REMEDIATION PUMPHOUSE #2, MALMSTROM AFB, MONTANA

General Response Action	Technology Type	Process Option	Technical Implementability	Effectiveness in Attaining Target Remedial Goals	Relative Cost	Retain
Aboveground Groundwater Treatment	Biological	Bioreactors	Requires excessive retention times and large reactors. BTEX is often volatilized in these systems. No groundwater extraction is proposed for the site.	Low	High	No
	Chemical/Physical	Air Stripping	Cost-effective technology for removing varying concentrations of BTEX. Potential permitting for air emissions. No groundwater extraction is proposed for the site	Low	Moderate	No
		Activated Carbon	Cost effective for more dilute concentrations of BTEX. Creates a carbon disposal problem. No groundwater extraction is proposed for the site	Low	Moderate	No
		UV/Ozone Reactors	Requires excessive retention times and large, expensive reactors. No groundwater extraction is proposed for the site	Low	High	No
		Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)	Viable option when an IWWTP is available and capable of handling BTEX available for site. No groundwater extraction is proposed for the site.	Low	High	No
Treated Groundwater Disposal	Discharge to IWWTP or Sanitary Sewer	IWWTP	Viable option when an IWWTP is available and capable of handling BTEX and hydraulic loading. IWWTP not available for this site. No groundwater extraction is proposed for the site.	Low	High	No

TABLE 1 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL AND GROUNDWATER REMEDIATION PUMPHOUSE #2, MALMSTROM AFB, MONTANA

General Response Action	Technology Type	Process Option	Technical Implementability	Effectiveness in Attaining Target Remedial Goals	Relative Cost	Retain
Treated Groundwater Disposal (cont.)	Discharge to IWWTP or Sanitary Sewer (cont.)	Sanitary Sewer	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable. No groundwater extraction is proposed for the site.	Low	Low when sewer available	No
	Treated Groundwater Reinjection	Vertical Injection Wells	Not recommended due to clogging and high maintenance. No groundwater extraction is proposed for the site.	Low	High	No
		Injection Trenches	Require large trenches and can be subject to injection well permitting. No groundwater extraction is proposed for the site.	Low	High	No
	Discharge to Surface Waters	Storm Drains	Generally requires NPDES or other discharge permit. No groundwater extraction is proposed for the site.	Low	Moderate Permitting Costs	No
Soil Remediation	Excavation/ Treatment of Soils	Excavation	Excavation only viable option for treatment of soil in drainage ditches.	High	Low	Yes
		Biological Landfarming	Existing landfarm can be used to treat soils removed from Pumphouse #2.	Moderate	Moderate	Yes
		Thermal Desorption	Would require installation of system for a small volume of soil to be treated.	Moderate	High	No
	In Situ	Bioventing	Bioventing would be successful at Pumphouse #2 based on pilot test results.	High	Low	Yes
		Soil Vapor Extraction	Vapor extraction has been successfully implemented at other sites; however, off-gas treatment will probably be required.	High	High due to off-gas treatment	No

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Calculation Sheet

Rev	By	Date	Ck	Date	Title
					ALTERNATIVE # 1 COST ESTIMATE
					MALMSTROM AFB EE/CA - PUMPHOUSE # 2
					Author RUSSELL FRISHMUTH Sheet 1 Of 3

ALTERNATIVE # 1

- EXCAVATION AND EX SITU TREATMENT OF SEDIMENTS
- INSTALL PERIMETER FENCING
- LONG-TERM GROUND WATER MONITORING

CAPITAL COSTS

(1) SEDIMENT REMOVAL + TREATMENT

- EXCAVATION - 24 CY
  - 4 CY / LABORER / DAY [1]
  - 3 DAYS (8 HOURS) W/ 2 LABORERS
  - 48 HOURS @ $60/HR — LABOR — $2,880

- TRANSPORTATION - 24 CY - 2 MILE R/T
  - BACKHOE - ½ CY BUCKET + 1 OPERATOR [1]
    - OPERATOR 24 HRS @ $60/HR — LABOR — $1,440
    - EQUIPMENT RENTAL $1,000/DAY — EQUIP. — $3,000

- TREATMENT - PROVIDED BY EXISTING LANDFARM OPERATING ON MALMSTROM AFB — $0.00

- BACKFILLING - 24 CY HAND TAMP
  - 24 CY BACK FILL - DELIVERED — MAT'L — $400
  - 8 CY / DAY / LABORER [1]
  - 1.5 DAYS (8 HOURS) W/ 2 LABORERS
  - 24 HOURS @ $60/HR — LABOR — $1,440

- OTHER DIRECT COSTS
  - TRAVEL (3 ROUND TRIPS) — $1,000.
  - SUPPLIES — $200.
  - PER DIEM (13 LABOR DAYS × $77/DAY) — $1,001.

1 - MANHOUR ESTIMATES FROM MEANS MANHOUR GUIDEBOOK, 1988.

CONTINGENCY (10 %) — $1,136

TOTAL — $12,500

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Calculation Sheet

Rev	By	Date	Ck	Date	Title ALTERNATIVE #1 COST ESTIMATE MALMSTROM AFB EE/CA - PUMPHOUSE #2
					Author RUSSELL FRISHMUTH Sheet 2 Of 3

CAPITAL COSTS: CONT.

(2) DESIGN/CONSTRUCT 3 ADDITIONAL POA WELLS

- DESIGN/PROCURE/CONSTRUCT/DEMOB - 80 HRS @ $60/HR	LABOR	$4,800
- DRILLING SUBCONTRACTOR - 10 LF @ $80/LF	SUBCONTRACTOR	$1,200
- PER DIEM - 10 LABOR DAYS @ $77/DAY	ODC	$770
- TRAVEL (2 ROUND TRIPS)	ODC	$666
- SUPPLIES	ODC	$200
	CONTINGENCY (10%)	$764
	TOTAL	$8,400

(3) INSTALL FENCING - 720 LF 6' CHAIN LINK W/ 3 STRAND BARBWIRE

- LABOR - CONSTRUCTION SUBCONTRACTOR INCLUDING PROCUREMENT	SUBCONTRACTOR	$3,000
- MATERIAL	MAT'L	$1,500
- PARSONS ES OVERSIGHT INCLUDING TRAVEL, LABOR, + PERDIEM (1 PERSON)		$2,050
	CONTINGENCY (10%)	$655
	TOTAL	$7,200

TOTAL CAPITAL COSTS: $28,100

PARSONS

Calculation Sheet

Rev	By	Date	Ck	Date	Title ALTERNATIVE # 1 COST ESTIMATE
					MALMSTROM AFB - EE/CA - PUMPHOUSE # 2
					Author RUSSELL FRISHAMUTH Sheet 3 Of 3

ANNUAL COSTS

(1) ANNUAL GROUNDWATER SAMPLING - 10 WELLS

- LABOR 80 HRS @ 60/HR — LABOR $4,800
- ANALYTICAL SUBCONTRACTING
  10 SAMPLES + 1 QA/QC } 11 SAMPLES
  11 BTEX @ $90/EA — SUBCONTRACTOR $990
- SUPPLIES (INCLUDING HEALTH SUPPLIES) — ODC $500
- EQUIPMENT RENTAL — $200
- TRAVEL (2 ROUNDTRIPS) — ODC $666
- PER DIEM (10 DAYS @ $77/DAY) — ODC $770
- OFFICE ODC (SHIPPING ETC.) — ODC $300

CONTINGENCY (10%) $823

TOTAL $9,050

(2) SITE MANAGEMENT
160 HR/YR × $60/HR — LABOR $9,600

PRESENT WORTH CALCULATIONS

- ANNUAL SAMPLING @ $9,050 FOR 5 YEARS
  $P/A^{7\%}_{12\ YEARS} = 7.94$ [2] — PRESENT COST = $71,857
- SITE MANAGEMENT @ $9,600 FOR 20 YEARS
  $P/A^{7\%}_{12\ YEARS} = 7.94$ [2] — PRESENT COST = $76,224

TOTAL PRESENT COST OF ALTERNATIVE # 1 = $176,181

2 - P/A COEFFICIENT FROM INTEREST TABLES

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Calculation Sheet

Rev	By	Date	Ck	Date	Title ALTERNATIVE # 2 COST ESTIMATE MALMSTROM AFB EE/CA – PUMPHOUSE # 2
					Author RUSSELL FRISHMUTH Sheet 1 Of 2

ALTERNATIVE # 2

- EXCAVATION AND EX SITU TREATMENT OF SEDIMENT
- INSTALL PERIMETER FENCING
- LONG TERM GROUNDWATER MONITORING
- SOURCE AREA BIOVENTING

CAPITAL COST

(1)	SEDIMENT REMOVAL	SEE ALTERNATIVE # 1	$ 12,500
(2)	DESIGN/CONSTRUCT 3 ADDITIONAL POA WELLS	SEE ALTERNATIVE # 1	$ 8,400
(3)	INSTALL FENCING	SEE ALTERNATIVE # 1	$ 7,200

(4) SOURCE AREA BIOVENTING

- DESIGN/PROCURE/CONSTRUCT/TEST
  300 HRS @ $60/HR — LABOR $18,000
- MATERIALS + EQUIPMENT
  5HP BLOWER
  ENCLOSURE
  PIPE + VALVE — MAT'L $ 6,000
- ELECTRICAL SUBCONTRACTOR — SUBCONT. $ 1,600
- PER DIEM (30 DAYS @ $77 DAY) — ODC $ 2,310
- EQUIPMENT RENTAL — ODC $ 1,500

CONTINGENCY (10%) $ 2,881

TOTAL $ 31,690

TOTAL CAPITAL COST $ 59,790

ANNUAL COSTS

(1)	ANNUAL GROUNDWATER SAMPLING	SEE ALTERNATIVE # 1	PRESENT WORTH	$ 71,857
(2)	SITE MANAGEMENT	SEE ALTERNATIVE # 1	PRESENT WORTH	$ 76,22[illegible]

PARSONS

Calculation Sheet

Rev	By	Date	Ck	Date	Title
					ALTERNATIVE #2 COST ESTIMATE
					MALMSTROM AFB EE/CA - PUMPHOUSE #2
					Author RUSSELL FRISHMUTH Sheet 2 Of 2

ANNUAL COSTS: CONT'D

(3) BIOVENTING SYSTEM MONITORING

1 PERSON 1 HR/WK = 52 HRS/YR
1 PERSON 3 DAYS/6 MONTHS = 48 HRS/YR

100 HRS/YR @ $ 60 HOUR

LABOR $ 6,000

$P/A_{2\,YRS}^{7\%} = 1.81$ → PRESENT WORTH = $ 10,860

TOTAL P.W. OF ANNUAL COSTS = $ 150,991

TOTAL P.W. OF ALTERNATIVE #2 = $ 218,730

APPENDIX H

SAMPLING AND ANALYSIS PLAN

SITE SAMPLING AND ANALYSIS PLAN

FOR

ENGINEERING EVALUATION/COST ANALYSIS AND LONG-TERM MONITORING PLAN
RISK-BASED APPROACH TO REMEDIATION
PUMPHOUSE #2, MALMSTROM AFB, MONTANA

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
(AFCEE) TECHNOLOGY TRANSFER DIVISION (ESR)
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USAF CONTRACT F41624-93-C-8044

September 1995

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The purpose of this site-specific sampling and analysis plan (SAP) is to provide the procedures to be followed when collecting data in support of the long-term monitoring plan (LTMP) for the risk-based approach to remediation at Pumphouse #2. Details on analytical requirements, desired quantitation (detection) limits, and proposed sampling locations are identified within section 10 of the Engineering Evaluation/Cost Analysis (EE/CA). The need to collect additional samples to meet quality assurance requirements are described in the program quality assurance project plan (QAPP) (Appendix I). Specific quality assurance sampling requirements for Pumphouse #2 are summarized herein as part of the site-specific sampling procedures. These additional samples will be used to determine the precision, accuracy, completeness, and representativeness of the final data set.

Soil gas sampling is described in Section 1; soil flux sampling is described in Section 2; drilling, soil sampling, lithologic logging, and groundwater monitoring well installation procedures are described in Section 3; and groundwater sampling procedures are described in Section 4; and field quality assurance/quality control (QA/QC) samples are described in Section 5.

1 SOIL GAS SAMPLING

Soil gas will be used as an indicator of subsurface hydrocarbon contamination and to assess the effectiveness *in situ* bioventing in removing source contamination at the site. The use of soil gas to delineate potential subsurface contamination and to determine bioventing effectiveness has several economic and technical advantages over more traditional drilling and soil sampling techniques. The labor and equipment cost can be significantly less than a conventional drilling and sampling team. Many new hydraulically driven, multi-purpose probes can be used for soil gas sampling. These probes can be advanced as quickly as conventional augers and do not produce drill cuttings which can require expensive analysis and disposal. Further, soil gas sampling can represent the average chemistry of several cubic feet of soil as compared to a discrete soil sample, which can only describe a few cubic inches of the subsurface. This is of particular importance in risk-based remediation projects where the extent of COC contamination and the degree of removal of COCs can most accurately be determined by using multiple soil gas sampling locations.

The test equipment and methods that will be required to conduct field soil gas sampling as part of the risk-based remediation at this site are described fully in the AFCEE document *Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential* (AFCEE, 1994). In summary, soil gas sampling will be conducted initially to establish a contaminant concentration baseline for the site. Sampling will then be conducted every 6 months during system operation to assess contaminant removal rates. Oxygen utilization and carbon dioxide production will also be measured at this time to calculate biodegradation rates. Once soil gas contaminant concentrations and respiration rates indicate that subsurface contaminants have been biodegraded, confirmatory soil samples will be collected.

Soil gas sampling will be conducted at the existing 4-inch diameter air injection wells and a three multi-depth vapor monitoring points installed during the pilot-scale test at Pumphouse #2. Samples will be collected using air-tight well tops or, in the

case of the vapor monitoring points, existing ball valves and hose barbs with flexible tubing.

Gaseous concentrations of carbon dioxide and oxygen will be analyzed onsite using an O_2/CO_2 analyzer. The analyzer will generally have an internal battery-powered sampling pump and range settings of 0 to 25 percent for both oxygen and carbon dioxide. Before analyzing samples, the analyzer must be checked for battery charge level. The analyzer will also be calibrated daily using atmospheric conditions of oxygen (20.9 percent) and carbon dioxide (0.05 percent) and a gas standard containing 0.0 percent oxygen and 5.0 percent carbon dioxide.

Total volatile hydrocarbon (TVH) concentrations will be used as the primary screening tool at this site. The TVH analyzer used at Pumphouse #2 will be capable of measuring hydrocarbon concentrations in the range of 1 to 20,000 parts per million, volume per volume (ppmv). The analyzer must also distinguish between methane and non-methane hydrocarbons. The battery charge level on the TVH analyzer will be checked prior to analysis of each collected soil gas sample. The TVH analyzer will also be calibrated daily using a hexane calibration gas.

All soil gas samples taken during system monitoring at Pumphouse #2 will be collected using 3-liter Tedlar™ bags and vacuum chambers. The soil gas sample will then be analyzed by attaching the O_2/CO_2 and TVH analyzers directly to the Tedlar™ bag. Sample locations identified for analytical compound-specific analysis will be re-sampled using 3-liter Tedlar™ bags and vacuum chambers. The sample will then be transferred to 1-liter SUMMA™ canisters and shipped to the laboratory for compound-specific analysis using EPA Method TO-3 (see Table 2.1 in the EE/CA).

Field QA/QC procedures for soil gas will include collection of one field duplicate for every 10 samples collected (e.g., frequency of 10 percent), use of analyte-appropriate containers, and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the analytical laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., soil gas), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature.

Soil gas QA/QC sampling for analytical purposes will include field duplicates at a frequency of 10 percent. However, the laboratory should also plan to conduct one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested for soil gas (i.e., required only once for soil gas extracted via soil gas monitoring point or obtained via flux chamber).

2 SOIL FLUX SAMPLING

Several soil flux tests will be conducted at the site prior to bioventing system startup to determine the natural background emissions from the site. Soil flux tests will also

be performed at the sample same locations during the first day of system operation. The purpose of these flux tests is to estimate potential air quality impacts from COC emissions forced from contaminated environmental medium by the subsurface air injection associated with bioventing. Flux samples will be collected at Pumphouse #2 using the procedures outlined in EPA guidance *Measurement of Gaseous Emissions Rates from Land Surfaces Using a Emission Isolation Flux Chamber* (EPA, 1985). The use of a flux box is the preferred method of measurement of surface emission rates of volatile contaminants. A flux box is used to isolate a known surface area from the ambient air, collect surface emissions, and mix the collected emissions with "sweep" air introduced into the chamber at a known flow rate. Data from the flux box can then be combined with a simple dispersion model to identify potential ambient air contamination impacts.

The procedures contained within EPA's protocol document on measuring emission rates (i.e., *Measurement of Gaseous Emission Rates from Land Surfaces using an Emission Isolation Flux Chamber* (EPA/600/8-86/008)) will be followed. In summary, gaseous emissions will be collected from an isolated surface area using a flux chamber and monitored using both "real-time" and discrete methods. Real-time measurements will be made with a portable hydrocarbon analyzer to determine when the chamber reaches steady-state conditions. Discrete samples will then be collected for chemical analysis.

To reduce the potential for cross-contamination, which can occur whenever high level or low level samples are sequentially analyzed, the flux chamber will be purged and tested with a blank after each sample is conducted. Emission tests will only be conducted when soil moisture levels are normal. Increased ground moisture as a result of rain or heavy dew can bias (lower) emission rates.

The sweep air to be used will be dry, organic free air equal to or better than commercial ultra high purity grade ($<$ 0.1 ppmv total hydrocarbon content). Discrete samples will be collected in SUMMA™ canisters and analyzed using EPA Method TO-3 to identify BTEX concentrations.

Field QA/QC procedures for soil flux sample will be identical to those required for soil gas. QA/QC requirements include collection of a field duplicate at a frequency of 10 percent, use of analyte-appropriate containers, and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the analytical laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., soil gas), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature.

Soil flux QA/QC sampling includes collection of a field duplicate at a frequency of 10 percent. However, the laboratory should also plan to conduct one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific

analysis requested for soil gas (i.e., required only once for soil gas extracted via soil gas monitoring point or obtained via flux chamber).

3 DRILLING, SOIL SAMPLING, AND GROUNDWATER MONITORING WELL INSTALLATION

To monitor contaminant plume migration at Pumphouse #2, three additional groundwater monitoring wells will installed downgradient of Pumphouse #2. The following sections describe the proposed well locations and completion intervals, equipment decontamination procedures, drilling and soil sampling, well installation, well development procedures, and well location and datum surveying. All drilling, soil sampling, and well installation will proceed from areas suspected to be least contaminated to areas suspected to be more contaminated.

3.1 Well Locations and Completion Intervals

Three wells will be installed approximately 120 feet downgradient of Pumphouse #2 to establish an operational point-of-action. If site-related contaminants are detected at concentrations exceeding promulgated state groundwater standards at any these POA wells, contingency actions will be considered as outlined in Section 9.3 of the EE/CA. Two of the three wells will be installed by hand (i.e., hand augering) in the drainage ditches adjacent to Flightline Drive downgradient from the site. These wells will be screened from 2 feet bgs to glacial till (approximately 8 feet bgs). The third well will be installed by traditional hollow stem drilling techniques and will be screened from 3 feet bgs to 10 feet bgs. The new well locations were selected to intercept a contaminant plume should one emanate from the source area. The two wells in the drainage ditches were placed to intercept any preferential flow that may be flowing along utility corridors underneath the drainage ditches. Based on plume migration predictions, contaminants exceeding groundwater quality standards should never reach the POA wells. Figure 10.1 in the EE/CA shows the proposed well locations.

3.2 Drilling and Soil Sampling Procedures

This subsection addresses the procedures for drilling soil borings that will be used for soil sampling and completed as new wells. All new monitoring wells will be installed in accordance with general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (EPA, 1987).

3.2.1 Pre-Drilling Activities

All necessary digging, drilling, and well installation permits will be obtained by Malmstrom AFB personnel prior to Parsons ES mobilizing to the field. In addition, all utility lines will be located and proposed drilling locations cleared prior to any drilling activities.

3.2.2 Equipment Decontamination Procedures

Water to be used in drilling, equipment cleaning, or grouting will be obtained from one of the base's onsite water supplies. Malmstrom AFB personnel will assist Parsons ES field personnel in locating a suitable source. Water use approval will be verified by

contacting the appropriate facility personnel. Only potable water will be used for the activities listed above. A decontamination water blank will be collected from the potable water source. The procedures for the collection of the decontamination water blank will be described in Section 5. The Parsons ES field hydrogeologist will make the final determination as to the suitability of site water for these activities.

Prior to arriving at the site, and between each drilling site, the drill rig, augers, drilling rods, bits, casing, samplers, tools and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination.

During drilling operations, the drill rig, augers, and any down-hole drilling and/or sampling equipment will be decontaminated at a temporary decontamination pad that will be set up at Pumphouse #2. The temporary decontamination pad will be constructed in a manner so as to contain all decontamination fluids. All decontamination fluids generated at the temporary decontamination pad will be placed in 55-gallon drums. The decontamination fluids will be disposed of following the procedures presented in Section 3.5.

All sampling tools will be cleaned onsite, prior to use and between each sampling event, with a clean water/phosphate-free detergent mix and a clean water rinse. All well completion materials that are not factory sealed will be cleaned onsite prior to use with a high-pressure, steam/hot water wash using approved water. Materials that cannot be cleaned to the satisfaction of the Parsons ES field hydrogeologist will not be used. All decontamination activities will be conducted in a manner so that the excess water will be controlled and not allowed to flow into any open borehole.

If contaminated soils are encountered during drilling (based on visual, olfactory, or volatile organic analyzer indications), and the potential for cross-contamination is anticipated, drilling will be stopped and modified drilling procedures will be implemented to prevent the transfer of contaminants to deeper strata.

Fuel, lubricants, and other similar substances will be handled in a manner consistent with accepted safety procedures and standard operating practices. Well completion materials will not be stored near or in areas which could be affected by these substances. The drill rigs will not be allowed onsite unless they are free from leaks in any hydraulic lines, and are free of any exterior oil and grease.

Surface runoff such as miscellaneous spills and leaks, precipitation, and spilled drilling fluid will not be allowed to enter any boring or well either during or after drilling/well construction. To prevent this from happening, starter casing, recirculation tanks, berms around the borehole, and surficial bentonite packs, as appropriate, will be used.

3.2.3 Drilling and Soil Sampling

Drilling in unconsolidated soils will be accomplished using hollow-stem augers. The borings will be drilled and continuously sampled to the proposed total depth of the monitoring well. For installation of ground water monitoring wells, the auger ID will

not be less than 4 inches. Determination of well completion details will be at the discretion of the Parsons ES field hydrolgeologist.

If subsurface conditions are such that the planned drilling technique does not produce acceptable results (e.g. unstable borehole walls or poor soil sample recovery) another technique deemed more appropriate to the type of soils present will be used. Any alternate soil sampling procedure used must be approved by the Parsons ES field hydrogeologist and will be appropriate for the subsurface lithologies present at the site.

Continuous soil samples will be obtained using a split-barrel continuous sampling device or another similar method judged acceptable by the Parsons ES field hydrogeologist. Samples will be collected continuously with a split-spoon sampler from the ground surface to glacial till. The Parsons ES field hydrogeologist will identify which samples from the continuous sampling device will be submitted for chemical analysis. Only soils that exhibit possible contamination will be retained for chemical analysis. If no evidence of contamination is found, a sample will be collected from approximately 1 foot above the beginning of the saturated zone. Soil samples which may be retained for chemical analysis will be placed in sample containers immediately after the core barrel is opened. A maximum of two soil samples for chemical analysis will be collected per borehole. All soil cores will be evaluated for lithologic characteristics, however. All soil samples collected will be removed from the continuous sampler and placed on clean aluminum foil for logging.

Every 2-foot interval of soil sample recovered will be subsampled, composited, and placed in a clean container for PID or similar hydrocarbon vapor analyzer headspace measurements for VOCs. Representative portions of the soil samples collected for the headspace procedure will be quickly transferred to the sample containers, which will be sealed and held for 15 minutes at an ambient temperature of 65 degrees Fahrenheit (°F) or greater. Semiquantitative measurements will be made by puncturing the container seal with the PID probe and reading the concentration of the headspace gases. The PID relates the concentration of total VOCs in the sample to an isobutylene calibration standard. The PID will be calibrated daily to 100 parts per million, volume per volume of isobutylene. It is anticipated that headspace measurements will be performed on all samples collected during the drilling operations to determine which soil samples will be submitted for chemical analysis. The PID will also be used to monitor the worker breathing zone.

As a check on the quality of field sampling activities (sampling, containerization, shipment, and handling) QA/QC trip blanks, field blanks, equipment rinseate samples, and field duplicates will be sent to the laboratory. QA/QC sampling will include duplicates for soil samples at a frequency of 10 percent, equipment rinseate samples at a frequency of 10 percent, one field blank per sampling event, and a trip blank for each individual cooler sent to the analytical laboratory. The procedures for the collection of field QA/QC samples are discussed below in Section 6. Laboratory QA/QC procedures will include one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested.

The Parsons ES field hydrogeologist will be responsible for observing all drilling and well installation activities, maintaining a detailed descriptive log of subsurface

materials recovered, photographing representative samples, and properly labeling and storing samples. An example of the proposed geologic boring log form is presented in Figure 1. The descriptive log will contain:

- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination;
- Soil or rock description, including: 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;
- Lithologic contacts: the depth of lithologic contacts and/or significant textural changes will be measured and recorded to the nearest 0.1 foot (1 inch); and
- Determination on whether soil sample will be submitted for chemical analysis or segregated as uncontaminated medium.

3.2.4 Minimization and Management of Drilling Residuals

Drilling activities will generate soil cuttings requiring proper handling and, if contaminated, proper disposal. Based on data from previous soil sampling efforts at the site, contamination outside the source area only exists in the narrow smear zone above the groundwater surface. Since all three proposed wells are downgradient of the contaminant plume, it is anticipated that contaminated soil will not be encountered. If contaminated soils are encountered care will be taken to segregate them clean soils. This limited drilling event will generate approximately 0.5 cubic yard of soil. All soils will be placed 55-gallon, D.O.T. approved, drums until analytical samples can be collected. Samples will be collected from the drums by Malmstrom AFB personnel. Base personnel will be responsible for disposal of all soils generated. If soils are clean, they will be used as fill elsewhere on base. If soils are contaminated, they will be treated in an existing on-Base landfarm until contaminant concentrations reach acceptable levels.

3.3 Groundwater Monitoring Well Installation

Groundwater monitoring wells will be installed in each of the 3 soil borings completed at Pumphouse #2. Except where specified, the entire thickness of the shallow aquifer will be screened. Detailed well installation procedures are described in the following paragraphs. A typical well completion diagram is included as Figure 2.

3.3.1 Well Material Decontamination

Well completion materials will be inspected by the Parsons ES field hydrogeologist and determined to be clean and acceptable prior to use. If not factory sealed, casing, screen, and casing plugs and caps will be cleaned with a high-pressure, steam/hot water cleaner using approved water prior to use. Prepackaged sand, bentonite, and Portland®

GEOLOGIC BORING LOG

BORING NO. _____ CONTRACTOR: _____ DATE SPUD: _____
CLIENT: _____ RIG TYPE: _____ DATE CMPL: _____
JOB NO.: _____ DRLG METHOD: _____ ELEVATION: _____
LOCATION: _____ BORING DIA.: _____ TEMP.: _____
GEOLOGIST: _____ DRLG FLUID _____ WEATHER: _____
COMMENTS: _____

Elev. (ft.)	Depth (ft.)	Pro-file	US CS	Geologic Description	Samples No.	Samples Depth (ft)	Sample Type	Penet. Res.	Remarks TIP = Bkgrnd/Reading (ppm)
	1								
	5								
	10								
	15								
	20								
	25								
	30								

sl – slight
tr – trace
sm – some
& – and
@ – at
w – with

v – very
lt – light
dk – dark
bf – buff
brn – brown
blk – black

f – fine
m – medium
c – coarse
BH – Bore Hole
SAA – Same As Above

SAMPLE TYPE
D – DRIVE
C – CORE
G – GRAB

C Core recovery

Core lost

Water level drilled

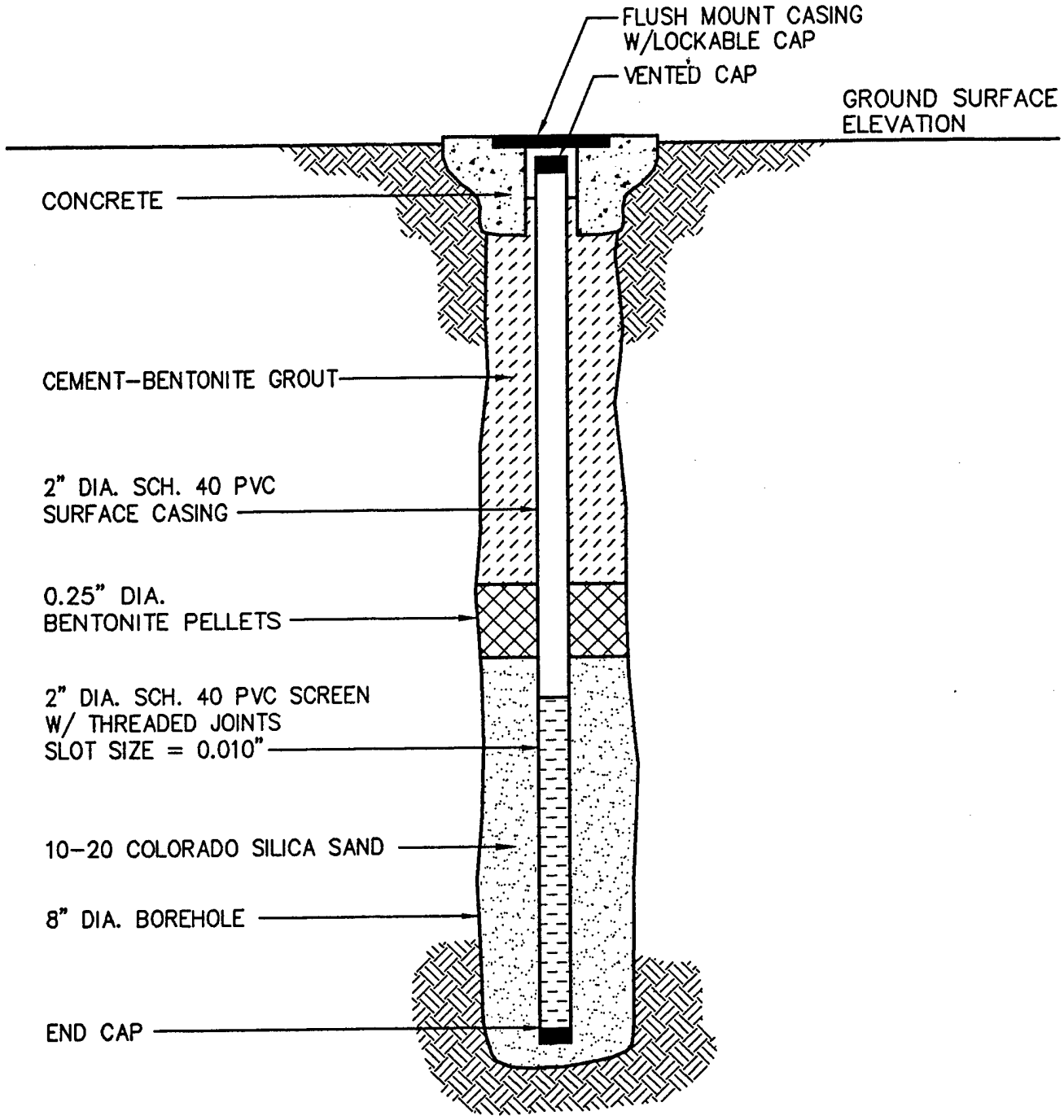


FIGURE 2

TYPICAL MONITORING WELL COMPLETION DIAGRAM

Risk-Based Approach to Remediation

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

K:\ELLSWRTH\95DN0910, 06/08/95 at 12:35

cement will be used in well construction, and the bags will be inspected for possible external contamination before use. Materials that cannot be cleaned to the satisfaction of the Parsons ES field hydrogeologist will not be used.

3.3.2 Well Casing

Upon completion of drilling to the proper boring termination depth, a monitoring well casing will be installed. Well construction details will be noted on a Monitoring Well Installation Record form, as shown in Figure 3. This information will become part of the permanent field record for the site. Blank well casing will be constructed of Schedule 40 polyvinyl chloride (PVC) with an ID of 2 inches. All well casing sections will be flush-threaded; glued joints will not be used. The casing at each well will be fitted with a threaded bottom plug and a top cap constructed of the same type of material as the well casing. The top cap will be vented to maintain ambient atmospheric pressure within the well casing.

The Parsons ES field hydrogeologist will verify and record the boring depth, the lengths of all casing sections, and the depth to the top of all well completion materials placed in the annulus casing and borehole wall. All lengths and depths will be measured to the nearest 0.1 foot.

3.3.3 Well Screen

Well screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 2 inches. The screens will be factory slotted with 0.010-inch openings. Each well will be screened so that seasonal fluctuations of the water table can be measured. The water level in the unconfined aquifer will be allowed to fluctuate within the screened interval. The position of the screen will be selected by the Parsons ES field hydrogeologist after consideration is given to the geometry and hydraulic characteristics of the stratum in which the well will be screened.

3.3.4 Sand Filter Pack and Annular Sealant

A graded sand filter will be placed around the screened interval and will extend at least 6 inches above the top of the screen. The sand filter will consist of 10-20 silica sand. An annular seal will be placed above the gravel pack using sodium bentonite pellets. The pellet seal will be a minimum of 1 foot thick and will be hydrated in place with potable water. The pellet seal will be overlain with concrete to the ground surface.

3.3.5 Flush-Mount Protective Cover

Each monitoring well will be completed with an at-grade (flush-mount) protective cover. In areas where pavement is present, the at-grade cover will be cemented in place using concrete which will be blended to the existing pavement. In areas where pavement is not already present, a 6-inch thick, 2-foot-diameter concrete pad will be constructed around the protective cover. In either case, the concrete immediately surrounding the well cover will be sloped gently away from the protective casing to facilitate runoff during precipitation events.

WELL CONSTRUCTION FORM

Installation: _____
Site: _____
Well ID: _____
Comp. started ___/___/___ (: m)

Project no. _____
Drilling contractors: _____
Comp. finished: ___/___/___ (: m)

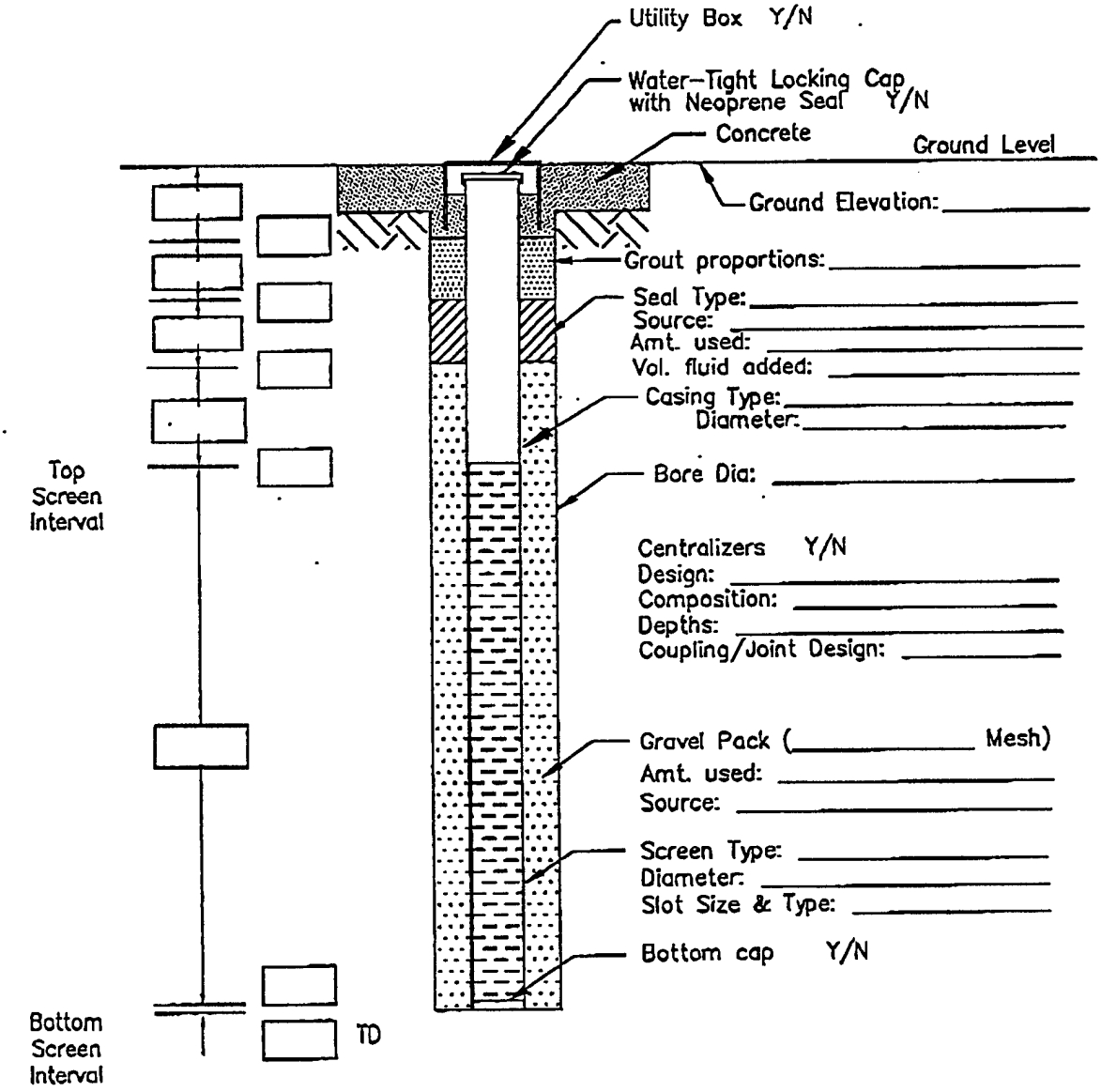


Figure 3
Monitoring Well Installation Record

3.4 Well Development

Before any new well can be considered in proper condition for monitoring water levels or taking water samples, it must be developed. Development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen. If a well is grouted prior to development, well development will occur no sooner than 48 hours after grouting of the annulus is completed.

Well development will be accomplished using a surge block and a disposable bailer. The block will be lowered into the well and rapidly moved up and down the screened interval of the well so that fines are agitated and removed from the well in the development water.

Development will be continued until a minimum of three casing volumes of water have been removed from the well and the water pH, temperature, and specific conductivity have stabilized. Temperature, pH and specific conductivity will be monitored during development (one reading for each parameter per well volume). Pumping will continue until these parameters have stabilized to within 10 percent among three consecutive readings and the water is clear and free of fines. The pH and specific conductivity meters will be calibrated on a daily basis. The pH meter will be calibrated by laboratory-prepared standard solutions following the manufactures calibration procedures. The specific conductivity meter will be calibrated using laboratory-prepared known conductivity solutions. If the development water still is turbid after removal of three casing volumes, development will be continued until the water becomes clear or the turbidity of the water produced has been stable after the removal of several casing volumes.

The development procedure specifies that three casing volumes of water be removed from the well. However, some wells completed in marginal aquifers will go dry during well development prior to the recovery of three casing volumes. In these low-productivity wells, development activity may have to be staged over a period of time to allow water to refill the well bore. In the event three casing volumes of water cannot be recovered, the water volume recovered will be noted in the development records.

All well purge water will be placed in 55-gallon drums supplied by the drilling subcontractor. Malmstrom AFB will be responsible for sampling, laboratory analysis and disposal of any contaminated or potentially contaminated purge and development water. Drums will be staged and temporarily stored onsite as directed by Malmstrom AFB personnel.

3.5 Well Development Records

A record of well development will be maintained for each well. The well development record will be maintained in a bound field notebook by the field hydrogeologist. Figure 4 is an example of the well development record. A summary well development record form will be prepared for each well and will become part of the written record for the site. Development records will include:

- Well number;

Well Development Record

Job Number_____ Job Name_____
Location_____ By_____ Date_____
Well Number_____ Measurement Datum_____

Pre-Development Information

Time (Start):

Water Level:

Total Depth of Well:

Water Characteristics

Color_____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material_____
pH_____ Temperature(^{O}F ^{O}C) _____
Specific Conductance(µS/cm)_____

Interim Water Characteristics

Gallons Removed

pH

Temperature (^{O}F ^{O}C)

Specific Conductance(µS/cm)

Post-Development Information

Time (Finish):

Water Level:

Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color_____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material_____
pH_____ Temperature(^{O}F ^{O}C) _____
Specific Conductance(µS/cm)_____

Comments:

Figure 4

- Date and time of development;
- Development method;
- Predevelopment water level and well depth;
- Volume of water produced;
- Description of water produced;
- Post-development water level and well depth; and
- Field analytical measurements, including pH and specific conductivity.

3.6 Water Level Measurements

Water levels at all wells will be measured within a short time interval so that the water-level data are comparable. Water levels in the new wells will not be measured until they are developed and the water level has stabilized. The depth to water below the measurement datum will be made using an oil/water interface electric probe to the nearest 1/8 inch (0.01 foot). The oil/water interface probe will be decontaminated prior to use, and between each measurement, following the decontamination procedures presented in Section 4.3.

3.7 Well Location and Datum Survey

The location and elevation of the new wells will be surveyed by a registered surveyor soon after well completion. Horizontal locations will be measured relative to the state plane coordinate system for the State of Montana. Horizontal coordinates will be measured to the nearest 0.01 foot. Vertical location of the ground surface adjacent to the well casing, the measurement datum (top of the interior casing), and the top of the outer well casing will be measured relative to a USGS MSL datum. The ground surface elevation will be measured to the nearest 0.1 foot, and the measurement datum, outer casing, and surveyor's pin (if present) elevation will be measured to the nearest 0.01 foot.

3.8 Site Restoration

After well installation and sampling is complete, each well site will be restored as closely to its original condition as possible.

4 GROUNDWATER SAMPLING

This section describes the scope of work required for collecting groundwater samples from the 10 monitoring wells in the long-term monitoring well network. All water samples collected from groundwater monitoring wells will be obtained using either disposable bailers or a thoroughly decontaminated peristaltic pump and new flexible tubing. Equipment blanks will be collected to assure that all equipment is properly cleaned. In order to maintain a high degree of quality control during this sampling event, the procedures described in the following sections will be followed.

Groundwater sampling will be conducted by qualified Parsons ES scientists and technicians trained in the conduct of well sampling, records documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed the work plan and this site-specific sampling and analysis plan prior to sample acquisition and will have a copy of both available onsite for reference.

Activities that will occur during groundwater sampling are summarized below:

- Assembly and preparation of equipment and supplies;
- Inspection of the well integrity, including:
  - Protective cover, cap and lock,
  - External surface seal and pad,
  - Well stick-up, cap, and datum reference,
  - Internal surface seal,
  - Condition of any dedicated equipment, if present;
- Groundwater sampling, including:
  - Water-level measurements,
  - Visual inspection of borehole water,
  - Well casing evacuation,
  - Sampling;
- Sample preservation and shipment, including:
  - Sample preparation and preservation, as appropriate,
  - Onsite measurement of physical parameters,
  - Sample labeling,
  - Sample packaging in appropriate shipping containers;
- Completion of sampling records;
- Completion of chain-of-custody records; and
- Sample shipment via overnight courier.

Detailed groundwater sampling and sample handling procedures are presented in following sections.

4.1 Groundwater Sampling Locations

Groundwater samples will be collected from the 10 wells shown in Figure 10.1 of the EE/CA, using either a disposable bailer or a thoroughly decontaminated peristaltic pump with new, dedicated flexible tubing.

4.2 Preparation for Sampling

All equipment to be used for sampling will be assembled and properly cleaned and calibrated (if required) prior to the beginning of the sampling event. In addition, all recordkeeping materials will be gathered prior to leaving the office. A brief organizational meeting will be held to ensure proper communication between project management staff and field personnel.

4.3 Equipment Decontamination

All portions of sampling and test equipment that will contact the sample will be thoroughly cleaned before each use. This equipment may include Teflon® bailers, water-level probe and cable, oil/water interface probe and cable, test equipment for onsite use, and other equipment or portions thereof which will contact the samples. Based on the chemical constituents present at Pumphouse #2, the following decontamination protocol will be used:

- Clean with potable water and phosphate-free laboratory detergent (Liquinox® or equivalent);
- Rinse with potable water;
- Rinse with distilled or deionized water;
- Rinse with reagent-grade isopropanol;
- Rinse with distilled or deionized water; and
- Air dry the equipment prior to use.

All decontamination fluids will be temporarily placed in 55-gallon D.O.T. approved containers. Final disposal will be the responsibility of Malmstrom AFB and determined based on laboratory analytical results.

Any deviations from these procedures will be documented in the field scientist's field notebook and on the groundwater sampling form. If pre-cleaned dedicated sampling equipment is used, the decontamination protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory and therefore will not need to be cleaned in the field. Equipment field blanks and equipment rinseate samples will be collected to assure that all containers and field equipment are free of contamination.

4.4 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturer's specifications prior to field use. This applies to equipment used for onsite chemical measurements such as pH, electrical conductivity, and temperature.

4.5 Sampling Procedures

Special care will be taken to prevent contamination of the groundwater and extracted samples. The two primary ways in which sample contamination can occur are through contact with improperly cleaned equipment and by cross-contamination through insufficient decontamination of equipment between wells. To prevent such contamination, the peristaltic pump and water level probe and cable used to determine static water levels and well total depth will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures presented in section 4.3. In addition to the use of properly cleaned equipment, a clean pair of new, disposable nitrile gloves will be worn each time a different well is sampled. New, clean tubing will be used for the peristaltic pump for each well sampled. Wells will be sampled sequentially from areas suspected to be least contaminated to areas suspected to be more contaminated. Plastic will be placed around each of the wells to be sampled and sampling equipment will not be allowed to come in contact with the ground surface at any time during the sampling event.

The following paragraphs present the procedures that comprise groundwater sample acquisition from all groundwater sampling locations. These activities will be performed in the same order as presented below. Exceptions to this procedure will be noted in the Parsons ES field scientist's field notebook.

4.5.1 Preparation of Location

Prior to starting the sampling procedure, the area around the well will be cleared of foreign materials, such as brush, rocks, and debris. These procedures will prevent sampling equipment from inadvertently contacting debris around the monitoring well. New, clean plastic (4 to 6 mil) we be placed around the well to prevent the contamination of both the ground surface and any equipment that may come into contact with the ground surface.

4.5.2 Water Level and Total Depth Measurements

Prior to removing any water from the well the static water level will be measured. An electrical water level probe will be used to measure the depth to groundwater below the datum to the nearest 0.01 foot. If the total depth of the well is not known or is suspected to be inaccurate, total well depth will be measured by slowly lowering the water level probe to the bottom of the well. Total well depth will be measured to the nearest 0.01 foot. Total depth will only be measured when absolutely necessary to minimize the amount of sediment disturbance in the well. Based on water level and total depth information, the volume of water to be purged from the well can be calculated.

4.5.3 Well Purging

The volume of water contained within the well casing at the time of sampling will be calculated, and three times the calculated volume will be removed from the well. Whenever practical, the purge rate will not exceed the recharge rate of the well to minimize groundwater draw down. This may not be possible in the slower recharging wells at the site. If a well is purged dry, it will be sampled as soon as enough groundwater to allow sampling reenters the well. Sample compositing, or sampling over a lengthy period by accumulating small volumes of water at different times to eventually obtain a sample of sufficient volume, will not be allowed. Care will also be taken to minimize the disturbance to the water column in the well. If a bailer is used, it will be lowered and removed from the water slowly. If a pump is used, the flow rate will be lowered to match the recharge rate of the well. The pH, temperature, dissolved oxygen, and specific conductivity will be monitored at the beginning of the purge and after each well volume. Purging will continue until these parameters have stabilized to within 10 percent among three consecutive readings. If a peristaltic pump is used for well purging, a flow cell may be used to take continuous measurements of the purge parameters. Purging should stop after all parameters have stabilized over a 5 minute period. All purge water will be placed in 55-gallon containers and disposed of as described in section 4.3. Disposable PVC or Teflon® bailers or a peristaltic pump with new tubing will be used for well evacuation.

4.5.4 Sample Extraction

Either disposable, polyethylene bailers or a peristaltic pump with new tubing for each well will be used to extract groundwater samples from the well. Bailers will be used only for those wells with known or suspected free product to minimize the potential for sampling equipment contamination. Both types of extraction equipment will be lowered into the water gently to prevent splashing and extracted gently to prevent creation of an excessive vacuum in the well. The sample will be transferred directly to the appropriate sample container. The water sample will be transferred from the bottom of the bailer using a bottom emptying device to allow a controlled flow into the sample container. Water from the peristaltic pump can be directly discharged into the sample container. The water should be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample. Sample containers for VOC analysis will be filled at approximately 200 milliliters per minute (mL/min) and all other sample collection rates will not exceed 400 mL/min. Volatile samples will be collected first, followed by any other analytical samples. Samples for field parameter analysis will be collected last.

Unless other instructions are given by the analytical laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be placed into the 55-gallon containers used for well purge waters and disposed of as described in section 4.3.

4.6 Onsite Chemical Parameter Measurement

Dissolved oxygen (DO) measurements will be taken onsite using a meter with a downhole oxygen sensor. The DO meter will be decontaminated, prior to each use, following decontamination procedures described in section 4.3. DO measurements will

be taken immediately following groundwater sample acquisition. Where DO measurements will be taken in wells which have not been sampled, the well will be purged until DO measurements stabilize.

Because the pH, temperature, specific conductance, redox potential, and other chemical parameters of a groundwater sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made in a clean, plastic, flow-through cell and the measured values will be recorded in the groundwater sampling record. Tables 10.1 and 10.2 in the body of the EE/CA lists the chemical analytical protocol for groundwater samples.

4.7 Sample Handling

This section describes the handling of samples from the time of sampling until the samples arrive at the laboratory.

4.7.1 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the laboratory. The sample containers will be filled as described in section 4.5.4, and the container lids will be tightly closed. Container lids will not be removed at any time prior to sample collection. The sample label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (groundwater, surface water, etc.);
- Sampling date;
- Sampling time;
- Preservatives added; and
- Sample collector's initials.

4.7.2 Sample Preservation

The laboratory will add any necessary chemical preservatives prior to shipping the containers to the site. Samples will be properly prepared for transportation to the laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of 4 degrees centigrade (°C).

4.7.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to Evergreen Analytical, Inc. of Wheat Ridge, Colorado, the AFCEE-approved laboratory for this demonstration. Samples will be shipped priority overnight via Federal Express®. The following packaging and labeling procedures will be followed:

- Package sample so that it will not leak, spill, or vaporize from its container;
- Label shipping container with:
  - Sample collector's name, address, and telephone number;
  - Laboratory's name, address, and telephone number;
  - Description of sample;
  - Quantity of sample; and
  - Date of shipment.

The packaged samples will be delivered to the laboratory as soon as possible after sample acquisition.

4.7.4 Chain-of-Custody Control

After the samples have been collected, chain-of-custody procedures will be followed to establish a written record of sample handling and movement between the sampling site and the laboratory. Each shipping container will have a chain-of-custody form completed in triplicate by the sampling personnel. One copy of this form will be kept by the sampling contractor after sample delivery to the analytical laboratory, and the other two copies will be retained at the laboratory. One of the laboratory copies will become a part of the permanent record for the sample and will be returned with the sample analytical results. The chain-of-custody will contain the following information:

- Sample identification number;
- Sample collector's printed name and signature;
- Date and time of collection;
- Place and address of collection;
- Sample matrix;
- Chemical preservatives added;
- Analyses requested;
- Signatures of individuals involved in the chain of possession; and

- Inclusive dates of possession.

The original chain-of-custody documentation will be placed inside the shipping container so that it will be immediately apparent to the laboratory personnel receiving the container, but will not be damaged or lost during transport. The shipping container will be sealed with chain-of-custody labels so that it will be obvious if the seal has been tampered with or broken.

4.7.5 Sampling Records

In order to provide complete documentation of the sampling event, detailed records will be maintained by the Parsons ES field hydrogeologist. At a minimum, these records will include the following information:

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;
- Sampling method;
- Field observations of
  - Sample appearance,
  - Sample odor;
- Weather conditions;
- Water level prior to purging;
- Total well depth;
- Purge volume;
- Water level after purging;
- Well condition;
- Sampler's identification;
- Field measurements of pH, temperature, and specific conductivity; and
- Any other relevant information.

Groundwater sampling activities will be recorded on a groundwater sampling form. Figure 5 shows an example of the groundwater sampling record.

Figure 5
Ground Water Sampling Record

SAMPLING LOCATION _____
SAMPLING DATE(S)_____

GROUND WATER SAMPLING RECORD - MONITORING WELL _____
(number)

REASON FOR SAMPLING: [ ] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: _____, 19___ _____ a.m./p.m.
SAMPLE COLLECTED BY: _____ of _____
WEATHER:_____
DATUM FOR WATER DEPTH MEASUREMENT (Describe):_____
_____
_____
_____

MONITORING WELL CONDITION:

[ ] LOCKED: [ ] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS:_____
INNER PVC CASING CONDITION IS:_____
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):_____
_____
_____

Check-off

1 [ ] EQUIPMENT CLEANED BEFORE USE WITH_____
Items Cleaned (List):_____
_____
_____

2 [ ] WATER DEPTH _____FT. BELOW DATUM
Measured with:_____

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:_____
Odor:_____
Other Comments:_____

4 [ ] WELL EVACUATION:
Method:_____
Volume Removed:_____
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:_____
Other comments:_____

Figure 5 (cont.)
Ground Water Sampling Record

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of: _____
[ ] Pump, type: _____
[ ] Other, describe: _____
_____

Sample obtained is [ ] GRAB; [ ] COMPOSITE SAMPLE

6 [ ] ON-SITE MEASUREMENTS:

Temp: _____ ° _____ Measured with: _____
pH: _____ Measured with: _____
Conductivity: _____ Measured with: _____
Other: _____
_____

7 [ ] SAMPLE CONTAINERS (material, number, size): _____
_____
_____
_____

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

[ ] Preservatives added:

Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [ ] CONTAINER HANDLING:

[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS: _____
_____
_____
_____
_____

4.8 Laboratory Analyses

Laboratory analyses will be performed on all groundwater samples and the required QA/QC samples (see section 4.9). The analytical methods and detection limit requirements for this sampling event are listed in Tables 10.1 and 10.2 in the body of the EE/CA. Evergreen Analytical Laboratories of Wheat Ridge, CO, will be performing laboratory analytical analysis for the 1996 annual sampling event.

Prior to sampling, arrangements will be made with the laboratory to provide a sufficient number of appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with laboratory protocol.

Laboratory personnel will specify any additional QC samples and prepare bottles for all samples. For samples requiring chemical preservation, preservatives will be added to containers by the laboratory prior to shipping. Shipping containers, ice chests with adequate padding, and cooling media will be sent by the laboratory to the site. Sampling personnel will fill the sample containers and return the samples to the laboratory.

4.9 Quality Assurance/Quality Control Procedures and Sampling

Field QA/QC samples for groundwater sampling will include collection of field duplicates, equipment rinseate samples, and field and trip blanks. QA/QC procedures will include decontamination of the water level probe, use of analyte-appropriate containers, and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the analytical laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., groundwater), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used, and water sample containers will be packaged in coolers with ice to maintain a temperature of 4°C.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature.

Groundwater QA/QC sampling frequency will be 10 percent or one sample for every ten well sampled. In the event that less than ten wells will be sampled in an event, a minimum of one sample will be collected. This ten percent frequency applies to equipment rinseate samples and field duplicates. One decontamination water sample and one field blank will be collected per sampling event. One trip blank will be sent with each sample shipment. The procedures for the collection of field QA/QC samples are described in section 2. The laboratory should plan to conduct one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested. A more comprehensive discussion of QA/QC requirements is presented in the QAPP (Appendix I).

5 FIELD QUALITY ASSURANCE/QUALITY CONTROL SAMPLES

As a check on field sampling, QA/QC samples, including trip blanks, field blanks, decontamination water blanks, equipment rinseate blanks, and field duplicates will be collected. Each type of QA/QC sample is described below.

5.1 Trip Blanks

A trip blank is defined as a sample bottle filled by the laboratory with analyte-free laboratory reagent-grade water, transported to the site, handled like a sample but not opened, and returned to the laboratory for analysis. One trip blank will accompany every cooler of environmental samples sent to the laboratory. Trip blanks are analyzed only for Method SW8020.

5.2 Decontamination Water Blank

A decontamination water blank is designed to check the purity of potable water used for equipment decontamination during the field operation. One decontamination water blank will be collected for each water source used during the field work. Decontamination water blanks are collected by filling the appropriate sample container directly from the potable water source. Decontamination water blanks are labeled, preserved, handled, and shipped in the same manner as an environmental water sample. The blank will be analyzed for the same analytes and parameters as the environmental samples.

5.3 Field Blanks

A field blank is designed to assess the effects of ambient field conditions on sample results. A field blank will consist of a sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for the same analytes and parameters as the environmental samples.

5.4 Equipment Rinseate Blanks

Equipment rinseate blanks will be collected from field equipment such as continuous core barrels. Equipment rinseate blanks are prepared by pouring distilled water over field equipment that has been decontaminated. The rinseate water is then collected, transferred to a sample bottle, and analyzed at the laboratory. The results of these sample analyses indicate how well the sampling equipment was decontaminated.

5.5 Field Duplicate Samples

A field duplicate is defined as two or more samples collected independently at the same sampling location during a single act of sampling. Soil samples are divided into two equal parts for analysis. Duplicates of water samples will be collected by filling additional sample containers at each duplicated sampling event.

Field duplicates will be indistinguishable from other samples by the laboratory. One complete sample set will be identified with a coded identifier, which will be in the

same format as other identifiers used with this matrix. Both the coded and actual sample identifiers will be recorded in the field notebook. The coded identifier will be used on the chain-of-custody forms.

APPENDIX I

QUALITY ASSURANCE PROJECT PLAN

TABLE OF CONTENTS

Page

1.0 MANAGEMENT SYSTEMS 1-1

1.1 General 1-1

1.2 Policy 1-2

1.3 Purpose 1-2

1.4 Scope 1-2

1.5 Organization and Responsibilities 1-2

1.6 Quality Assurance Program 1-3

1.7 Planning 1-3

1.8 Work Processes 1-5

1.8.1 Process Control 1-5

1.8.2 Work Procedures/Instructions 1-5

1.9 Personnel Training and Qualifications 1-5

1.10 Procurement of Items and Services 1-6

1.11 Records 1-7

1.11.1 Records Management 1-6

1.12 Computer Hardware and Software 1-6

1.12.1 Testing 1-7

1.12.2 Software Requirements 1-7

1.13 Measuring and Test Equipment 1-7

1.14 Assessment and Response 1-8

1.14.1 Management Assessments 1-8

1.14.2 Independent Assessment 1-9

1.15 Quality Improvement 1-10

2.0 SAMPLING AND LABORATORY QUALITY ASSURANCE 2-1

2.1 Planning and Scoping 2-1

2-2 Goals for Sampling and Laboratory QA 2-1

TABLE OF CONTENTS (continued)

2.3 Sampling Procedures 2-1
2.3.1 Sampling Protocols 2-1
2.3.2 Field Operations 2-1
2.4 Existing Data Review 2-2
2.4.1 Site Background 2-2
2.4.2 Physical Setting 2-2
2.5 Design of Data Collection Operations 2-3
2.5.1 Data Handling Methods 2-3
2.5.2 Design Documents 2-4
2.6 Implementation of Planned Operations 2-4
2.6.1 Field Quality Assurance/Quality Control Samples 2-4
2.6.1.1 Trip Blanks 2-4
2.6.1.2 Decontamination Water Blank 2-4
2.6.1.3 Field Blanks 2-4
2.6.1.4 Equipment Rinseate Blanks 2-5
2.6.1.5 Field Duplicate Samples 2-5
2.6.2 Sample Control 2-5
2.7 Data Quality Objectives 2-5
2.7.1 Analytical Data Quality Levels 2-6
2.7.2 Concentrations of Concern 2-7
2.7.3 Project Quality Assurance Objectives 2-7
2.8 Definition of Criteria 2-8
2.8.1 Accuracy 2-8
2.8.2 Precision 2-8
2.8.3 Completeness 2-9
2.8.4 Comparability 2-9
2.8.5 Representativeness 2-10
2.9 Laboratory Sample Handling 2-10
2.9.1 Sample Custody 2-10
2.9.2 Sample Handling 2-11
2.9.3 Sample Custody Records 2-12

TABLE OF CONTENTS (continued)

2.10 Analytical Methods 2-13
2.10.1 Identification of Methods 2-13
2.10.2 Detection and Quantitation Limits 2-13
2.10.3 Laboratory Organic Data Reporting Flags 2-14
2.10.4 Laboratory Inorganic Data Reporting Flags 2-14
2.10.5 Sampling and Laboratory Calibration Methods 2-15
2.11 Data Management 2-15
2.12 Data Deliverables 2-16
2.12.1.1 Data Validation 2-16
2.12.1.2 Reporting 2-17
2.13 Laboratory Quality Control 2-18
2.13.1 Method Blanks 2-18
2.13.2 Bottle Blanks 2-18
2.13.3 Surrogate Spike Analyses 2-18
2.13.4 Matrix Spike Analyses 2-19
2.13.5 Second Column Confirmation 2-20
2.13.6 Quality Control and Audit 2-20
2.13.7 Control Limits 2-20
2.14 Acceptance Criteria for the Control Limits 2-20
2.15 Corrective Action 2-21
2.15.1 Response to Out-of-Control Events 2-22
2.15.2 Reestablishment of Control 2-23
2.15.3 Documentation 2-23
2.16 Quality Assurance Reports 2-23
2.16.1 Reporting Procedure 2-23
2.16.2 Report Content 2-23
2.17 Final Sample Disposition 2-24
2.18 Storage of Data 2-24
2.19 Preventive Maintenance 2-24
2.19.1 Procedures 2-24
2.19.2 Schedules 2-24

2.19.3 Spare Parts 2-24
3.0 DATA INTERPRETATION AND ANALYSIS 3-1
3.1 Remedial Goals 3-1
3.2 Bioplume II Model 3-1
3.3 Risk Determination 3-3
3.4 Development of an Appropriate Remedial Approach 3-3
3.5 Evaluation of Source Removal/Risk Reduction Options 3-3
3.6 Selection of a Recommended Approach 3-4
3.7 Long-Term Monitoring Plan 3-5
3.8 Regulatory Coordination Strategy 3-5
4.0 DESIGN, CONSTRUCTION, AND OPERATION OF ENVIRONMENTAL TECHNOLOGY 4-1
4.1 Planning 4-1
4.2 Design of Systems 4-1
4.2.1 Readiness Review 4-3
4.3 Construction/Fabrication of Systems and Components 4-3
4.3.1 Inspections and Tests 4-3
4.3.2 Control of Items 4-3
4.4 Operation of Systems 4-3
4.4.1 Status Indicators 4-4
4.4.2 Inspection and Test Control 4-4
4.5 Inspection and Acceptance 4-4
4.5.1 Inspection 4-4
4.5.2 Acceptance Testing 4-4

SECTION 1

MANAGEMENT SYSTEMS

1.1 General

The Quality Assurance Program Plan (QAPP) for the field test of the risk-based approach for the remediation of eight sites has been prepared to present the organization, objectives, functional activities, and specific quality assurance (QA) and quality control (QC) activities associated with Parsons Engineering Science's (Parsons ES) work under Contract F41624-93-C-8044, "Risk-Based Approach to Fuel Spill Remediation." This multi-site initiative is sponsored by the Air Force Center for Environmental Excellence (AFCEE) at Brooks Air Force Base (AFB), Texas. This QAPP incorporates the criteria established by the American National Standards Institute/American Society for Environmental Programs (ANSI/ASQC E-4-1994), in *"Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs,"* July 1994, (Draft) and the guidelines established by the US Environmental Protection Agency (EPA) in *"Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual"* [Parts A, B, and C] (EPA, 1989a, 1991a, and 1991b).

The eight AFCEE sites selected for remediation using the risk-based approach are as follows:

- Carswell AFB - ST-14A,
- Carswell AFB - ST-14B,
- Wurtsmith AFB - OT-42,
- Wurtsmith AFB - KC-135,
- Myrtle Beach AFB, - MOGAS Storage,
- Ellsworth AFB-Area D,
- Malmstrom AFB - Pumphouse #2, and
- Charleston AFB - ST-27.

This QAPP describes the specific sampling, sample handling and storage, custody, and field and laboratory measurement and analysis protocols which will be followed at the aforementioned sites. It also describes the incorporation of sampling results into a

risk-based approach to determine the best remediation alternative for each of the eight sites.

The EPA requires that all environmental monitoring and measurement efforts mandated or supported by EPA participation include a centrally managed QA program (EPA, 1980). Any party generating data under such a program has the responsibility to implement minimum procedures to assure that the precision, accuracy, completeness, comparability, and representativeness of its data are known and documented. To ensure that this responsibility is met uniformly, each party must prepare a written QAPP covering each project it is to perform. This QAPP has been prepared to satisfy these requirements.

1.2 POLICY

This QAPP sets forth Parsons Engineering Science, Inc.'s commitment to quality in all activities, products, and services. This QAPP is designed to assure that projects and activities managed and conducted by Parsons ES are accomplished in an approved, prescribed manner by trained and competent staff.

Parsons ES management, assisted by the Quality Assurance (QA) staff, is responsible for achievement and documentation of product or service quality. The QA staff is charged with verifying the achievement of quality as well as providing assistance to the project organization in developing and implementing viable QA methods.

1.3 PURPOSE

This document establishes the QA requirements for Parsons ES and assigns responsibility for ensuring that project objectives will be achieved. It consists of the QA Program requirements which are responsive to ANSI/ASQC E4-1994(Draft).

1.4 SCOPE

The requirements of this document apply to Parsons ES and its laboratories. Quality requirements specified in this document are tailored to the needs of the AFCEE risk-based remediation demonstration program. Parsons ES-wide QA programs that supplement project-specific requirements are also briefly discussed.

1.5 Organization and Responsibilities

Parsons ES is committed to performing quality work for our clients. This is accomplished as a company and as individuals by completely understanding the requirements to be met and meeting these requirements the first time. Quality is as important as cost and schedule, and therefore receives an equal amount of management attention and effort.

The primary responsibility for meeting the quality objectives of a project remains with the operational personnel. They will perform their work in accordance with the standards of their profession, accepted practices, and applicable regulations. In the absence of specific guidelines, they will follow best scientific or technical judgment.

Management will regularly assess and document the adequacy of the quality system. The management of Parsons ES defines the objectives of the assessment process and determines the measures for ensuring that the quality program has been established, documented, and implemented effectively. The Parsons ES QA/QC manager (John Giammona) will have primary responsibility for reviewing the field and analytical data, and for assuring that the work is performed in accordance with this QAPP.

To ensure that each of the eight remediation sites is managed using the Total Quality (TQ) Methodology, regularly scheduled briefings will be conducted with both regulatory and AFCEE personnel. These briefings will aid in defining project goals and scope as well as redefining objectives, as needed, and addressing current issues as the multi-site remediation project progresses. These meetings will allow for the coordination of field work, sampling and analysis, and feedback to Parsons ES regarding what risks are indicated by the data. The meetings will be an integral part of defining a site-specific risk-based approach.

The responsible officers for the QAPP implementation are as follows:

John Giammona -- QA/QC Manager

Doug Downey -- Project Manager

Leigh Benson -- Deputy Project Manager

1.6 Quality Assurance Program

This QAPP is an integral part of the Parsons ES Quality Improvement Program (QIP). It constitutes a philosophy of and commitment to continuous improvement of Parsons ES products and services, and total satisfaction of internal and external customers. It is through Parsons ES employees, using teamwork, establishing measurable goals, and ensuring the attainment of these goals, that quality is achieved. This program has the endorsement of Parsons ES Responsible Managers who have the authority, responsibility, and accountability to establish management systems consistent with the requirements of this document and to ensure successful implementation.

Environmental compliance programs meet the applicable requirements of the Parsons ES QA Program. At a minimum, the environmental program controls apply to procurement, document/record control, sampling, analysis, data verification/validation, audits, inspections, calibration of equipment, nonconformance/ corrective action control, control of items and services, and training activities.

1.7 PLANNING

The Parsons ES QA program establishes a systematic planning process to:

- Identify the customer(s), their needs, and their expectations of the work to be performed;
- Identify the technical and quality goals required to meet the needs and expectations of the customer;
- Translate the technical and quality goals into specifications that will produce the desired result;
- Consider any cost and schedule constraints within which project activities are required to be performed; and
- Identify acceptance criteria by which the results will be evaluated and customer satisfaction will be determined.

The development of a QA plan represents Parsons ES's decision to carry out a specific project, and represents the detailed and systematic examination of all factors involved in the performance of a project. The size and scope of a project determine the complexity of a plan. However, no matter what the project size or scope, a good plan:

- Is based on facts and valid assumptions;
- Provides for the necessary organization and assigns responsibilities;
- Delegates authority consistent with control and/or responsibility;
- Provides for the use of existing resources;
- Provides for personnel, material, training, etc.;
- Is simple;
- Is flexible;
- Provides for contingencies;
- Is coordinated;
- Provides for control (lines of communication); and
- Provides for successful completion of the project.

1.8 WORK PROCESSES

1.8.1 Process Control

The Parsons ES QA Program promotes the concept that quality is integrated into work processes through each employee who has been properly trained, motivated, and empowered and who is knowledgeable of the procedures, instructions, drawings, specifications, and other related administrative and technical documents that control the work. Work process control is applicable to engineering, procurement, material control, installation, modification, construction, maintenance, operations, testing, inspection, hazardous waste management and transportation, environmental characterization and restoration, document control and management, and research and development. Processes are fully integrated with the federal, state, industry, and client requirements.

1.8.2 Work Procedures/Instructions

The Project Manager (Doug Downey) ensures that activities that affect quality are planned, authorized, prescribed, and accomplished by clear and concise management systems. The degree to which procedures are detailed and used is based on the importance of the item, activity, or service to the environment, public, safety, cost, or schedule. Activities identified in this QA Program will be incorporated in approved procedures as appropriate.

Procedures will be developed, reviewed, approved, and validated by qualified personnel and designated as controlled documents before release for use. All Parsons ES personnel are responsible for complying with approved work process procedures and instructions.

1.9 Personnel Training and Qualifications

Personnel involved in activities affecting the quality of operations will be trained and, where applicable, certified to perform assigned duties.

Development of training programs and conduct of training are the responsibilities of line management. Training programs are conducted according to appropriate training policies and are designed so that the employee:

- Possesses adequate knowledge of the processes and procedures needed to conduct the assigned tasks;
- Has a working knowledge of the tools required;

- Has an understanding of acceptance and rejection criteria of the work process, systems terminology, and reasons for specific controls so that process variability is maintained at a minimum;

- Has an acceptable understanding of the safety conditions of the work tasks;

- Knows the consequences of inadequate quality attainment; and

- Is provided training for continued maintenance of job proficiency and process improvement.

Training procedures establish requirements for the conduct of training and maintenance of training records. Training is conducted by qualified and knowledgeable instructors. Personnel performing work requiring special skills are trained and qualified before performing the work. Proficiency is demonstrated by testing, on-the-job demonstration, or classroom attendance as determined by the Project Manager, instructor, or the requirements of established standards or regulations. Continued proficiency is evaluated, maintained, and documented. Management development programs provide training to enhance the development of professional skills in management, interpersonal relationships, and communications.

1.10 PROCUREMENT OF ITEMS AND SERVICES

The Parsons ES QA Program establishes a procurement process designed to ensure that procured items and services comply with documented requirements and that they perform acceptably in service.

Procurement technical specifications are reviewed and approved to ensure the inclusion of applicable codes, standards, tests, acceptance standards, quality requirements, and the identification of records to be maintained or submitted.

Procurement and engineering procedures establish requirements to ensure that the appropriate elements of the Quality Program have been incorporated into procurement documents, based on the level of quality associated with the procured item or service.

Commercial-grade item procurement documents incorporate requirements to ensure that identified critical characteristics have been satisfied. Changes to technical specifications receive the same review and approval as the original document.

The process of tagging and segregating materials provides assurance that only acceptable items are issued for use. Before releasing an item for critical installation or use, documentation is available to support the acceptance of the item based on compliance with the required technical requirements, testing, documentation, and closure of all applicable nonconforming conditions.

Significant items of nonconformance identified with supplier-furnished items or services, whether known or unknown by the supplier, are processed according to the actions and responsibilities necessary to control the procurement of items and services.

1.11 RECORDS

The Parsons ES QA Program requires that the scope of the quality records and project records to be retained are identified within QA plans. These records, at a minimum, apply to design, procurement, receipt inspection, assessments, deficiency documents, material control, installation, maintenance, testing, modifications, operations, environmental monitoring, and hazardous waste management and transportation. Special procedural controls document the generation, collection, maintenance, and control of safeguarded records. Procedures establish controls for the physical protection, preservation, traceability, and retrievability of records.

Project records generated under this program to be retained by Parsons ES shall be maintained in a central, dedicated file system. Quality and project records to be retained by laboratories shall be maintained according to requirements specified by Parsons ES in subcontract documents.

1.12 COMPUTER HARDWARE AND SOFTWARE

Computer hardware and software configurations include, but are not limited to:

- Experimental design,
- Design analysis,
- Modeling of environmental processes and conditions,
- Operation or process control of environmental technology systems, and
- Data bases containing environmental data.

1.12.1 Testing

The Parsons ES QA program requires that computer hardware and software configurations are tested prior to actual use, and that the results are documented and maintained. Changes to hardware and software configurations are assessed to determine the impact of the change on the technical and quality objectives of the projects; appropriate actions are then taken.

1.12.2 Software Requirements

The Parsons ES QA program ensures that computer software meets user requirements and conforms to all applicable consensus standards, or data management criteria. The Program Manager or designee establishes acceptance criteria for the use of commercially acquired software and program documentation. Reference guides and user manuals will be easily accessible to users.

Software developed specifically for the project will be developed using an approved software development methodology that considers the complete life-cycle aspects of the software. User-developed programs are independently validated, verified, and documented according to the intended use of the software. Changes to user-developed software will be assessed to determine the potential impact of the change on the performance of the software, and appropriate actions are then taken.

1.13 MEASURING AND TEST EQUIPMENT

The Parsons ES QA Program for control of Measuring and Test Equipment (M&TE) has been established to ensure that the selected M&TE is the proper type, range, accuracy, and tolerance for the intended use. Tools, gauges, instruments, and other M&TE used for activities affecting data quality (such as sampling, data gathering, fabrication, and construction) will be calibrated at specified periods to maintain accuracy within specified limits.

Equipment found to be unsatisfactory for the prescribed use will be recalibrated and certified within tolerance before being used again. The validity of measurements, analyses, and tests performed with out-of-calibration equipment will be evaluated, and such measurements and tests will be repeated, as required, using calibrated equipment. Out-of-calibration equipment or devices will be tagged or segregated and withheld from use until they have been recalibrated. If any equipment is consistently out of calibration, it will be repaired or replaced. Additional calibration will be performed whenever the accuracy of the equipment is suspect. Calibration and control measures are not required for standard commercial devices such as rulers, tape measures, or levels.

Calibrations will be conducted using certified equipment and/or standards with known valid relationships to nationally recognized performance standards. If no such nationally recognized standards exist, the alternative basis for the calibration will be documented. Documentation of calibration for all tools, gauges, and instruments will be maintained and will be traceable to the item.

1.14 ASSESSMENT and Response

1.14.1 Management Assessments

Parsons ES management is committed assessing the success or lack of success in realizing office, division, or department objectives. The assessments are conducted by evaluating the performance of the QIP teams and the effectiveness of the TQM program, in addition to evaluating QA Status Reports, audit reports, surveillance reports, and corrective action status reports. At a minimum, activities are assessed to ensure that:

- The mission goals and objectives are clearly identified, communicated, and understood by those responsible for mission success;
- The requirements for internal and external customer satisfaction are understood and work processes for continuous improvements are routinely evaluated;
- The empowerment and training of employees is emphasized so that the effective use of resources to maximize quality and reduce process variability and costs is a part of the management system;
- Evaluations of trend analyses, lessons learned, performance indicator results, and other information gathered from the quality improvement program are analyzed and improvements are initiated as required;
- Required management systems are in place and effective in achieving mission objectives according to quality, environmental, and safety expectations; and
- focus is being given to methods of obtaining continuous improvement in the quality system and identifying barriers to achieving established missions and objectives.

Management has the responsibility and will be directly involved in conducting assessments, evaluating assessment results, ensuring effective problem evaluations, and taking corrective action. Senior managers routinely monitor the assessment activities of their subordinate managers and supervisors and conduct reviews to determine the reasons for success or failure in the achievement of objectives. Management assessments will be conducted by individuals with the necessary technical skills required to make effective conclusions about system performance. Line managers and supervisors have the responsibility to "walk their spaces" and personally take part in monitoring and assessing activities.

1.14.2 Independent Assessment

The Parsons ES QA Program provides for the development and implementation of a documented program by which independent audits, surveillances, and other assessments are conducted of all projects and departments, with emphasis on quality improvement.

Audits, surveillances, and other assessments are scheduled in a coordinated manner. The schedule is based on corporate, client, and regulatory requirements; trend data of an activity; complexity of an activity; history of compliance; and importance to safety and associated consequences as related to the public, employees, and the environment. Audit schedules are prepared with sufficient flexibility to permit unscheduled audits to take place for activities of questionable performance.

The audit program documents audit planning, qualification of audit personnel, audit performance, reporting, problem identification, corrective action, follow-up, and maintenance of audit records. Audit planning and the audit criteria place emphasis not only on compliance, but also on ensuring that performance excellence has been accomplished through work processes. Audits are conducted to measure conformance to established practices. Audits are accomplished by monitoring actual work performance, evaluating if work practices and procedures are adequate and conducive to an acceptable end product; identifying substandard practices; and providing recommendations for improvement. Audits are used as a management tool to verify the implementation and adequacy of the approved management systems in place.

Audits are conducted with a no-fault attitude toward identifying problems and in a spirit of helping to achieve excellence through problem identification and corrective action. The audit plan is directed toward the requirements of the documented quality program and not toward subjective interpretation of codes and standards. The audit process provides for reporting observations in addition to audit findings. Observations identify areas that merit improvement and do not require a response from the managers of the organizations being evaluated.

Results of audits, surveillances, and assessments are reviewed with the management of the evaluated organization at the completion of the activity, and followed up with a documented report. Findings identified during an audit or surveillance are formally tracked to closure. Unacceptable findings or untimely responses are escalated to the management level necessary to obtain satisfactory corrective action.

Management response to an audit finding must:

- Determine extent of reported condition;
- Determine root cause;

- Identify corrective action;
- Implement action to prevent recurrence;
- If appropriate, enter corrective actions into program/project lessons learned; and control the corrective action in accordance with existing QA and QIP procedures.

Technically qualified personnel validate the response to audit findings and verify the acceptability of the responses on a selected basis.

Personnel performing independent assessments are technically knowledgeable and focus on improving the quality of the process being assessed. They do not have direct responsibility in the assessment area of work.

1.15 Quality Improvement

All Parsons ES employees are trained in TQM processes through the QIP. The Parsons ES QIP endorses and promotes a no-fault environment in which all personnel have the freedom and are expected to identify nonconforming items, activities, and procedures without fear of reprisal or recrimination. Personnel are encouraged to identify and communicate methodologies for improving quality and restricting process methods that would lead to unacceptable performance.

Items, processes, and services that do not meet established criteria and/or predetermined quality requirements are identified and documented, analyzed, disposed of, corrected, and validated. Causal factors are evaluated to establish a root cause condition, based on the importance to safety and the significance of the identified problem.

Responsible Managers provide senior managers with routine reports that document the results of analyses made of quality improvement data. The reports may address results of trend analyses, lessons learned, performance indicator evaluations, precursors to possible problems, corrective actions proposed, and any perceived barriers to improvement. Responsible managers ensure that resources are available to provide for timely resolution and correction of identified problems. When deposition cannot be resolved, the problem is escalated to a higher level of management for resolution and the process is documented.

Nonconforming items and activities are identified and controlled to prevent inadvertent installation, testing, or use. Any use-as-is dispositions of nonconforming items receive a documented justification by the organization that conducted the original review or by a designated qualified organization. Repaired, reworked, or replacement

items are installed and tested according to the original requirements or technically designated alternatives.

Personnel who analyze or dispose of nonconforming items and activities are technically qualified and have pertinent background data available for their information and use.

SECTION 2

SAMPLING AND LABORATORY QUALITY ASSURANCE

2.1 PLANNING AND SCOPING

The generation, acquisition, and use of environmental data will be planned and documented. The type and quality of environmental data needed are identified using a systematic planning process related to the intended use of the data. Project-specific planning involves key users and customers of the data, as well as the technical staff responsible for obtaining, analyzing, and evaluating the data. Results of planning activities are subject to review for conformance to technical and quality expectations.

2.2 Goals For sampling and laboratory qa

The overall or project precision of measurement data is a mixture of sampling and analytical factors. Analytical precision is much easier to control and quantify than sampling precision. Accuracy measures the bias in a measurement system and is difficult to measure for the entire data collection activity. Sources of error are the sampling process, field contamination, preservation, handling, sample matrix, sample preparation, and analytical techniques. Sampling accuracy may be assessed by evaluating results of field/trip blanks; analytical accuracy may be assessed through use of known and unknown QC samples and matrix spikes.

2.3 Sampling Procedures

2.3.1 Sampling Protocols

Detailed sampling protocols will be provided on a site-by-site basis depending on the data required to support a risk-based remediation. Appendix H of each EE/CA, RAP, or CMS will include a brief description of the sampling protocols for each of the media of interest - soil gas, soil flux, soil, ground water, and surface water, as appropriate.

2.3.2 Field Operations

Field operations include field sampling procedures, QC sample collection, sample handling, sample custody, and sample analyses summaries. A detailed discussion of the procedures used to document, establish, and maintain custody of field samples is presented in each EE/CA, RAP, or CMS prepared under this program. Additionally, these requirements are set forth in the laboratory subcontract document. Parsons ES sampling personnel must complete all proper forms and documents for each sample taken. After collection, containerization, and documentation, samples will be maintained under the custody of field team members until relinquished to the overnight

courier service. The sample shipment container will not be unsealed until the laboratory receives custody and breaks the sample seal.

2.4 existing data review

Existing site-specific data will be used initially to describe the physical characteristics of environmental media and the nature and extent of contamination at each of the eight sites. Review of available site data will aid in defining additional site characterization data necessary to fill existing data gaps, support quantitative modeling efforts, develop long-term risk-based cleanup levels, and evaluate, select, and implement the most cost-effective remedial alternative for the site.

2.4.1 Site Background

A detailed description of site background is necessary to support additional site characterization needs and to quantitatively evaluate remedial options. Site-specific information to be included is geographic site location and corresponding map, historical and present site use, known petroleum-based product usage and storage areas, and information regarding when contamination was first detected at the site. Any prior site investigation work relevant to this remediation project will also be solicited and incorporated as appropriate.

2.4.2 Physical Setting

Data from previous site characterization efforts will be collected and used to define the physical setting at each site. Both site topography and surface hydrology data will be reviewed and used as necessary. Historical flow rates from nearby/impacted waterways, surface water, and surface elevation ranges will be noted. In addition, surficial soil permeability will also be included to aid in determining the risk of contaminant transport/migration in this surficial medium for health-based risk calculations.

Site geology and hydrogeology data generated from previous investigations will also be collected to aid in the overall determination of the fate and transport of the contaminants in a known geological stratum. Historical flow rates and direction of water flow will be included to aid in defining potential contaminant pathways which may pose a threat to human health and the environment. Maps of the approximate ground water surface will be included as visual aids.

Any information which may contribute to a preliminary determination of the nature and extent of contamination will be included. Soil gas data, soil data, surface water data, and ground water data will be used to determine the probable extent of contamination. In addition, findings of free-phase product will also be denoted. The aforementioned sampling information will be mapped out on a site-specific map noting both depths and concentrations of contaminants found to date and any suspected plumes of contaminants in the subsurface region. This information is critical to defining additional data needs.

2.5 DESIGN OF DATA COLLECTION OPERATIONS

This program consists of field tests of an innovative approach to remediation. Therefore, specific data will be necessary to supplement any existing data. Data collection is an important component of this effort. The design of data collection operations are defined, controlled, verified, and documented. The design process provides specifications for:

- Sample types, numbers, quantities, and sampling location requirements;
- Selection of testing methodology, including specific analytical instrumentation requirements;
- Requirements for field laboratory QA/QC activities;
- Sample handling, packaging, shipping, and custody requirements;
- Selection of analytical methods and quality performance expectations;
- Requirements and qualifications for sampling and analysis personnel;
- Selection of analytical facilities;
- Requirements for calibration and performance evaluation samples for analytical methods used;
- Assessments needed during the project;
- Data validation and verification methods;
- Techniques for assessing limitations on data use;
- Data reporting requirements;
- Waste disposal or minimization procedures; and
- Requirements for data security and archival.

Design of environmental and waste characterization data collection operations uses consensus-accepted experimental design techniques where possible, including the use of statistics. Key variables that determine or directly affect the quality of the results are identified and controlled, as appropriate, according to the design specifications.

2.5.1 Data Handling Methods

The data collection design process ensures that data are traceable to the procedures used to generate the data. Data transfer, reduction, verification, analysis and interpretation methods, and validation requirements will be determined and

documented. Restrictions on the use of any interim results will be identified and stated with the data in a manner that clearly defines the nature of the restriction and the specific data to which it applies.

2.5.2 Design Documents

Results of the design process are documented in the project-specific EE/CA, RAP, or CMS. Included are work plans, sampling and analysis plans, field sampling plans, instruction guides, standard operating procedures, and operating manuals. Changes to data collection designs or procedures, including field changes, are subject to the same review and approval protocols as the original documents.

2.6 IMPLEMENTATION OF PLANNED OPERATIONS

The environmental data operations are implemented to ensure that the type and quality of environmental data required and expected will be obtained. Deviations from the plan will be documented and reported to management.

Data management, including transmittal, storage, validation, assessment, processing, and retrieval, will be performed in accordance with approved instructions, methods, and procedures.

2.6.1 Field Quality Assurance/Quality Control Samples

As a check on field sampling, QA/QC samples, including trip blanks, field blanks, decontamination water blanks, equipment rinseate blanks, and field duplicates will be collected. Each type of QA/QC sample is described below.

2.6.1.1 Trip Blanks

A trip blank is defined as a sample bottle filled by the laboratory with analyte-free laboratory reagent-grade water, transported to the site, handled like a sample but not opened, and returned to the laboratory for analysis. One trip blank will accompany every cooler of ground water, surface water, and soil samples sent to the laboratory. Trip blanks are analyzed only for Method SW8020.

2.6.1.2 Decontamination Water Blank

A decontamination water blank is designed to check the purity of potable water used for equipment decontamination during the field operation. One decontamination water blank will be collected for each water source used during the field work. Decontamination water blanks are collected by filling the appropriate sample container directly from the potable water source. Decontamination water blanks are labeled, preserved, handled, and shipped in the same manner as an environmental water sample. The blank will be analyzed for the same analytes and parameters as the environmental samples.

2.6.1.3 Field Blanks

A field blank is designed to assess the effects of ambient field conditions on sample results. A field blank will consist of a sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for the same analytes and parameters as the environmental samples.

2.6.1.4 Equipment Rinseate Blanks

Equipment rinseate blanks will be collected from field equipment such as continuous core barrels and bailers. Equipment rinseate blanks are prepared by pouring distilled water over field equipment that has been decontaminated. The rinseate water is then collected, transferred to a sample bottle, and analyzed at the laboratory. The results of these sample analyses indicate how well the sampling equipment was decontaminated.

2.6.1.5 Field Duplicate Samples

A field duplicate is defined as two or more samples collected independently at the same sampling location during a single act of sampling. Soil samples are mixed and divided into two equal parts for analysis. Duplicates of water samples will be collected by filling additional sample containers at each duplicated sampling event.

In some instances, field duplicates will be indistinguishable from other samples by the laboratory. One complete sample set will be identified with a coded identifier, which will be in the same format as other identifiers used with this matrix. Both the coded and actual sample identifiers will be recorded in the field notebook. The coded identifier will be used on the chain-of-custody forms.

2.6.2 Sample Control

Handling, storage, cleaning, packaging, shipping, and preservation of field and laboratory samples are detailed in Section 2.9 of this QAPP and will be performed according to the required specifications, protocols, or procedures to prevent damage, loss, deterioration, artifacts, or interference. Sample chain-of-custody will be tracked and documented.

Inspections and acceptance testing of sampling, measurement, and analytical instrumentation or other measurement systems and their components will be performed to confirm that the items conform to the specified design.

Final acceptance will be performed by independent personnel. When acceptance criteria are not met, deficiencies are resolved and re-inspection will be performed as necessary.

2.7 Data Quality Objectives

The objective of these field tests is to determine the three-dimensional distribution of fuel hydrocarbon contamination at a site, to obtain the additional data needed to evaluate the effectiveness of specific remedial technologies including bioventing and intrinsic remediation to establish site-specific remediation goals that minimize or eliminate risks, and to implement the approved remedial design. This QAPP has been developed for use in conjunction with the sampling activities at United States Air Force bases and describes the QA/QC procedures and protocols that will be used during sample analysis. The QAPP will serve as a controlling mechanism during these investigations to ensure that a sufficient quantity of data is collected and that all data collected are valid, reliable, and defensible.

2.7.1 Analytical Data Quality Levels

Analytical data quality is specified in terms of levels defined in the data quality objectives (DQOs) guidance document (EPA, 1987a). Five analytical levels are defined:

Level I - Field screening using portable instruments, such as photoionization detectors. Results are often not compound-specific and not quantitative, but results are available in real-time. It is the least costly of the analytical options.

Level II - Field analyses using more sophisticated portable analytical instruments, such as a portable gas chromatograph (GC). In some cases, the instruments may be set up in an onsite mobile laboratory. A wide range in the quality of data may be attained, depending on the use of suitable calibration standards, reference materials, sample preparation equipment, and training of the operator. Results are available in real-time or within several hours.

Level III - Analyses performed in offsite laboratories. The laboratories may or may not use EPA Contract Laboratory Program (CLP) procedures, but do not usually use the stringent validation and documentation procedures required of CLP Level IV analyses.

Level IV - Analyses performed in offsite laboratories according to CLP protocols, which require stringent QA/QC procedures, documentation, and data validation.

Level V - Analyses by nonstandard methods performed in an offsite analytical laboratory.

For the risk-based remediation program, the following analytical levels will be used as indicated:

- Level I analytical methods will be used for air screening in worker breathing zones for health and safety purposes. Level I may also be used to screen

samples to select portions for further analysis. For example, soil sample headspace may be screened to determine if laboratory analyses are required.

- Level II analyses will be used to determine the presence of compounds supporting the intrinsic remediation option for ground water. These data will be used to evaluate the effectiveness of intrinsic remediation at the site.

- Level III analyses will be used to satisfy the requirements for site characterization, risk analysis, decision document preparation, and site cleanup prioritization. Level III data from previous site investigations will be combined with newly acquired data to evaluate the magnitude and extent of contamination at certain sites. Level III data acquired during this investigation will be used to evaluate remedial alternatives.

- Level IV analyses will not be required.

- Level V analyses will not be required.

An effective QA program addresses quality objectives for both sampling and laboratory methodologies. Parsons ES field QA efforts are aimed primarily at assuring that samples are representative of the conditions in the various environmental media at the time of sampling. Laboratory QA efforts are aimed primarily at assuring that analytical procedures provide sufficient accuracy and precision to quantify contaminant levels in environmental samples. The laboratory will also ensure that analyzed portions are representative of each sample, and that the results obtained from analysis of each sample are comparable to those obtained from analysis of other similar samples.

2.7.2 Concentrations of Concern

In order to define data needs, potential concentrations of concern must be established. The *Guidance for Data Usability in Risk Assessments* (EPA, 1992) specifies that, to the extent possible, the analytical detection limit for a contaminant of concern should be no greater than 20 percent of the concentration of concern (e.g., risk-based criterion). The method detection limits (MDLs) to be used during this project have been chosen such that both nondetects and detects will be usable to the fullest extent possible for the risk assessment process to be followed.

2.7.3 Project Quality Assurance Objectives

The QA/QC program will provide the basic guidelines for evaluating analytical results for each site. Data quality assessments will be used to identify accurate and precise data that may be used to establish remediation quals and evaluate alternatives for each site. QA/QC is ensured through appropriate sample collection, preservation, and transport methods combined with an evaluation of laboratory analytical performance through the analysis of QC samples.

When analytical data fail to meet the required QA objectives, the technical report will discuss why the objectives were not met. Two major categories of non-compliance with QC requirements need to be considered:

- Requirements that are fully under a laboratory's control; and
- Requirements limited by the nature of the sample matrix.

Corrective action for noncompliance with QC standards that are fully under a laboratory's control (e.g., laboratory blanks, calibration standards, tuning, and laboratory check or control samples) will be addressed with a thorough reevaluation of the system and all calculations and, where practical, reanalysis of noncompliant samples. Corrective action for noncompliance with QC standards that is limited by the nature of the sample matrix (e.g., field blanks, matrix spikes, and duplicates) will be addressed with a thorough check of the system and all calculations, and the attachment of appropriate data qualifiers to noncompliant data.

2.8 Definition of Criteria

The data assessment criteria measure the quality of both the field and laboratory performance for the entire project and are expressed in terms of analytical accuracy, precision, completeness, comparability, representativeness, holding times, and detection limits. These criteria are described in the following subsections.

2.8.1 Accuracy

Accuracy is a measure of the closeness of a reported concentration to the true value. Accuracy is usually expressed as a bias (high or low) and is determined by calculating percent recovery (PR) from spiked samples. The level of recovery of an analyte and the resulting degree of accuracy expected for the analysis of QA samples and spiked samples are dependent upon the sample matrix, method of analysis, and the contaminant. The concentration of the analyte relative to the detection limit of the method is also a major factor in determining the accuracy of the measurement.

During field sampling and sample shipping, contamination may be introduced to the samples that could affect the accuracy of analysis results. Field and trip blanks will be used during sample collection and shipment to detect possible field contamination. Contamination affecting accuracy can also be introduced during laboratory analysis. Method blanks will be used during laboratory procedures to assess laboratory-introduced contamination.

Because accuracy information is critical when results are reported at or near a concentration of concern, the appropriate number of field blanks, trip blanks, and method blanks will be collected at each site to ensure that accurate information can be obtained.

Field spiking of environmental samples will not occur. Laboratory spiking methods are expected to be completed under more controlled conditions, and should therefore

provide more reliable data than that which could reasonably be implemented in the field. However, field measurements for parameters such as pH and parameters involving colorimetric analyses will be assessed for accuracy in the field. Specifically, field instruments will be assessed for accuracy by the response to a known sample (such as a calibration standard). The objective for accuracy of field measurements is to achieve and maintain factory equipment specifications for the field equipment.

2.8.2 Precision

Precision is a quantitative measure of the variability of a set of measurements compared to the mean. It is usually reported as a coefficient of variation or a standard deviation of the arithmetic mean. Analytical results for QC samples are used to calculate the precision of the measurement process. During collection of samples, precision can be affected by the spatial variability of pollutant concentrations. Collection of adequate field duplicate samples will enable a determination of variability due to sampling and laboratory analysis practices. Analytical variability can be measured by analysis of laboratory duplicates and/or performance evaluation samples. Standard deviations and coefficients of variation can be used to determine the confidence level of data reported near a concentration of concern. Precision will be expressed in terms of the standard deviation or the relative percent difference (RPD) between the values resulting from duplicate analyses.

Because the concentration of analytes may be below detection limits in many environmental samples, RPD data will be generated by preparing matrix spikes in duplicate. The precision of the analytical method will thus be measured by calculating the RPD between the duplicate spikes, rather than environmental samples. Acceptable levels of precision will vary according to the sample matrix, the specific analytical method, and the analytical concentration relative to the method detection limit. For field duplicate samples, the target RPDs are 20 percent for water samples, 50 percent for soil samples, and 35 percent for soil gas samples.

At each site, adequate numbers of field and laboratory duplicates will be analyzed to allow for accurate calculations of the precision of analytical results. At a minimum, one field duplicate will be collected for every 10 environmental samples (i.e., frequency of 10 percent).

2.8.3 Completeness

Completeness is defined as the percentage of measurements, either field or laboratory, which are judged to be valid measurements on a method-by-method basis. Valid data will be defined as all data and/or qualified data considered to meet the DQOs for this project. Data completeness is expressed as percent complete (PC) and should not be less than 90 percent. At the end of each sampling event, the completeness of the data will be assessed. If any data omissions are apparent, the parameter in question will be resampled and/or reanalyzed, if feasible. Laboratory results will be monitored as they become available to assess laboratory performance

and its effect on data completeness requirements. When appropriate, additional samples will be collected to ensure that laboratory performance meets PC requirements.

2.8.4 Comparability

Comparability expresses the confidence with which data from a sample, sampling round, site, laboratory, or project can be compared to those from another. Comparability during sampling involves sampling program design and time periods. Comparability during analysis involves analytical methods, detection limits, laboratories, units of measure, and sample preparation procedures. The objective for comparability is determined on a qualitative rather than quantitative basis. For this project, comparability of all data collected will be ensured by adherence to standard sample collection procedures, standard field measurement procedures, and standard reporting methods including consistent units.

In developing site-specific sampling plans, previous studies have been reviewed. Past designs have been incorporated whenever possible and appropriate to improve comparability as well as to build upon existing information about the site. For example, previously collected information about soil horizon stratification and depth to contamination will be used in selecting soil sampling depths. Data that are not comparable between studies will not be used quantitatively in this program.

2.8.5 Representativeness

Representativeness expresses the extent to which collected data define site contamination. Where appropriate, sample results will be statistically characterized to determine the degree to which the data accurately and precisely represent a characteristic of a population, parameter variation at a sampling point, process, or environmental condition. The data will be tested against the normal distribution when 30 or more samples are available for testing. A nonparametric test will be used when fewer than 30 samples are available.

Sampling selection, handling, and analytical procedures will strive to obtain the most representative sample possible. Sample handling and analytical procedures also incorporate consideration of obtaining the most representative sample possible. Representative samples will be achieved by the following:

- Collection of samples from a location(s) fully representing site conditions;
- Use of appropriate sampling methodology and equipment;
- Use of appropriate sampling procedures, including equipment decontamination;
- Use of appropriate analytical methodologies for the required parameters and detection limits; and
- Analysis of samples within the required holding times.

Sample representativeness is also affected by which portion of each collected sample is chosen for analysis. The laboratory will adequately homogenize all samples prior to taking aliquots for analysis to ensure that the reported results are representative of the sample received. Because many homogenization techniques may contaminate the sample, or cause loss of contaminants through volatilization, homogenization will be avoided or modified in some cases to minimize these risks.

2.9 LABORATORY SAMPLE HANDLING

2.9.1 Sample Custody

Sample custody is critical to ensuring the integrity of field sampling and laboratory analysis. Parsons ES's project task manager or quality assurance (QA) officer will notify the laboratory project coordinator of anticipated field sampling activities and the subsequent transfer of samples to the laboratory. This notification will include information concerning the number and type of samples to be shipped as well as the anticipated date of arrival. All sample shipments to the laboratory will be accompanied by chain-of-custody (COC) forms which are to be completed by the laboratory. Copies of the completed COC records for the appropriate samples will be transmitted to Parsons ES upon receipt of samples. One copy of the COC form will be maintained by the laboratory. The original COC will be returned to Parsons ES with the report package.

2.9.2 Sample Handling

The types of sample containers, sample volumes, methods of preservation, and holding times for each sample matrix by analytical method will be defined by Parsons ES prior to mobilization to the field. Parsons ES field team members will ship samples daily upon sample collection, normally Monday through Friday, to enable the laboratory to analyze the samples within the specified holding times. The laboratory will provide clean containers for each type of analysis, including preservatives, where appropriate. The laboratory will provide documentation attesting to the cleanliness of the containers. The laboratory will also document and guarantee the purity of any reagents supplied as preservatives.

To facilitate sample preparation and analysis within the specified holding times, the laboratory will track the progress of sample preparation, analysis, and report preparation. Samples received by the laboratory will be checked carefully for label identification, COC, and any discrepancies. The laboratory will also note physical damage, air bubbles in samples of volatile organic compounds (VOCs), incomplete sample labels, incomplete paperwork, discrepancies between sample labels and paperwork, broken or leaking containers, and inappropriate caps or bottles. The temperature and pH of samples will be determined and recorded as appropriate. The laboratory project coordinator will designate the samples to be included in each analytical batch consistent with the applicable holding time restrictions.

Laboratory sample custody will be maintained by the following procedure:

- The laboratory will designate a sample custodian responsible for maintaining custody of the samples and all associated paperwork documenting that custody.

- Upon receipt of the samples, the sample custodian will sign the original COC form and compare the analyses requested thereon with the tag on each sample container.

- A qualitative assessment of each sample container will be performed to note any anomalies such as broken or leaking bottles, or lack of preservation (e.g., ice melted enroute). This assessment will be recorded as part of the incoming COC procedure.

- If all data and samples are correct, and there has been no tampering with the custody seals, the "received by laboratory" box on the COC form will be signed and dated.

- Care will be exercised to document any labeling or descriptive errors. In the event of discrepant documentation, breakage, or conditions that could compromise the validity of analyses, the laboratory project coordinator will immediately contact the Parsons ES team or project manager as part of the corrective action process.

- Samples will be logged into the laboratory management computer system, which includes a tracking system for extraction and analysis dates.

- The samples will be stored in a secured area at a temperature of approximately 4 degrees Centigrade (°C) (as applicable) until analyses commence.

- The samples will be distributed to the appropriate analysts, with names of individuals who receive samples recorded in internal laboratory records.

- The original COC form will accompany the laboratory report submitted to Parsons ES and will become a permanent part of the project records.

The laboratory will notify Parsons ES's team or project manager by telephone if the holding times specified by the required methods may be exceeded. The laboratory will provide alternatives for completing the specified analyses within the required holding time.

2.9.3 Sample Custody Records

Each sample will be logged into the laboratory system by assigning it a unique sample number. This laboratory number and the field sample identification number will be recorded on the laboratory report. Samples will be stored and analyzed as appropriate for the method specified on the sample containers.

The laboratory coordinator (or designee) will provide the Parsons ES team or project manager with a written report upon receipt of samples which includes, at a minimum, samples received, condition of samples upon receipt, field identification numbers, laboratory sample identification numbers, tests to be performed, and the projected date of completion of the specified analyses. In addition, the laboratory project coordinator (or designee) will provide Parsons ES's project QA officer with a written sample tracking report upon receipt of samples. This report will present, at a minimum, the following information for each sample received:

- Sample identification number,
- Date of sample collection,
- Location of sample,
- Date of laboratory receipt,
- Required analytical tests,
- Required date of extraction (if applicable),
- Required date of analysis, and
- Date analyzed or date of expected analysis.

If the data are directly acquired from instrumentation and processed, the analyst will verify that the following are correct:

- Project and sample numbers,
- Calibration constants and response factors,
- Output parameters such as units of measurement, and
- Numerical values used for detection limits if a value is reported as "below practical quantitation limit" (BQL), "below method detection limit" (BMDL), or "not detected" (ND)."

2.10 ANALYTICAL METHODS

Application of a specific analytical method depends on the analytes to be identified and the sample matrix. Methods for each of the parameters in the analytical program, as well as detection limits, are presented in the following subsections.

2.10.1 Identification of Methods

All of the analytical methods anticipated to be used as part of this program, and the source references for each method, are summarized in section 2 of the RAP. Not all of the analytes will be run for each sampling event. This list may be supplemented to support site-specific data needs. The laboratory shall use its standard operating procedures (SOPs) for each method identified.

2.10.2 Detection and Quantitation Limits

A method detection limit (MDL) is the lowest concentration that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. MDLs are experimentally determined and verified for each analyte of the analytical methods in the sampling program. MDLs are based on the results of spiking reagent-grade water with a pure standard to achieve a concentration at the estimated detection limit for that analyte. The spiked sample is then carried through the appropriate extraction procedure and analyzed according to the method. The analytical results are then used to calculate the MDL for the method. All nondetected values will be reported at the MDL. The MDL will be the reporting level for this project. The confidence level for eliminating false negatives will be 99 percent for this project, which corresponds to two times the MDL, and will be called the reliable detection level (RDL) (RDL = 2 x MDL). The Required Quantitation Limit (RQL) is the concentration which is two times the RDL (RQL = 2 x RDL = 4 x MDL). This recognizes that the RDL estimates produced at different times by different operators for different representative matrices will not exceed the RQL. All MDLs will be less than the CRQL. The RQL may not be less than the CRQL. In these cases, the MDL will be the reporting level. The laboratory will provide the MDL studies to be used for this project for each method.

If an analyte is present at a concentration greater than the linear range of the analytical method, the sample must be diluted for accurate quantitation. The dilution factor (DF) raises the reporting limit above the RQL to a higher limit or sample quantitation limit (SQL). The SQL is equal to the RQL multiplied by the DF. The RQLs are equal to the SQL when the DF is equal to 1.

Detected concentrations lower than the RQL but greater than or equal to the RDL will be reported as estimated values only (flagged J). Detected concentrations less than the RDL will be reported as estimated values (flagged U). Nondetected concentrations are reported as undetected at the RQL. A complete description of laboratory flags follows in Section 2.10.3.

2.10.3 Laboratory Organic Data Reporting Flags

The following flags must be used by the laboratory when reporting results of organic analyses.

Value - If the result is a value greater than or equal to the practical quantitation limit (PQL), the value is reported.

U - Indicates the compound was analyzed for but not detected. The number is the project reporting level (e.g., the CRQL or MDL) for the sample.

J - Indicates an estimated value. This flag is used to estimate a concentration for tentatively identified compounds where a 1:1 response is assumed or when the mass spectral data indicate identification criteria, but the result is less than the specified detection limit. This flag will also be used to identify values falling between the MDL and the PQL.

UJ - A combination of the "U" and "J" qualifiers. The analyte analyzed for was not present above the level of the associated value. The associated numerical value may not accurately or precisely represent the concentration necessary to detect the analyte in the sample.

B - Used when the analyte is found in the blank, as well as in a sample. It indicates possible/probable blank contamination and warns the data user to take appropriate action.

2.10.4 Laboratory Inorganic Data Reporting Flags

The following flags (concentration and method) must be used by the laboratory when reporting results of inorganic analyses (such as nitrate, sulfate).

Concentration Flag:

B - The reported value was obtained from a reading that was less than the PQL, but greater than or equal to the MDL or IDL.

U - The analyte was analyzed for but not detected. The number is the project reporting level (e.g., the nondetect level) for the sample.

2.10.5 Sampling and Laboratory Calibration Methods

Instruments and equipment used to gather, generate, or measure the environmental data will be calibrated with sufficient frequency and in such a manner that accuracy and reproducibility of results are consistent with standards of the discipline, based on approved written SOPs. Records of calibration, repairs, or replacement will be filed and maintained by the designated personnel performing QC activities. These records will be filed at the laboratory and will be subject to QA audit.

For all instruments, the laboratory will maintain a factory-trained repair staff with in-house spare parts, or will maintain service contracts with vendors. Instruments and

equipment used to gather, generate, or measure the environmental data will be calibrated with sufficient frequency and in such a manner that accuracy and reproducibility of results are consistent with standards of the discipline, based on approved written SOPs. Records of calibration, repairs, or replacement will be filed and maintained by the designated personnel performing QC activities. Calibration of instruments and equipment will be performed at time intervals as specified by the manufacturer, method, contract laboratory program (CLP) protocols, or more frequently, as conditions dictate. Calibrations will be performed at the start of each test run and verified throughout the analysis to the QC specifications of the appropriate analytical method. Such calibrations will also be reinitiated as a result of excess delay, or at such timely intervals as specified in the analytical method. In all cases, the laboratory's QAPP and SW-846 method-specified calibration procedures and frequencies take precedence over the following general guidelines.

2.11 DATA MANAGEMENT

Parsons ES has developed a data management plan to meet the data deliverable requirements of the risk-based remediation program. Laboratory data will be reported in a computerized format. All data entered into data files will correspond to the data contained in the original laboratory reports and other documents associated with sampling and laboratory activities. Parsons ES will supply the laboratory with a sample reporting diskette upon acceptance of a support contract. All data will be maintained in a Paradox™ data base or equivalent in a modified format taken from the Air Force Installation Restoration Program Information Management System (IRPIMS) Data Loading Handbook, Version 2.3, May 1994. The preferred format for data submittal is Excel™ .XLS. The laboratory will return the diskette with sample results within two weeks of acceptance of a contract. A satisfactory data reporting system will be completed within three weeks of acceptance of a contract. (Parsons ES will check the sample diskette for form and format and will provide assistance in correcting any problems noted on the reporting diskette.) The electronic reporting diskette is to be delivered along with two copies of the hard copy deliverables.

The laboratory will enter analytical test method, result, and QC data on data sheets which will be filed for permanent storage at the laboratory. A separate book will be maintained for each analytical procedure. The data entered will be sufficient to document all factors used to derive the final (reported) value for each sample. Calculations may include factors such as sample dilution ratios, corrections for blank readings, or conversion to dry-weight basis for solid samples. Instrument chart recordings and calculator printouts will be labeled and attached to their respective pages or cross-referenced and stored in the project file. Calculations for GC/MS analyses will be performed in the data system and kept in the system printout. These will be filed in chronological order.

Concentration units will be listed in reports, and any special conditions will be noted. The analysis report will include the unique sample number given to each sample and the dates of sample receipt and analysis.

2.12 DATA DELIVERABLES

Data deliverables required for the analytical results include both a hard copy and an electronic copy of field analytical results in a specified format and QA/QC results. Data reporting requirements are listed below.

2.12.1 Reporting Analytical Data

Reporting of analytical results for this project will include analytical results summaries for field samples, analytical results summaries for QC samples, and detailed data on analytical methods, procedures, and reporting levels. The following items will be reported to Parsons ES by the laboratory in the specified format. Note that many of these items are to be provided to the laboratory upon sample transmittal.

- Project identification,
- Site name,
- Abbreviated site name,
- Sample locations,
- Laboratory batch number,
- Sample collection date,
- Sample interval,
- Sample matrix,
- Sample QC code,
- Analytical method,
- Laboratory sample number,
- Extraction method,
- Extraction date,
- Parameter classification,
- Analysis date,
- Units of measure,
- Basis of measure,

- Chemical (parameter) name,
- Analytical result,
- Precision of analytical result,
- Detection limit,
- Precision of detection limit,
- Practical quantitation limit, and
- Practical quantitation limit precision.

Case narratives for each data report are to be provided. However, raw data system printouts will not be delivered as part of the report package. The laboratory will maintain these records so that they can be accessed and retrieved with nominal effort within the next 5 years. Format requirements will be established for both hard copy and electronic copy data reports.

2.12.2 Assessment of Data Usability

Data from QC samples will be assessed by Parsons ES using the procedures and criteria presented earlier in this section. This assessment will be a continuous process in which QA problems are identified immediately and the appropriate corrective action is implemented. Additionally, Parsons ES will assess the usability of analytical data. Any limitations on data use will be expressed quantitatively to the extent practicable and will be documented in any reporting of the data.

This data usability review will include 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 (see Section 2.8 of this QAPP). The outcome of this data evaluation will be a data set appropriate to support quantitative fate and transport analyses and risk analysis. The data evaluation methods defined by EPA (1989b) in OSWER Directive 9285.7-01a *Risk Assessment Guidance for Superfund (RAGS), Volume 1: Human Health Evaluation Manual* (EPA/540/1-89/002) and OSWER Directive 9285.7-09a *Guidance for Data Usability in Risk Assessment* (EPA, 1992) will be used as appropriate.

Data will then be qualified according to intended use. The qualification of data will be based on the performance measures for the project specified during the design process and described in the QAPP. Any limitation of data use will be expressed quantitatively, if possible, and will be documented. Project reports containing analytical data or relying on analytical data will be reviewed to confirm that the data or results are presented correctly. These reports will be approved by management before release, publication, or distribution.

2.13 LABORATORY QUALITY CONTROL

QC samples will be analyzed routinely by the laboratory as part of the laboratory QC procedures. Laboratory QC results will constitute at least 10 percent of each data set generated, and will consist of analysis of blanks, replicates, standards, matrix spikes, and surrogate spikes. Surrogates will be added to all samples requiring GC/MS analyses. One method blank will be run for every 20 samples analyzed. These laboratory QC sample analyses will be run independently of the field QC samples. Results of these analyses will be reported with the sample data and kept in the project QC data file.

2.13.1 Method Blanks

To verify that the procedures and reagents used do not introduce contaminants that affect the analytical results, method blanks will be run for all analyses. The method blank will be prepared by addition of all reagents to a substance or matrix similar to the sample and undergo all of the procedures required for sample preparation. The resultant solution will be analyzed with the field samples prepared under identical conditions. Contaminants found in the blank sample shall not exceed three times the MDL. An analyte concentration in the blank of two times the MDL will be used as an advisory limit. Results greater than three times the MDL indicate a need for corrective action and will require reanalysis, within the holding time requirements, of the samples prepared with the blank for those parameters where the contaminant is an analyte of interest. Corrective actions shall be performed prior to proceeding with reanalysis. The reported data will not be corrected for method blank contamination.

2.13.2 Bottle Blanks

If bottles are cleaned in the laboratory, bottle blanks must be performed at 5 percent frequency for each cleaned lot of bottles, and verification of bottle cleanliness provided to Parsons ES for each project-specific analytical method. If precleaned bottles are purchased, certificates of cleanliness will be shipped with the bottles to the site.

2.13.3 Surrogate Spike Analyses

Surrogate spike analyses are used to determine the efficiency of analyte recovery in sample preparation and analysis. Calculated percentage recovery of the spike is used to measure the accuracy of the analytical method. A surrogate spike is prepared by adding to an environmental sample (before extraction) a known amount of a pure compound similar in type to the environmental sample to be assayed by GC/MS. Surrogate compounds will be added to all samples analyzed by GC and GC/MS methodology, including method blanks and duplicate samples. Compounds used as surrogates and their spike recoveries may be used as addressed in the laboratory QA plan. Surrogate spike recoveries should fall within the limits established by laboratory QC protocol. If a recovery is not within these limits, the corrective actions described in the method will be implemented.

2.13.4 Matrix Spike Analyses

To determine the effect of matrix interference on the results of GC and GC/MS analyses, aliquots of the same sample will be prepared in the laboratory, and each aliquot will be treated exactly the same throughout the analysis. Spikes are added at concentrations specified in the method. At a minimum, the laboratory must analyze the QC sample specified in the analytical method at the frequency indicated by the method. At least one matrix spike/matrix spike duplicate (MS/MSD) pair will be analyzed for every 20 project samples for each project analytical method. The relative percent difference (RPD) between the values of the spiked duplicates is taken as a measure of the analytical method precision.

Selected samples will be spiked to determine accuracy as a preliminary review (PR) of the analyte from the sample matrix. In exception to CLP-protocol, matrix spike and duplicate samples will be assigned in the field. The laboratory will notify Parsons ES's team or project manager in situations where the required MS/MSD samples have not been specified on the COC report to acquire identification of a MS/MSD sample. In an extreme situation where Parsons ES cannot be contacted and sample holding time will be adversely affected, the laboratory will select an appropriate sample for MS/MSD analysis. At all times, the required MS/MSD samples will be analyzed at the appropriate frequency for each matrix and analytical method. These matrix spikes will be prepared using reagent-grade salts, pure compounds, or certified stock solutions whenever possible. Concentrated solutions will be used to minimize differences in the sample matrix resulting from dilution. Samples will be split into identical duplicates, one of which will then be spiked with a known mass of the analyte. The final concentration after spiking should be within the same range as the samples being analyzed to avoid the need for dilution, attenuation of instrument outputs, or other required alterations in procedure which might affect the instrument response and determination of accuracy.

The results of the analyses will be reviewed by the laboratory supervisor. Deviations from established QC criteria will be noted, and reanalysis or another corrective action will be instituted as appropriate for the situation.

A laboratory control sample (LCS) will be analyzed during each initial instrument calibration and the recovery must be within the range of 80 to 120 percent. In the event of low spike recovery for MS/MSD samples analyzed by inductively coupled plasne (ICP), the results of an analytical spike (LCS/LCS duplicate [LCSD]) will be used to determine the need for reanalysis. The mean PR and standard deviation from a minimum of 20 analyses will be calculated. A warning limit of two standard deviations from the mean, and a control limit of three standard deviations will be used to determine if the test is providing accurate data. If the LCS/LCSD results are out of control, then corrective action is required and the batch must be reextracted and reanalyzed. When the analysis of the LCS/LCSD samples verify a matrix interference problem, all sample values for that batch will be qualified as estimated.

2.13.5 Second Column Confirmation

To ensure precision of analytical results at or near the MDL, a small subset of field ground water samples will be identified by Parsons ES for second column confirmation. Second column confirmation will be completed using GC/MS Method SW8240 (8260). No more than 10 percent of the ground water samples taken at each site will be marked for second column confirmation.

2.13.6 Quality Control and Audit

QC results will be calculated by the analyst and reviewed by the laboratory supervisor to determine the accuracy and precision of the analytical results. The laboratory supervisor or manager will review all final reports and associated QC data. Approval is shown by signature. Results will be recorded on the QC report forms for the appropriate tests and correlated to the analysis results. The QC results will also be used to prepare control charts for each test and type of matrix. The laboratory QC results and procedures will be available for review by Parsons ES for up to 2 years after completion of the work.

2.13.7 Control Limits

The QC checks, their frequency, acceptance criteria, and corrective actions for out-of-limit data are summarized in Appendix A for each analytical method listed as part of this program. The laboratory should supplement this criteria according to their SOPs and historical data. The degree of accuracy, or percent recovery, is dependent upon the sample matrix, specific analytical method, and the concentration of the analyte relative to its detection limit. The laboratory will identify control parameters for each analytical method, experimentally establish control limits and reevaluate them at regular intervals. The acceptance criteria for analyte recovery will be based on laboratory historical data. The laboratory will provide Parsons ES with this criteria within two weeks of acceptance of a contract. The laboratory may default to method-specified limits.

2.14 ACCEPTANCE CRITERIA FOR THE CONTROL LIMITS

The laboratory will perform in-house analytical data reduction and validation under the direction of the laboratory's QA officer. Laboratory control limits for matrix spikes, matrix spike duplicates, and surrogate spikes will be those presented in Appendix A. The laboratory's QA officer is responsible for assessing data quality and advising Parsons ES of any data which were rated "preliminary," "unacceptable," or otherwise which would caution the data user of possible unreliability. Data reduction, validation, and reporting will be conducted as follows:

- Raw data produced by the analyst are turned over to the respective area supervisor.

- The area supervisor reviews the data for attainment of QC criteria as outlined in EPA CLP protocols and/or established EPA methods and for overall reasonableness.

- Upon acceptance of the raw data by the area supervisor, a computerized report is generated and sent to the laboratory QA officer.

- The laboratory QA officer will complete a thorough audit of reports at a frequency of one in ten, and an audit of every report for consistency.

- The laboratory QA officer and area supervisor will decide whether any sample reanalysis is required.

- Upon acceptance of the preliminary reports by the laboratory QA officer, final reports will be generated and signed by the laboratory project manager. The components of the laboratory package will be presented in the same order in which the samples were analyzed.

Data reduction reporting procedures should be followed. The laboratory will prepare and retain full analytical and QC documentation similar to that required by the EPA CLP.

The laboratory will report the data in the same chronological order in which it is analyzed, along with QC data. For organic analyses, the data packages must include matrix spikes, matrix spike duplicates, surrogate spike recoveries, and GC/MS chromatograms and spectra.

A final QC requirement document, as well as a more specific deliverables list per method, will be provided prior to the beginning of the sampling event.

Parsons ES will conduct a systematic review of the data for compliance with the established QC criteria based on the spike, duplicate, and blank results provided by the laboratory. An evaluation of data accuracy, precision, comparability, and completeness will be performed and presented in the analytical data report.

Parsons ES will identify any out-of-control data points and data omissions, and will interact with the laboratory to correct data deficiencies. Decisions to repeat sample collection and analyses may be made by the Parsons ES project manager based on the extent of the deficiencies and their importance in the overall context of the project.

2.15 CORRECTIVE ACTION

The following procedures have been established to assure that conditions adverse to data quality, such as malfunctions, deficiencies, deviations, and errors, are promptly investigated, evaluated, and corrected.

All subcontractor personnel have the responsibility, as a part of normal work duties, to promptly identify, report, and solicit approved correction of conditions adverse to quality. Corrective actions may be initiated if any of the following conditions apply:

- Sample holding time limits are not met;
- Predetermined acceptance standards are not attained (objectives for precision, accuracy, and completeness);
- Reports or data compiled are determined to be inconsistent or faulty;
- Equipment or instrumentation is found to be faulty;
- Samples and test results are not readily traceable;
- QA requirements have been violated;
- Designated approvals have been circumvented;
- System and performance audit results warrant; or
- Management assessment results warrant.

2.15.1 Response to Out-of-Control Events

When a significant condition adverse to data quality is noted at the laboratory location, the cause of the condition will be determined, and corrective action will be taken (up to and including the laboratory replacement) to preclude repetition. Condition identification, cause, reference documents, and corrective action planned will be documented and reported to Parsons ES's QA/QC manager and involved management. Implementation of corrective action will be verified by follow-up action.

Appropriate corrective actions for laboratory conditions which would adversely affect data quality are listed below as follows:

- Observations corrected at the bench. If calibration of an instrument is not linear, the analyst will correct it before continuing to analyze samples. The laboratory will document this correction and note that the corrective action was to recalibrate and that no samples were affected, as none were analyzed prior to calibration.
- Corrective actions taken by laboratory supervisor. If a matrix spike recovery is out of control, and is discovered by the laboratory supervisor after the samples for the day have been analyzed, the supervisor will document the occurrence and the actions taken. Corrective action generally will consist of flagging the data as estimated.

- Corrective actions at the receiving level. If a sample container is broken, the analyst will note the breakage and document if more sample is available. If additional sample is not available, the laboratory will notify the Parsons ES task or project manager. Samples may be recollected if completeness criteria are jeopardized.

- Statistical out-of-control events. If a control chart is being monitored and the measured parameter exceeds the criteria, then the point at which the parameter exceeded the statistical limits will be documented. The data will be flagged as estimated, and the sample will be reanalyzed when QC is reestablished. The conditions necessary to reestablish control and the criteria for ensuring that the system is operating properly will be documented.

2.15.2 Re-establishment of Control

Procedures for re-establishment of control after the occurrence of an out-of-control event include the specific actions described above. If samples are reanalyzed, the assessment procedures will be repeated, and the control limits will be reevaluated to ascertain if corrective actions have been successful.

2.15.3 Documentation

Out-of-control events and corrective actions will be documented in writing by the laboratory QA manager. Any nonconformance with the established QC procedures will be identified and corrected. A nonconformance report will summarize each nonconformance condition. Corrective actions will be implemented and documented. A stop-work order may be initiated by Parsons ES's project manager if corrective actions are insufficient.

2.16 QUALITY ASSURANCE REPORTS

2.16.1 Reporting Procedure

Periodic QA reports will be prepared by the laboratory QA manager for review by Parsons ES's project QA manager. Reports to be prepared include:

- Audit reports (periodic as needed), and

- Progress report (monthly).

2.16.2 Report Content

The specific content of reports will depend upon the type of report. In general, the reports will address:

- Changes in a QA project plan;

- Summary of QA/QC programs, training, and accomplishments;
- Results of technical systems and performance evaluation audits;
- Significant QA/QC problems, recommended solutions, and results of corrective actions;
- Data quality assessment relative to precision, accuracy, representativeness, completeness, comparability, MDL, and CRQL;
- Indication of whether the QA objectives were met; and
- Limitations on use of the measurement data.

2.17 FINAL SAMPLE DISPOSITION

Upon completion of all required analyses and acceptance of the data reporting by Parsons ES, the laboratory shall be responsible for proper disposal of any remaining samples, sample containers, shipping containers, and Styrofoam or plastic packing materials in accordance with sound environmental practice, based on the sample analytical results. However, the laboratory will give prior notification to and receive the approval of Parsons ES before disposing of any remaining samples. The laboratory shall maintain proper records of waste disposal methods and disposal company contacts on file for inspection.

2.18 STORAGE OF DATA

The laboratory will archive copies of all hard copy data, project reports, and electronic data files for a period of five years. The laboratory will then notify Parsons ES in writing requesting Parsons ES's written authorization to dispose of the archived data.

2.19 Preventive Maintenance

2.19.1 Procedures

Equipment, instruments, tools, gauges, and other items requiring preventive maintenance will be serviced in accordance with the manufacturers' specified recommendations or written procedures developed by the operators.

2.19.2 Schedules

Manufacturers' procedures identify the schedule for servicing critical items in order to minimize the downtime of the measurement system. It will be the responsibility of the individual operator assigned to a specific instrument to adhere to the instrument maintenance schedule and to promptly arrange any necessary service. Servicing of the

equipment, instruments, tools, gauges, and other items will be performed by qualified personnel.

The laboratory will establish logs to record maintenance and service procedures and schedules. All maintenance records will be documented and will be traceable to the specific equipment, instruments, tools, and gauges.

Records produced for laboratory instruments will be reviewed, maintained, and filed by the operators at the laboratories. The Parsons ES QA/QC manager may audit these records to verify complete adherence to these procedures.

2.19.3 Spare Parts

A list of critical spare parts will be requested from manufacturers and identified by the operator. These spare parts will be stored for availability and use in order to reduce downtime due to equipment failure and repair.

SECTION 3

DATA INTERPRETATION AND ANALYSIS

The risk-based approach to remediation is dependent on conservatively estimating levels of contamination that can remain onsite without posing an unacceptable risk to human health or the environment. The risk-based approach provides site-specific flexibility in determining which potential remedial alternatives afford the highest degree of long-term effectiveness appropriate for the current and future uses of a site. The EPA recognizes that the mere presence of a contaminant does not necessarily warrant remediation, and that the goal of remediation investigations is to determine what remedial actions are necessary to eliminate or minimize risks to human health and the environment (EPA, 1987b). Using site-specific data, a quantitative source-and-release analysis and an exposure pathway analysis will be completed as part of this project to determine which, if any, of the four contaminant phases (i.e., soil gas, contaminated vadose zone soils, free-phase product, and dissolved-phase contamination) may pose a risk to human health and the environment. Quantitative contaminant fate and transport models such as Bioplume II (Rifai et al., 1988) will be used to determine whether fuel contaminants could migrate to a potential receptor exposure point.

3.1 REMEDIAL GOALS

For each of the eight demonstration sites, site-specific data will be used to aid in the selection of a low-cost source removal technology which reduces the risk associated with petroleum hydrocarbon contamination. Remediation goals will be developed to address site-specific conditions. These remediation goals will aid in determining the most cost-effective remedial technology for the site by identifying which media and which contaminants need to be addressed to protect human health and the environment. All developed remediation goals will be based on widely accepted risk assessment guidance (e.g., EPA Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation, Part B - Development of Risk-Based Preliminary Remediation Goals). All calculated remedial goals will be developed by Parsons ES personnel familiar with risk assessment procedures. Final remediation goals will be critically reviewed by an Parsons ES senior or supervisor risk assessor, the technical director, and the project manager.

3.2 bioplume ii model

After the site has been adequately characterized using both historical data and data collected under this project, fate and transport analyses will be performed to determine the potential for contaminant migration and whether any exposure pathway is complete. The Bioplume II computer model (Rifai et al., 1988) will be used to predict plume migration and contaminant attenuation by natural biodegradation.

The Bioplume II model will be used to assess the influence of key electron acceptors on the fate and transport of contaminants. The Bioplume II model is based upon the U.S. Geological Survey (USGS) two-dimensional (2-D) solute transport model MOC, which has been modified to include a biodegradation component activated by a superimposed plume of dissolved oxygen. However, as part of this demonstration project, the biodegradation of fuel contamination will be simulated based on the actual assimilative capacity of the ground water. Work completed as part of the Natural Attenuation (Intrinsic Remediation) demonstration program, also sponsored by AFCEE, suggests that many compounds can act as electron receptors at a fuel site. Incorporating additional electron acceptors into the Bioplume II model should provide a better estimate of the effectiveness of natural attenuation processes at minimizing contaminant migration and reducing contaminant mass and toxicity. Use of possible electron acceptors should also provide a better estimate of response time. Use of oxygen as the only electron acceptor can seriously underestimate the effects of natural degradation processes.

Bioplume II solves the USGS 2-D solute equation twice, once for hydrocarbon concentrations in the ground water and once for a dissolved oxygen plume. The two plumes are then combined using superposition at every particle move to simulate biological reactions between fuel products and oxygen. Using even the most realistic, conservative data, Bioplume II generally predicts very limited migration of BTEX plumes due to natural attenuation processes. Bioplume II has been used to simulate the effectiveness of intrinsic remediation at several sites (e.g., Wilson et al., 1986; Chiang et al., 1989; Rifai et al., 1988; Malone et al., 1993; Wiedemeier et al., 1993).

The risk-based approach to remediation is aimed at providing scientific evidence of the positive effects of intrinsic remediation and other innovative source removal technologies. The type and magnitude of these effects will be factored into the development of a final remedial alternative for the site. It is likely that intrinsic remediation alone will be insufficient at many fuel hydrocarbon-contaminated sites to reduce or eliminate contaminant migration and receptor risks. Other innovative source removal technologies, such as bioventing, will be included in the fate and transport calculations, risk analysis, and remedial design as necessary to ensure that the final remedial alternative will protect current and future receptors from adverse exposures to any site-related contamination (e.g., soil gas, soil, and ground water).

The Bioplume II model has been validated as a commercial package by Parsons ES personnel. A series of tests was performed to verify that the model is capable of yielding valid results. Any assumptions made during the actual modeling will be documented and discussed in the technical report. The model software will be run by Parsons ES personnel with knowledge of both the theory of contaminant fate and transport and the computer software to ensure that defensible conclusions can be drawn from the results. Any other models used to estimate exposure point concentrations as part of designing a remedial approach for a site will be validated as a commercial package. Any assumptions and uncertainties associated with model development and results will be clearly identified.

3.3 risk determination

The potential risks to human and ecological receptors will be determined by comparing calculated exposure concentrations derived from field data and quantitative fate and transport analyses to the remediation goals identified to be protective of human health and the environment given site-specific conditions. Comparison of these values will determine the type and magnitude of remediation that will be necessary to minimize risks to the maximum extent practicable.

3.4 development of an appropriate remedial approach

Using both the risk calculation and Bioplume II modeling results, remedial technologies will be identified and evaluated based on

- long-term effectiveness and ability to reduce contaminant toxicity, mobility, or volume;
- technical and administrative implementability; and
- cost.

The risk-based approach to remediation is intended to quickly define a remedial alternative for each specific site that will reduce or eliminate significant risks to human health and/or the environment. An RAP will be prepared for the site to document the approach used to identify an appropriate remedial action. The RAP will provide sufficient technical data on the recommended remedial alternative to show that it eliminates or abates present and future threats to human health and the environment to the maximum extent possible, and that appropriate control measures such as long-term monitoring are designed to supplement intrinsic remediation or any engineering controls.

3.5 Evaluation of Source Removal/Risk Reduction Options

To provide adequate data and analyses in support of the selection, design, and implementation of an appropriate remedial alternative, it will be necessary to critically evaluate single or combined remedial technologies in terms of long-term effectiveness, implementability, and cost. Field data, quantitative fate and transport modeling designed to explore the potential effectiveness of natural attenuation processes, and several other institutional and engineering technologies will be evaluated for their risk reduction potential. Combinations of institutional controls and cost-effective site remediation methods will be evaluated. Based on guidance from AFCEE, a minimum of three options will be evaluated for a site. Each option will be evaluated against three primary criteria: protectiveness of human health and the environment, implementability, and cost.

Effectiveness - Each remedial alternative will be analyzed to determine how effectively it will protect both current and future receptors from potential risks associated with contamination. This analysis will be based on determining whether the

remedial alternative can achieve and maintain final remediation goals. Effectiveness will also include permanence and ability to reduce contaminant mass, volume, and toxicity.

Implementability - The technical implementation of each remedial option will be evaluated. The expected technical effectiveness of each remedial alternative will be described. Potential shortcomings and difficulties in construction, operations, and monitoring will be presented and weighed against perceived benefits. The administrative implementation (regulatory and community acceptance) of each remedial approach also will be discussed. This is an important element of the RAP, particularly when intrinsic remediation is determined to be the most cost-effective method of risk reduction.

Cost - The estimated cost of each remedial option will be presented. Both capital and operating costs will be estimated, along with a present worth cost estimate for the predicted operating life of each option. Cost assumptions will be clearly stated and the cost sensitivity of assumptions discussed.

It is important to note, however, that the most effective remedial technology or remedial alternative may not be the most cost-effective option for the site. A cost-effective remedial alternative is one that achieves the best balance between long-term effectiveness and cost of all the remedial alternatives which meet the cleanup objectives for the site. The test of cost-effectiveness may be more extensive for a range of remedial alternatives which vary only in degree of long-term effectiveness, but which will all achieve the site cleanup goals. The remedial alternative which achieves the site cleanup goals at the lowest cost will be identified. The total cost for the other remedial alternatives will also be estimated, and all remedial alternatives will be ranked according to their degree of long-term effectiveness. The remedial alternative that provides the best balance between long-term effectiveness and cost would be the most cost-effective.

3.6 Selection of a Recommended Approach

Based on an evaluation of the protectiveness, implementability, and cost of each option, Parsons ES will recommend the option which provides the greatest protection for the lowest cost.

If this comparison indicates that natural attenuation of site contamination is occurring and is sufficient to reduce the potential risks to human health and the environment to acceptable levels, Parsons ES will recommend implementation of natural attenuation with long-term monitoring as the preferred remedial alternative. Otherwise, Parsons ES will use an iterative process to identify and design an appropriate remedial approach that couples at least two low-cost remedial technologies. If additional remediation of the source area is recommended, a conceptual design of the remediation system will be prepared and included in the RAP for Air Force and regulatory review. If bioventing is selected for source removal, any existing designs will be updated to include any areas of soil contamination discovered during the site investigation activities conducted as part of this project. If intrinsic remediation is an

integral part of the recommended option, a long-term monitoring plan will be developed to ensure that both soil and ground water contamination are decreasing according to the remediation strategy.

3.7 LONG-TERM MONITORING PLAN

A site-specific, long-term monitoring plan will be included as part of the RAP. This plan will specify the location of confirmation and point-of-compliance wells and sampling frequencies to demonstrate long-term effectiveness and permanence of the selected remedial alternative. Long-term monitoring as part of this demonstration project will likely involve the installation and sampling of confirmation and point-of-compliance wells. Confirmation wells will be located immediately downgradient of the existing plume and will provide for early confirmation of model and engineering predictions. The point-of-compliance wells will be located further downgradient to verify that site-related contamination does not pose an unacceptable risk to potential receptors over time. All point-of-compliance wells will be located and established in concert with regulatory agencies and cognizant base officials. Any requirements for institutional controls or long-term monitoring required to protect human health and the environment will be clearly described in the RAP. Requirements for long-term monitoring will depend upon the permanence or degree of long-term effectiveness afforded by the recommended remedial alternative.

Following the implementation of any required source removal technologies at the site, Parsons ES will operate the source removal system for a total of 600 days. At the end of the 600 days of treatment, Parsons ES will return to the site and resample soils in the source area to determine the degree of contaminant removal and evaluate the potential impact of source removal on the long-term fate and transport of contamination. A letter report will be prepared outlining the interim source removal results, the potential impact on the ground water plume, and the need for continued source removal if required.

3.8 regulatory coordination strategy

Following AFCEE and base review of the draft RAP, comments will be incorporated into a final draft for regulatory review and approval. When the final draft is completed, AFCEE and Parsons ES will provide a technical presentation to base officials and regulatory agencies to familiarize them with the key findings and recommendations of the RAP. Copies of the RAP will be provided to regulators at the meeting and a 30-day review will be requested.

SECTION 4

DESIGN, CONSTRUCTION, AND OPERATION OF ENVIRONMENTAL TECHNOLOGY

4.1 PLANNING

Project-specific planning for environmental technology involves key users and customers of the systems, as well as those responsible for activities affecting quality. Results of these planning activities are subject to reviews for conformance to technical and quality requirements.

System planning is coordinated among organizations participating in the activities and includes the following elements at a minimum:

- Program/task scope and objectives, and a list of the primary activities involved;
- Identification of the individuals needed to participate in the project and their roles in planning, design, construction, operation, and maintenance activities;
- Specific system components to be designed, constructed, and operated;
- Technical, performance, regulatory, and quality standards, criteria, or objectives;
- Personnel, equipment, and other resources required;
- Delivery, handling, storage, identification, inspection, testing, and installation requirements;
- Program technical reviews, peer reviews, and system assessments;
- Acceptance criteria for completed systems; and
- Project and QA records required.

Documentation of project and activity planning includes the appropriate use of work plans, QAPPs, design criteria, schedules, and conceptual design drawings.

4.2 DESIGN OF SYSTEMS

The Parsons ES design control system is documented and implemented using procedures generated in conformance with this QA program, as well as Parsons ES engineering policies, procedures, and standards. The system also provides the controls

necessary to maintain conformity of Parsons ES design projects. Technology designs will be standardized and then modified for individual site applications.

The design control program includes control of design inputs (design basis, design criteria, regulatory requirements, codes and standards, fire protection, reliability data, environmental data, and computer programs), design process controls, outputs (specifications, drawings, procedures, analyses), design changes, configuration control systems, records, and organizational interfaces. Design control requirements for procured design and engineering services are incorporated into procurement specifications. Changes to the design documents will receive the same review and approval as the original document. The design input document is translated into design output documents in drawings, procedures, and specifications.

Nonconforming items, field changes, and modifications must be justified, documented, and evaluated using the same design basis (input documents) as were used in the original design. Such changes are reviewed and approved by the same design organization that reviewed and approved the original, or an approved alternate organization. All design changes will result in revisions to applicable design documents.

Design interfaces are identified and controlled, and design efforts are coordinated among participating organizations. Interface controls address responsibilities, reviews, design basis, deliverables, and associated approvals and requirements by which configuration management is maintained.

The design control program provides controls to ensure that records and documents are maintained to provide evidence of the acceptability of the design and continued configuration. Design records are maintained to support the basis and activities of the design process. These records shall include the design input basis documents, calculations, approved drawings and their revisions, computer programs, analyses, and prototype testing data. Documents supporting the design configuration and the final performance per the design basis are verified and retained.

Design analysis is validated to ensure that correct input data and assumptions are incorporated into the computer software program, and are verified to ensure that correct solutions to physical problems are produced within predetermined limits. The documented computer software program requires that the process and changes are documented and approved by qualified technical personnel.

The design verification review is conducted by qualified individuals or groups other than those who prepared the original design. The design reviewer may be from the same organization as the designer, provided that the reviewer did not have responsibility for the original design effort. The reviewer may be a supervisor if other design personnel are not available and if the supervisor did not do the original calculation. Design verification does not need to be duplicated for multi-use items intended for the same application. The extent of the design verification is based on the complexity of the item and its importance to safety and reliability.

Design documents are verified in one of three ways: by conducting a formal design review, by producing alternate calculations, or by performing qualification testing. A single design verification may be applied for multiple items when a design is based on a single application and performance requirement.

4.2.1 Readiness Review

The Parsons ES QA Program provides for a system review to assure the readiness of projects, activities, or systems where completion (or completion of its phases) has been achieved. Verification of system readiness is required before final client inspection.

4.3 CONSTRUCTION/FABRICATION OF SYSTEMS AND COMPONENTS

The Parsons ES QA Program requires that the construction (fabrication/manufacture/erection) of engineered environmental systems be performed under appropriately controlled conditions according to the drawings, specifications, and requirements of the approved design. Only qualified and accepted services or items are used in those places indicated in the design. Identification of acceptability is maintained on such items themselves, in documentation traceable to the items, or in a manner ensuring identification.

All components and systems are installed according to current, approved designs. All in-process and final inspections are planned and specified. Acceptance of engineered environmental systems is contingent upon meeting or exceeding expected performance criteria.

4.3.1 Inspections and Tests

Inspections or tests are performed at appropriate points during the construction/fabrication process to verify conformity to design specifications. Such inspections or tests are planned and specified and clearly reflect the acceptance criteria applied. Equipment or material which does not meet specifications will not be installed and will be returned to the equipment manager for turn-in and crediting.

4.3.2 Control of Items

Handling, storing, cleaning, packaging, shipping, and preserving equipment, components, and parts are controlled during construction/fabrication to prevent damage, loss, and deterioration. Items in storage are checked periodically to prevent and detect possible deterioration.

4.4 OPERATION OF SYSTEMS

Engineered environmental systems are operated according to approved design documentation and operation and maintenance manuals. Such operating guides include, but are not limited to:

- Operating procedures and maintenance requirements for specific components and system configurations; and

- Manufacturer information, specifications, and schematics of key system components.

4.4.1 Status Indicators

Status indicators are provided to indicate the operating status of systems and components. The indicators prevent inadvertent operation, or removal from operation, of any system or component when such actions would adversely affect performance of the systems, constitute an operational safety or environmental hazard, or violate statutory/regulatory compliance requirements.

4.4.2 Inspection and Test Control

Inspections or tests are performed periodically during operation to verify conformity to operating specifications or parameters. Such inspections or tests clearly indicate the acceptance criteria applied.

Periodic preventive and corrective maintenance of engineered systems is performed according to operating guidance and/or design specifications to ensure satisfactory system performance. The availability of critical spare parts is established and maintained according to operating experience, manufacturer's guidance, and/or design specifications.

4.5 INSPECTION AND ACCEPTANCE

4.5.1 Inspection

The Parsons ES QA program provides for the development of inspection plans and procedures and for the conduct of inspections to ensure that the design requirement are met. Types of inspections are: receiving inspections, in-process inspections, source inspections, examination, and required code in-service inspections. Inspections are conducted on activities or items affecting quality to verify conformance with codes, standards, regulatory requirements, procedures, and procurement documents or specific client requirements.

4.5.2 Acceptance Testing

The Parsons ES QA program requires the Responsible Manager to identify items to be tested and to develop testing procedures. The testing procedures provide direction and inspection criteria by which testing can demonstrate that items and services are satisfactory in service and meet design acceptance requirements. The scope of acceptance testing includes, as appropriate, receiving inspection testing, post-maintenance testing, testing of installed equipment, and in-service systems testing.